BETTER GROWTH BETTER CLIMATE

The New Climate Economy Report

THE GLOBAL REPORT

THE GLOBAL COMMISSION ON THE ECONOMY AND CLIMATE

THE **NEW** CLIMATE **ECONOMY**

The Global Commission on the Economy and Climate

PARTNERS

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New Climate Economy
c/o World Resources Institute
10 G St NE
Suite 800
Washington, DC 20002, USA
+1 (202) 729-7600

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The Global Commission on the Economy and Climate, and its flagship project **The New Climate Economy,** were set up to help governments, businesses and society make better-informed decisions on how to achieve economic prosperity and development while also addressing climate change.

This programme of work was commissioned in 2013 by the governments of seven countries: **Colombia, Ethiopia, Indonesia, Norway, South Korea, Sweden** and the **United Kingdom.** The Commission has operated as an independent body and, while benefiting from the support of the seven governments, has been given full freedom to reach its own conclusions.

The Commission's programme of work has been conducted by a global partnership of eight leading research institutes: World Resources Institute (WRI, Managing Partner), Climate Policy Initiative (CPI), Ethiopian Development Research Institute (EDRI), Global Green Growth Institute (GGGI), Indian Council for Research on International Economic Relations (ICRIER), LSE Cities, Stockholm Environment Institute (SEI) and Tsinghua University.

The Global Commission on the Economy and Climate

The Global Commission on the Economy and Climate has overseen the New Climate Economy project. Chaired by former President of Mexico Felipe Calderón, the Commission comprises former heads of government and finance ministers, and leaders in the fields of economics, business and finance.

Members of the Global Commission endorse the general thrust of the arguments, findings, and recommendations made in this report, but should not be taken as agreeing with every word or number. They serve on the Commission in a personal capacity. The institutions with which they are affiliated have therefore not been asked formally to endorse the report and should not be taken as having done so.

Felipe Calderón, Former President of Mexico (Chair)

Nicholas Stern, I G Patel Chair of Economics and Government, London School of Economics and Political Science (Co-Chair); President, British Academy

Ingrid Bonde, Chief Finance Officer and Deputy Chief Executive Officer, Vattenfall AB

Sharan Burrow, General Secretary, International Trade Union Confederation

Chen Yuan, Vice-Chair, National Committee of the Chinese People's Political Consultative Conference; former Chairman, China Development Bank

Helen Clark, Administrator, United Nations Development Program; former Prime Minister of New Zealand

Luísa Diogo, Former Prime Minister of Mozambique

Dan L. Doctoroff, President and Chief Executive Officer, Bloomberg LP

S. Gopalakrishan, Executive Vice-Chairman, INFOSYS; President, Confederation of Indian Industry

Angel Gurría, Secretary-General, Organisation for Economic Co-operation and Development

Chad Holliday, Chairman, Bank of America

Paul Polman, Chief Executive Officer, Unilever; Chair, World Business Council for Sustainable Development

Sri Mulyani Indrawati, Managing Director and Chief Operating Officer, World Bank; former Finance Minister of Indonesia

Caio Koch-Weser, Vice Chairman, Deutsche Bank Group; Chair, Supervisory Board of the European Climate Foundation

Ricardo Lagos, Former President of Chile

Michel M. Liès, Chief Executive Officer, Swiss Re

Trevor Manuel, Former Finance Minister of South Africa

Takehiko Nakao, President, Asian Development Bank

Eduardo Paes, Mayor of Rio de Janeiro; Chair, C40 Cities Climate Leadership Group

Annise Parker, Mayor of Houston, Texas

Nemat Shafik, Deputy Governor, Bank of England; former Deputy Managing Director, International Monetary Fund (until June 2014)

Jens Stoltenberg, United Nations Secretary-General's Special Envoy on Climate Change; former Prime Minister of Norway

Maria van der Hoeven, Executive Director, International Energy Agency

Zhu Levin, President and Chief Executive Officer, China International Capital Corporation

The Economics Advisory Panel

The project was advised by a panel of distinguished economists, leaders in their respective disciplines. While the Economics Advisory Panel (EAP) has provided valuable guidance that has influenced the work of the Commission, they were not asked to formally endorse the report and should not be taken as having done so. Their wide-ranging contributions are described in "Theories and perspectives on growth and change: Guidance from the Economics Advisory Panel to the report of the Commission" by Nicholas Stern, published as part of this report.

Nicholas Stern (Chair), I G Patel Chair of Economics and Government, London School of Economics and Political Science; President, British Academy

Philippe Aghion, Robert C Waggoner Professor of Economics, Harvard University

Isher Judge Ahluwalia, Chairperson, Indian Council for Research on International Economic Relations

Kaushik Basu, Senior Vice President and Chief Economist, World Bank

Ottmar Edenhofer, Professor of the Economics of Climate Change, Technical University of Berlin

Fan Gang, Director of the National Economic Research Institute, China

Ross Garnaut, Distinguished Professor of Economics, Australian National University

Benno Ndulu, Governor, Central Bank of Tanzania

Daniel Kahneman, Professor of Psychology and Public Affairs Emeritus, Woodrow Wilson School, Princeton University, and Nobel Laureate

Ian Parry, Principal Environmental Fiscal Policy Expert, International Monetary Fund

Carlota Perez, Professor of Technology and Socio-Economic Development, Tallinn University of Technology; and Centennial Professor, London School of Economics and Political Science

Torsten Persson, Professor of Economics, Institute of International Economic Studies, Stockholm University

Dani Rodrik, Albert O. Hirschman Professor of Social Science, Institute for Advanced Study

Michael Spence, Professor of Economics, New York University, and Nobel Laureate

Rintaro Tamaki, Deputy Secretary General, Organisation for Economic Co-operation and Development

Preface

All over the world, people want to achieve better lives for themselves and for their children. Governments want to secure economic growth, improve living standards, create jobs and reduce poverty. Businesses want to expand and become more profitable.

Today we also know that the world must deal with the challenge of climate change.

Can these aspirations all be met at the same time? Is it possible to tackle long-term climate change while also, now, promoting economic growth and development? Or must we choose between our future security and our current living standards?

It was to provide an objective, independent examination of these questions that the Global Commission on the Economy and Climate was established in 2013 by a group of seven countries.

Our report is addressed to economic decision-makers across the world in both public and private sectors. Its core conclusion is that, by shaping the major processes of structural and technological change now occurring in the global economy, we can create lasting economic growth while also tackling the immense risks of climate change.

We are extremely grateful to the governments of Colombia, Ethiopia, Indonesia, the Republic of Korea, Norway, Sweden and the United Kingdom for their vision and support. They have given us freedom in conducting our work, and the findings and recommendations in this report are entirely independent of them.

The Commission is made up of 24 former heads of government and finance ministers, and leaders of businesses, cities, international organisations, and research institutions. Their wealth of experience gives confidence that our research has been grounded in reality, and that the recommendations of this report can be implemented. The Commission has been advised by a panel of 15 distinguished economists, all of them world leaders in their respective economic disciplines. Their diverse perspectives on the economics of growth, development and structural transformation, public policy, risk and economic history have guided the project's intellectual approach.

The research programme has been conducted by a dedicated team, supported by a partnership of economic and policy research institutions from five continents. The work has drawn on extensive engagement with economic decision-makers in governments, states, cities, communities, companies, trade unions, international organisations and financial institutions throughout the world. Over 100 organisations have actively contributed to the work of the Commission through research papers, data, team members, feedback, advice and support. This report therefore reflects the insights and experience of many institutions and experts. We are grateful to all of them.

The issues dealt with in this report could not be more important. Almost every country today faces difficult economic problems. Climate change is an unprecedented challenge that confronts the world as a whole. The 10-point Global Action Plan we propose in this report can help catalyse action to achieve both better growth and a better climate. It proposes practical measures which can be taken not just by national governments, but by cities and regional authorities, businesses, communities and international organisations. The Commission and the New Climate Economy project remain committed to engaging further with all those interested in these issues.

The need is urgent, for decisions made today and over the next few years will determine the future course of both economic growth and climate change. World leaders will come together in 2015 to decide on new goals for sustainable development and to achieve a new climate agreement. At home they will continue to make vital economic decisions. As they do so, we hope they will consider seriously the research and recommendations presented in this report.

FELIPE **CALDERÓN**
Chair of the Global Commission on the Economy and Climate

JEREMY **OPPENHEIM**
Global Programme Director of the New Climate Economy project

NICHOLAS **STERN**
Co-Chair of the Global Commission and Chair of the Economics Advisory Panel

Executive Summary

The Global Commission on the Economy and Climate was set up to examine whether it is possible to achieve lasting economic growth while also tackling the risks of climate change.

Its report seeks to inform economic decision-makers in both public and private sectors, many of whom recognise the serious risks caused by climate change, but also need to tackle more immediate concerns such as jobs, competitiveness and poverty. The report brings together evidence and analysis, learning from the practical experience of countries, cities and businesses across the world.

The report's conclusion is that countries at all levels of income now have the opportunity to build lasting economic growth at the same time as reducing the immense risks of climate change. This is made possible by structural and technological changes unfolding in the global economy and opportunities for greater economic efficiency. The capital for the necessary investments is available, and the potential for innovation is vast. What is needed is strong political leadership and credible, consistent policies.

The next 15 years will be critical, as the global economy undergoes a deep structural transformation. It will not be "business as usual". The global economy will grow by more than half, a billion more people will come to live in cities, and rapid technological advance will continue to change businesses and lives. Around US$90 trillion is likely to be invested in infrastructure in the world's urban, land use and energy systems. How these changes are managed will shape future patterns of growth, productivity and living standards.

The next 15 years of investment will also determine the future of the world's climate system. Climate change caused by past greenhouse gas emissions is already having serious economic consequences, especially in more exposed areas of the world. Without stronger action in the next 10-15 years, which leads global emissions to peak and then fall, it is near certain that global average warming will exceed 2°C, the level the international community has agreed not to cross. On current trends, warming could exceed 4°C by the end of the century, with extreme and potentially irreversible impacts. By building up greenhouse gas concentrations and locking in the stock of high-carbon assets, delay in reducing emissions makes it progressively more expensive to shift towards a low-carbon economy.

Future economic growth does not have to copy the high-carbon, unevenly distributed model of the past. There is now huge potential to invest in greater efficiency, structural transformation and technological change in three key systems of the economy:

- **Cities** are engines of economic growth. They generate around 80% of global economic output, and around 70% of global energy use and energy-related GHG emissions. How the world's largest and fastest-growing cities develop will be critical to the future path of the global economy and climate. But much urban growth today is unplanned and unstructured, with significant economic, social and environmental costs. As pioneering cities across the world are demonstrating, more compact and connected urban development, built around mass public transport, can create cities that are economically dynamic and healthier, and that have lower emissions. Such an approach to urbanisation could reduce urban infrastructure capital requirements by more than US$3 trillion over the next 15 years.
- **Land use** productivity will determine whether the world can feed a population projected to grow to over eight billion by 2030, while sustaining natural environments. Food production can be increased, forests protected and land use emissions cut by raising crop and livestock productivity, using new technologies and comprehensive approaches to soil and water management. Restoring just 12% of the world's degraded agricultural land could feed 200 million people by 2030, while also strengthening climate resilience and reducing emissions. Slowing down and ultimately halting deforestation can be achieved if strong international support is combined with strong domestic commitment to forest protection and rural income development.
- **Energy** systems power growth in all economies. We are on the cusp of a clean energy future. Coal is riskier and more expensive than it used to be, with growing import dependence and rising air pollution. Rapidly falling costs, particularly of wind and solar power, could lead renewable and other low-carbon energy sources to account for more than half of all new electricity generation over the next 15 years. Greater investment in energy efficiency – in businesses, buildings and transport – has huge potential to cut and manage demand. In developing countries, decentralised renewables can help provide electricity for the more than one billion people without access.

Across all these systems, three "drivers of change" need to be harnessed to overcome market, policy and institutional barriers to low-carbon growth:

- **Raising resource efficiency** is at the heart of both growth and emissions reduction. In many economies, both market and policy failures distort the efficient allocation of resources while simultaneously increasing emissions. While subsidies for clean energy amount to around US$100 billion, subsidies to polluting fossil fuels are now estimated at around US$600 billion per year. Phasing out fossil fuel subsidies can improve growth and release resources that can be reallocated to benefit people on low incomes. A strong and predictable price on carbon will drive higher energy productivity and provide new fiscal revenues, which can be used to cut other taxes. Well-designed regulations, such as higher performance standards for appliances and vehicles, are also needed.

- **Investment in infrastructure** underpins modern economic growth. Low-carbon forms of infrastructure are essential to reduce current emissions trajectories. Yet many economies today are failing to mobilise sufficient finance to meet their infrastructure needs. This is not due to a shortage of capital in the global economy. It results, in many countries, from a lack of public financing capacity and the market perception that investments are high-risk. Financial innovations, including green bonds, risk-sharing instruments and products which align the risk profile of low-carbon assets with the needs of investors, can reduce financing costs, potentially by up to 20% for low-carbon electricity. National and international development banks should be strengthened and expanded.
- **Stimulating innovation** in technologies, business models and social practices can drive both growth and emissions reduction. Advances in digitisation, new materials, life sciences and production processes have the potential to transform markets and dramatically cut resource consumption. But technology will not automatically advance in a low-carbon direction. It requires clear policy signals, including the reduction of market and regulatory barriers to new technologies and business models, and well-targeted public expenditure. To help create the next wave of resource-efficient, low-carbon technologies, public research and development (R&D) investment in the energy sector should triple to well over US$100 billion a year by the mid-2020s.

Well-designed policies in these fields can make growth and climate objectives mutually reinforcing in both the short and medium term. In the long term, if climate change is not tackled, growth itself will be at risk.

Consistent, credible, long-term policy signals are crucial. By shaping market expectations, such policy encourages greater investment, lowering the costs of the transition to a low-carbon economy. By contrast, policy uncertainty in many countries has raised the cost of capital, damaging investment, jobs and growth. In the long run, there is a significant risk that high-carbon investments may get devalued or "stranded" as action to reduce greenhouse gas emissions is strengthened. **The quality of growth matters, as well as its rate.**

Many low-carbon policies deliver multiple other benefits, including greater energy security, less traffic congestion, improved quality of life, stronger resilience to climate change and environmental protection. Many can help reduce poverty. In the 15 countries with the highest greenhouse gas emissions, the damage to health from poor air quality, largely associated with the burning of fossil fuels, is valued at an average of over 4% of GDP. Many countries are now recognising the costs of a high-carbon model of development.

Managed well, the additional investments in infrastructure needed to make the transition to a low-carbon economy will be modest. The infrastructure requirements for a high-carbon economy, across transport, energy, water systems and cities, are estimated at around US$90 trillion, or an average of US$6 trillion per year over the next 15 years. By combining renewable energy with reduced fossil fuel investment, more compact cities, and more efficiently managed energy demand, low-carbon infrastructure will increase investment requirements by only an estimated US$270 billion a year. These higher capital costs could potentially be fully offset by lower operating costs, for example from reduced expenditure on fuel. Investing in a low-carbon economy is a cost-effective form of insurance against climate risk.

The report proposes a 10-point Global Action Plan of key recommendations. This asks decision-makers to:

1. **Accelerate low-carbon transformation by integrating climate into core economic decision-making processes.** This is needed at all levels of government and business, through systematic changes to policy and project assessment tools, performance indicators, risk models and reporting requirements.
2. **Enter into a strong, lasting and equitable international climate agreement,** to increase the confidence needed for domestic policy reform, provide the support needed by developing countries, and send a strong market signal to investors.
3. **Phase out subsidies for fossil fuels and agricultural inputs, and incentives for urban sprawl,** to drive more efficient use of resources and release public funds for other uses, including programmes to benefit those on low incomes.
4. **Introduce strong, predictable carbon prices** as part of good fiscal reform and good business practice,

sending strong signals across the economy.

5. **Substantially reduce capital costs for low-carbon infrastructure investments**, expanding access to institutional capital and lowering its costs for low-carbon assets.

6. **Scale up innovation in key low-carbon and climate-resilient technologies,** tripling public investment in clean energy R&D and removing barriers to entrepreneurship and creativity.

7. **Make connected and compact cities the preferred form of urban development,** by encouraging better-managed urban growth and prioritising investments in efficient and safe mass transit systems.

8. **Stop deforestation of natural forests by 2030,** by strengthening the incentives for long-term investment and forest protection, and increasing international funding to around US$5 billion per year, progressively linked to performance.

9. **Restore at least 500 million hectares of lost or degraded forests and agricultural lands by 2030,** strengthening rural incomes and food security.

10. **Accelerate the shift away from polluting coal-fired power generation,** phasing out new unabated coal plants in developed economies immediately and in middle-income countries by 2025.

The first six recommendations provide the conditions necessary for a strong and credible framework to foster low-carbon and climate-resilient investment and growth. The last four point to vital opportunities for change which can drive future growth and lower climate risk in cities, land use and energy systems.

Implementation of the policies and investments proposed in this report could deliver at least half of the reductions in emissions needed by 2030 to lower the risk of dangerous climate change. With strong and broad implementation, rapid learning and sharing of best practice, this number could potentially rise to 90%. All the measures would deliver multiple economic and social benefits, even before considering their benefits to climate. Further action will also be required. Some of this, such as the development of carbon capture, use and storage technologies, will have net costs to be borne solely for the purpose of reducing climate risk. Beyond 2030 net global emissions will need to fall further towards near zero or below in the second half of the century. But the costs will be much lower and the opportunities for growth much greater if the foundations of a low-carbon economy are laid now.

A strong and equitable international agreement is essential to support ambitious domestic action. Developed countries will need to show leadership through their own strong emissions reductions, and by mobilising financial and technological support for developing countries. At the same time, developing countries already account for around two-thirds of annual greenhouse gas emissions. Global reductions on the scale required will therefore not be possible unless all countries play their part.

The shift towards a low-carbon, climate-resilient path of growth and development will not be easy, and governments will need to commit to a just transition. Not all climate policies are win-win, and some trade-offs are inevitable, particularly in the short term. Although many jobs will be created, and there will be larger markets and profits for many businesses, some jobs will also be lost, particularly in high-carbon sectors. The human and economic costs of the transition should be managed through support for displaced workers, affected communities and low-income households. Strong political leadership and the active participation of civil society will be needed, along with far-sighted, enlightened business decisions.

The wealth of evidence presented by the report shows that there is now huge scope for action which can both enhance growth and reduce climate risk. Leading businesses, cities and countries are showing how this can be done. The world's economic leaders face a remarkable opportunity to set the world on the path to sustainable prosperity. The prize is immense, and the moment of decision is now. We can achieve both better growth and a better climate.

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Theories and Perspectives on Growth and Change: Guidance from the Economics Advisory Panel for the Report of the Commission

The core argument of this report, entitled, "Better Growth, Better Climate", is that by investing in and building "better growth" we can make great strides towards managing the immense risks of climate change, and thus build a "better climate". In other words, fostering strong and sustainable growth in living standards can and should come together with a fundamental reduction in climate risk. That progress relative to these two objectives can support each other so well is, in large measure, because over the next two decades we have a remarkable coincidence of two vital transitions in world history.

The first is in the structure of the world's economy and society. This will embody: a rapidly shifting balance in the source of economic activity from developed to developing countries; great moves of population into cities; rapid growth of population; significant changes in the ways we generate and use energy; movement out of agriculture in to (mainly) services; and still further pressure on forests, land and water. The second is a decisive two decades for a transition to a low-carbon economy which will determine whether or not we can avoid the immense risks of climate change. The first transition will happen come what may. The second is a fundamental choice of our generation. The central argument of this report, and the key insight that has shaped the analysis, is that if we manage the first transition well, we will have made great strides towards success in the second. If the first goes badly, the second will be much more difficult. We are at a fork in the road.

We have been brought to this point by a remarkable period in the economic history of the world. The last three decades have seen two decades of strong growth, driven in large measure by the emerging market economies, followed by the greatest financial and economic crisis in almost a century in the rich countries. In these decades, the international division of economic activity has been transformed. In 1985, the rich countries with 1 billion out of a world population of then 5 billion, had around two-thirds of the world's output (PPP, current international $), whereas now they have less than half. The shares of global carbon dioxide (CO_2) emissions have followed a similar track. In 1985, rich countries accounted for more than half of annual global CO_2 emissions, whereas now they emit around a third. Whilst poverty in all its dimensions remains deeply troubling across the world, this period has seen life expectancy rise steeply and hundreds of millions have been lifted out of poverty. Demand for resources has risen sharply. Technological change in information and communications, in materials, and in biotechnology has been extraordinary.

The financial and economic crises in rich countries have contributed to faltering world growth. China, the most powerful driver of growth in the last three decades, is recognising that its growth will slow. At the same time China's policy-makers also recognise that the pattern and structure of their growth should change to become more sustainable. Developing and emerging countries continue to see economic growth and its role in overcoming poverty as central to their development ambitions. The last quarter of a century has also brought a deepening understanding of the challenges of climate change, with the Intergovernmental Panel on Climate Change (IPCC) founded in 1988, and the United Nations Framework Convention on Climate Change (UNFCCC) in 1992.

The great economic questions of the coming years will be whether the world can continue the story of growth and poverty reduction, manage the further structural transformations which are in train, and tackle the immense and growing potential risks of climate change. Thus the report is about the next fundamental transformation of the world economy which follows from and is shaped by the great transformations of the preceding quarter of a century. At the heart of this next transformation, and where we will make our key choices, are our cities, energy systems and land use.

The rapid changes of the last three decades were part of long-term trends of economic history, but the acceleration was remarkable. Change in the next few decades will no doubt be different and there will be many surprises. But we can be fairly confident of the following: cities will grow rapidly and older cities will require reform and renewal; energy systems will be created as many countries pass through stages of development when energy demand will grow strongly and richer countries will refurbish their systems; and many of the battles to save and enhance forests and ecosystems will be resolved in the face of strong pressures from growth of population and demand for materials, food and water. Our decisions, for better or worse, implicit or explicit, considered or haphazard, will shape our cities, energy systems and land use for decades or centuries.

These next few decades are critical for climate change because, as a result of rapid hydrocarbon powered growth and the destruction of forests, we have already reached atmospheric concentrations of 400 parts per million (ppm) of CO_2 or around 450ppm of CO_2 equivalent (taking account of other greenhouse gases). If the world stays substantially above those levels for a long time it will be difficult or impossible to have a reasonable (say 50-50) chance of holding global average surface temperature to 2°C above pre-industrial levels. This is the level above which, in the words of the UNFCCC, climate change becomes dangerous, partly because the risk of tipping points and destabilising feedbacks increases strongly. We currently appear to be on a course which could take the world to 4°C or more, temperatures not seen for tens of millions of years. The consequences in terms of catastrophic events, desertification, flooding, sea-level rise and so on could cause hundreds of millions of people, perhaps billions, to move, likely resulting in extended and severe conflict.

Delay is dangerous because the principal greenhouse gas, CO_2, is so long-lived and concentrations are very difficult to reduce. Furthermore, much of the relevant infrastructure and capital is long-lasting and, in a period of rapidly growing energy demand, we risk "locking-in" high-carbon equipment and structures. That the "window for action" is closing has been emphasised strongly by a number of international institutions including the International Energy Agency (IEA) and the World Bank.

The coinciding of these two transitions is both a challenge and an opportunity. The report shows that putting the response to these two challenges together offers a real chance of success on both. And in so doing it demonstrates that we have an extraordinary opportunity for growth, poverty-reduction, and a much more attractive and sustainable way of consuming, producing and living. That opportunity comes not just from the coinciding of the two transformations, but also from the very rapid advances in technology that we have seen in recent decades. For example, the extraordinary advances in information and communications technology (ICT) have enormous potential for resource efficiency and fostering further innovation. Furthermore, experience with various policies, such as carbon pricing, has taught us many lessons. We understand better, from both successes and failures, how to manage the kind of change experienced over the last few decades. And we can be confident that the technical advances we have seen, and that are on the way, will generate great further opportunities.

Failure to foster growth and poverty reduction, and to manage structural change will prevent the coherent global action necessary to manage climate change. Failure to manage climate change will undermine and potentially reverse the development achievements and poverty reduction of the last few decades. If we fail on one, we fail on the other. Will we behave in a way to seize opportunities for growth, and growth that is sustainable? I hope that the report will help steer us towards a positive answer.

It is this overall understanding and definition of the challenges of the next two or three decades, based on the analyses and lessons of economics and economic history, particularly of the last two or three decades, that have shaped the guidance given by the Economics Advisory Panel (EAP), which has advised the Commission. The EAP has not written the report, but its distinguished and independent economists have provided counsel and guidance, and have brought an extraordinary range of insight, talent and perspectives to it. Furthermore, the range of experience in different kinds of economics within the EAP and its international make-up reflect the character and structure of the economic challenges. Many of its members have participated at a senior level in making or guiding economic policy. They understand the realities of practical politics. They have provided challenge, rigour and a constructive spirit in offering their advice. In what follows there are a number of references to their academic contributions. A bibliography of some of their relevant writings is provided as an appendix to the report.

I am very grateful, as chair of the EAP and co-chair of the Commission, for the guidance they have given. I must emphasise, however, that whilst I have consulted with them and been guided by them, the views expressed in this note are my own.

Why another report now? Please excuse me if I start from the Stern Review published in October 2006. Technical progress has moved much more strongly than was expected at that time. There is more experience with climate policies. The world has struggled with a great recession. Meanwhile, the science looks still more worrying. Emissions have continued to rise, still more strongly than expected at that time, and some effects are coming through more rapidly than anticipated. The politics on emissions looks more worrying; in many countries the political will to act is weak. This report goes beyond the Stern Review in its central focus on both structural change and on how growth and climate action can be mutually supportive.

There are also important changes in the subject of economics. Many are probing more deeply into the determinants of development and growth, with great emphasis on innovation, learning and institutions. The "Schumpeterian" story is rising still further in the attention of economists, for example through the work of Aghion (an EAP member). There have been important advances too in behavioural economics, particularly associated with the work of Kahneman (an EAP member), which guide us on how decisions are understood and made, and how responses to change take place.

There have also been many helpful reports over recent years. The IEA, through its World Energy Outlooks, has examined energy systems and how they might develop, with a strong focus on the detail of economic and energy structures around the world and the energy investments that are necessary to reduce emissions on the scale required. They are the major source of much data and analysis on investment in energy infrastructure. The World Bank 2012 report Turn Down the Heat: Why a 4°C Warmer World Must be Avoided provides a comprehensive review of climate impacts at such temperatures, which have not been seen on the planet for millions of years. Angel Gurria of the Organisation for Economic Co-operation and Development (OECD) has brought to centre stage the need for zero-emission energy in the second half of this century and established the OECD as a leading institution for research on the economics of climate change. And the International Monetary Fund (IMF) has produced valuable research on energy taxation and subsidies and associated externalities and market failures. While this report is different in its emphasis on rapid structural change across the world economy, particularly in cities, energy and land use, it builds on the valuable earlier work of these institutions. And it draws on a whole range of perspectives and research from economics and other disciplines.

With the challenges defined in this way, it is clear that both standard growth models and the usual shorter term macroeconomic models of output and unemployment simply do not carry the features and analytical foundations which allow a satisfactory analysis of the key questions for the report. Standard growth models, often focused on the longer run, have offered real insights into how savings and investment, population growth and technical progress can combine to generate growth. Shorter-term macroeconomic models have been of help in guiding the management of demand, unemployment and inflation. But neither of them is designed to inform the analysis of radical structural change.

The transformations that will shape the coming decades are already under way. We cannot defer or "push out" the necessary transformational investments and innovation to some vague medium or longer term, to be examined and decided later, an argument also emphasised strongly, for example, in the work of Edenhofer (an EAP member), the IEA and many others. The structural transformations under way and the actions necessary on climate change involve major investments. Such investments will drive the transformations. They will boost growth and bring other valuable returns, for example to air quality and energy security. But transformations and major new investments can involve dislocations. Moving early and strongly towards the world I am describing is not an easy win-win. But a central conclusion of the report is that credible and coherent action now has great potential and attractiveness for growth, poverty reduction, ways of living, and sustainability — surely much greater potential than something that attempts minimal change whilst sending mixed signals to investors and trying to stick with current patterns.

This report takes a major step in the direction of bringing together economic analyses and perspectives that fit the analytical tasks at hand. In so doing it charts an attractive and wise way forward. It is not a rigid plan, but a path of growth and discovery which promises a strong and sustainable future of continued development and poverty reduction. It is focussed exactly on identifying and analysing key areas which are core to the processes of transformation and decision-making, i.e. cities, energy systems and land use, and key drivers of change, i.e. resource efficiency, infrastructure and innovation.

The nature of the problem and the need for deep and broad approaches to growth, poverty reduction and structural transformations has motivated the analytical guidance given by the EAP. On growth and structural change, the guidance of the EAP and the work of the report team have been much influenced by the Schumpeterian perspectives on medium- to long-term technological transformations. Such transformations are precisely what are at issue here. As Freeman, Perez (an EAP member) and others have shown, periods of major technological transformation are usually accompanied by innovation, investment and growth over a few decades.

This Schumpeterian tradition is complemented by, and interwoven with, models of learning and endogenous growth in the tradition of Arrow, Aghion (an EAP member) and others (see Aghion et al. 2014). The report is also informed by the Kuznets and Chenery analyses of the relationship between growth and sectoral change which in recent times have been deepened and taken forward by Rodrik and Spence (both EAP members). These are complemented again by advances in economic geography (see work by Krugman, Venables and others) and analyses of cities, often building on the pioneering work of Jane Jacobs. In India, for example, Ahluwalia (an EAP member), has led applied work on growth of cities and necessary infrastructure investment. Fan Gang, Garnaut and Stern (EAP members) have examined how urbanisation and sectoral change are transforming the Chinese economy. Ndulu (also EAP member) has provided guidance on transformation in Africa.

Modern public economics is at the heart of the Commission's work on policy. Much of this body of theory proceeds by analysing both market failures and government failures. It is firmly based in the tradition of Meade, Samuelson, Arrow, etc. (and earlier Dupuit, Wicksell, Marshall and Pigou).

Emissions of greenhouse gases (GHGs) represent a market failure as the emitter does not bear the costs of the damage and disruption from their activities. In the Stern Review, I suggested that emissions of GHGs may be the largest market failure the world has seen: all people are involved in the cause, all will experience the impacts, and those impacts are potentially immense. In this sense carbon pricing, which corrects for the externality and thus promotes the sound functioning of markets, is the most urgent policy to get in place today. It involves a relatively simple application of widely accepted tax principles and can be applied in a number of ways, including through an explicit tax or cap-and-trade scheme, or by adjusting existing fuel taxes to reflect their carbon content.

Market failures extend beyond the fundamental one of GHG emissions, to more dynamic failures such as the public spillover of ideas in research and development (R&D), networks, capital markets and information, as well as co-benefits of ecosystems, efficiency, health and so on. At the same time, governments who must shape the environment for investment and innovation can over-reach themselves or be influenced by vested interests. The presence of these more dynamic market failures potentially amplifies the size and duration of the consequences of government failure, making the issue of accountability of institutions all the more important. The analytical challenge here is to bring out and examine the dynamics associated with these perspectives. We need to combine the economics of Pigou with that of Schumpeter. Strong carbon prices, and strong investment in and policies towards R&D and innovation are likely to be very powerful in driving the necessary change. A number of members of the EAP have been strongly involved in the literature on modern public economics and its dynamics (Aghion, Rodrik, Spence, Stern, for example).

Policies for flexibility help manage processes of resource allocation arising from evolving patterns of demand, the advance of technology and the emergence of new competitors. Examples of such policies include trade openness, supportive labour market policies (including income support where necessary), investment in skills and education, support for R&D and innovation, flexible housing markets, competition policy, and product market regulation. All these can help promote movement of resources and manage dislocation, particularly in its effects on poorer people.

Credibility of policy will be just as important as its nature. Institutional structures, such as development banks, mechanics of collaboration and transparent long-term policy bodies can play a key role. Modern approaches to institutional economics can be very helpful here (a number of EAP members have emphasised this perspective). More broadly, the advice of the EAP has also recognised the vital role of institutions (social, economic, governmental, international, financial, and so on) in influencing how transformations can occur, and indeed their timing, structure and success (see, for example, the work of Besley and Persson, Acemoglu and others, including EAP members Aghion, Rodrik, Persson, Spence). If market failures themselves arise from or reflect problems in property rights, transaction costs, information and trust, then, in addition to standard government interventions (subject to issues around government failure), one can also think about the way in which institutional structures have been, and can be, created within and between communities, to help overcome problems of both government and market failure, and facilitate creativity and change. The insights of Ronald Coase and Elinor Ostrom would be a key starting point.

The whole report is essentially about risk management, on an immense scale, in structural transformation, in growth and poverty reduction, and in climate change. The EAP has not suggested a formal or narrow approach here. The economic theorist's work-horse of expected utility theory, whilst helpful for some simple frameworks of decision-making, is not well-structured for the scale of risks, international action and difficulties of perception involved here. What is necessary is a broader approach, in the sense of an understanding of change, uncertainties involved, and strategies for managing and reducing risk. Such perspectives and analyses point to an examination of policy options according to what they could deliver in terms of a range of outcomes with their many risks and dimensions. That is how wise decision-making can be informed and guided. It provides a way to look at and assess advantages and disadvantages, pros and cons, and costs and benefits, with their associated uncertainties. It is an approach which can be called structured consequentialism in the sense that it provides a structured framework for decisions in terms of careful evaluation and assessment of possible consequences. It is transparent. But it does not proceed by attempting to summarise the entire consequences for the world into one model for net benefits and one optimal policy or one number for expected utility. In this context this latter approach is cavalier and often lacking in transparency and honesty as to what is behind the "results".

Our climate will change given past and future emissions. Adaptation to these changes is an important example of risk management and flexibility. Robust infrastructure will be of great importance to adaptation and flexibility in general. This report has focused primarily on the fostering of a low-carbon economy, and as such adaptation has not been at centre stage. We should not, however, take that as a statement that it is unimportant. Far from it, given the changes on the way it will be crucial. And it is important to recognise that mitigation, adaptation and development are intimately interwoven, in agriculture, buildings, transport, and infrastructure, including across the whole economy. Examples are in the report.

This next two to three decades constitute a crucial period for poverty reduction and advance in well-being across the full range of economic and human dimensions. The EAP has generally been informed and guided by a broad view of development, as embodied in the work of Sen and others, and a number of EAP members have contributed strongly to the literature on the meaning and measurement of poverty, and the processes for poverty reduction. The EAP has been fortunate also to have with it leading economists of the key international institutions associated with growth and development: The World Bank (Basu), IMF (Parry) and OECD (Tamaki). Their experience of the practical, political, and conceptual issues involved, as well as the economics, has been of profound importance.

Human behaviour, in the form of understanding and perceptions, reactions, decisions and so on, particularly in the context of rapid change, may not be as simple or systematic as portrayed in standard economic models. It is important to ask how decisions to follow a radically different path, and in real time, could emerge or be fostered. Here the EAP has been able to draw on the insights of modern behavioural economics, as led, for example, by Kahneman. Social movements can be powerful agents for change. Leadership will be at a premium. And sometimes when leaders get together in the face of shared threats they may take a more long-term view of policy than when narrowly driven by local politics – as, for example, with the building of international cooperation after the Second World War, which fostered a strong period of growth and trade in many countries. But such an outcome cannot be taken for granted. Much worse is possible. The better outcome depends on a shared understanding of dangers and of what can be done in the way of action. It is crucial to be able to see a constructive and attractive way forward. I hope that the report contributes to such an understanding.

Cooperation and simultaneous action is critical to success in the challenge of fostering growth and transformation and managing climate change. Greenhouse gas molecules in the atmosphere have the same effect regardless of origin. This is a collective action problem. Hence the international make-up of the EAP, and the concern to understand how individuals and nations can cooperate and learn together, have been key aspects of its work. For international cooperation, institutions matter, particularly in the context of anticipating the actions and reactions of others and building mutual confidence and, where possible, trust. Principles of game theory and the ideas of cooperation of Ostrom (see above) can provide valuable insight here.

The EAP took into account the challenges involved in the work leading to the crucial UNFCCC meeting in Paris at the end of 2015. These international discussions, ethically, economically and politically, should examine directly the critical question of equity. Climate change is deeply inequitable in both its origins and impacts. The analyses and recommendations of the report take collaboration and equity carefully into account.

Political economy inevitably pervades the whole report. Local, national and international policy structures and decisions are subject to many pressures by those who see themselves as potential winners or losers, particularly the latter. There are inevitably discussions and judgements at many places in the analysis about the nature of these forces and how they might play out. Most of the EAP members have worked in "real policy environments" and are keenly aware of the importance of these issues.

The work of the Commission has thus embodied or been informed by the fundamental economics of growth, structural transformation, economic history, economics of public policy, economics of risk, theories and experience of development and poverty reduction, international economics, and institutional and behavioural economics amongst others. These ideas, theories and perspectives are at the core of our approach. The subject matter requires breadth and depth in theory, evidence and perspectives.

It should be clear from the definition of the problem, and the theories and perspectives brought to bear, that it makes little sense to try to embed the analysis into one single model. The story is neither short-run management nor long-run growth around which much modelling is oriented. It is a story of transformation, disruption and radical change – stable structures are not what it is about. But that does not mean less theory, rather it means more, as I have argued. Many perspectives are involved and single rigid frameworks are not up to the task.

It is unfortunate therefore that the economic models in the climate literature have been heavily focussed, too heavily in my view, on one particular approach. These models are usually called Integrated Assessment Models (or IAMs) which have the worthy aim of bringing together scientific models of climate change and models of economic growth. These have made a worthwhile, although modest, contribution. Nevertheless the current literature, in its portrayal of potential damages, misses out much of the scientific risk, potential catastrophes and tipping points. There is little there, for example, of any seriousness about the potential for huge loss of life that could come with 4°C and above, both directly, and from the movement of people and resulting conflict.

In the analyses of the costs of action, such models usually embody a rigid economic framework of exogenous growth and fixed cost and production structures, thereby assuming away most of the challenges of investment, innovation and structural change which lie at the heart of the problem. In addition, they usually have rising marginal costs of action in a context where dynamic increasing returns may be important. Taken together, these defects in modelling have often led to damage from climate change being systematically and grossly underestimated and the costs of economic change being substantially overestimated.

These IAMs, which take the underlying structure of the economy over the coming decades as given, are simply not equipped to take on the analytical challenges of transformations identified here as being at the core of the issues. As Edenhofer has argued, it is time for a new generation of IAMs (see also Stern 2013 and Dietz and Stern, forthcoming, on the structures of the IAMs). There has indeed been some improvement. But even improved IAMs are likely to be very limited in their ability to capture the key elements of the kinds of perspectives and analyses, described above, which must be brought to bear. Yet it is these IAMs that have dominated much of the formal modelling of the economics of climate change, including estimates of the Social Cost of Carbon (SCC). And for the reasons described, the SCC is systematically, and probably substantially, underestimated in such models. To look across current literature on IAM models and to see where it stands on assessing potential damages from climate change and costs of action is essentially to "average" across work which is systematically biased.

Some models of economic growth have been used by Treasuries and some international institutions to assess the shorter-run impact of climate action on growth, e.g. Computable General Equilibrium (CGE) models (these are sometimes embedded in IAMs). These models often start from the assumption of an economy where resources are already efficiently allocated and there are no market failures. Therefore there is a danger that such model structures assume directly that introducing climate policy inevitably diverts resources away from profitable activities and thus has an impact on short-run gross domestic product (GDP). But we live in an imperfect, inefficient and constantly changing world where there are multiple frictions, unemployment and other dynamics, and multiple unpriced benefits from climate policies such as reduced local air pollution, increased energy security and stronger biodiversity. Thus, the models often fail to capture these key features when simulating the GDP impact of climate policy on output. We must recognise that there are some promising attempts (including from the OECD) to improve these models and some progress has been made. I would encourage further investment in such improvements.

No single model, however, is ever likely to be able to tell the full story of the dynamics of an economy with many sectors, many goods, where lives may be lost on a substantial scale, where innovation is at the core of the story and where there are complex imperfections. Multiple scenarios from multiple models will be valuable, including, multi-model comparison such as that undertaken by the Energy Modeling Forum (EMF), the Mercator Research Institute on Global Commons and Climate Change (MCC) and the Potsdam Institute for Climate Impact Research (PIK) for the Commission. Such an approach avoids the risks of cherry-picking from different model results. But the fundamental limitations of the models remain. In multi-model comparisons it is vital to examine the literature carefully for the systematic biases identified above: that should be a key aspect of any overall assessment in such exercises.

Notwithstanding the limitations of models, most model-based estimates of the long-run costs of efficient climate policy (see IPCC, AR5, WGIII) are in the order of 1-4% of global GDP in 2030 from taking ambitious climate action consistent with a 50-50 chance of stabilising global average warming at 2°C above pre-industrial levels. These costs will vary by country. But, and this is a crucial point, if policies are weak, misguided or inconsistent, action could be much more expensive; policy mistakes in the process of fostering the transition can be very costly. Much of the work of the Commission has been on how to do policy well. This is a point that extends far beyond these models.

It would be wrong to argue that managing the structural transformations will inevitably provide all the emissions reductions necessary for a responsible management of climate. The required urgency and scale of emissions reductions will necessitate going beyond a sound structural transformation, i.e. viewed as sound in the absence of concern over emissions. We do not want to pretend that emissions reductions are all win-win, or there is a "lunch" that is totally free. But the extra resources necessary for responsible management of climate provide a "lunch well worth paying for", particularly when we include, as we should, the co-benefits of a cleaner, safer, more energy secure, and more bio-diverse economy along with the huge benefits of reduced climate risk.

The approach of the report does not allow the precision, spurious in our view, which can come via the answer to certain questions through one single model. On the other hand by looking at a number of models, disaggregating, and bringing different perspectives, theory and ideas to bear, it does allow us to tackle the questions that matter. And it offers a perspective for an informed choice of strategy based on an assessment of the coming structural changes, the potential gains from managing them well, the close connections with GHG reductions, the co-benefits of those reductions, and the reduced risks of climate change. This is what broad perspectives and a marshalling of the lessons of economics and economic history as a whole can bring.

I trust that the perspectives and theories the EAP has brought to bear have both guided the work of the Commission and are essential for an understanding of the processes of growth and change, which are at the heart of the challenges and choices at the fork in the road where we now stand. I am deeply grateful to the members of the EAP for their work and guidance.

Nicholas Stern

Co-Chair of the Global Commission and Chair of the Economics Advisory Panel.

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Introduction

This report seeks to understand how countries with different kinds of economies can meet the goals of stronger economic growth and development while also reducing the risks of dangerous climate change.

These issues have sometimes become embroiled in controversy and ideological argument. The aim of the New Climate Economy project has been to gather and assess the evidence as independently and objectively as possible.

The approach taken by the project has been to adopt the perspective of those who make the major economic decisions which affect people's lives today: ministers of finance and other ministers in government, heads of businesses and financial institutions, leaders of states and provinces, city mayors, trade union and community leaders. These decision-makers are trying to achieve goals and deal with problems which appear far more immediate and acute than those of climate change. Yet at the same time it is the decisions they make which will determine the future course of the climate system. So the question the project has sought to explore is not "how can greenhouse gas emissions be reduced?" – others have done this comprehensively – but "how can economic decision-makers achieve their principal goals while also reducing their impact on the climate?" The underlying assumption is that it will be easier for peoples and countries to make the necessary political decisions about tackling climate change if the economic benefits and opportunities, as well as the costs, are clearer. And it will be easier if they can see how the necessary climate-related actions and investments fit with their ambitions for growth, poverty reduction and structural change.

This report presents the findings of the project's year-long programme of research and engagement with major economic decision-makers. The research has sought to access and bring together the best available evidence, drawing on important and detailed work done by many other institutions and researchers. They are listed in the Acknowledgements. This has been supplemented by original research conducted across a range of countries, much of which will be published separately as national reports and contributing papers.

The report does not try to be comprehensive: its focus is on the areas where the relationship between economic growth and climate risk is largest and most pressing. There are many economic issues and sectors it does not discuss in depth. In particular it does not focus on how economies should adapt to the climate change that is already occurring. Adaptation is essential, given the climate change that is in train. It is interwoven with the issues of growth and development and a crucial part of the economic strategies discussed here. But it was not the focus of our research.

The New Climate Economy project has constantly looked for practical solutions which decision-makers can adopt and implement in the 'real worlds' they inhabit. The report tries to reflect the imperfect conditions which firms, consumers and governments confront in real economies: never in possession of the information needed for perfect decisions; always needing to adjust and adapt to change; typically trading off between short-, medium- and long-term priorities. A global report inevitably has to generalise across very different kinds of economies. But it seeks to recognise the different circumstances diverse countries face.

The approach to economic analysis taken by the report goes beyond a traditional static view of how economies work. It has been framed in a dynamic context of change and transformation. Guided by the advice of the Commission's Economics Advisory Panel, the project team has drawn widely on economic history, the economics of public policy and of risk, theories and experiences of development and poverty reduction, and international, institutional and behavioural economics, amongst other approaches.

Economic models can generate precise numbers – for GDP growth, jobs or emissions – but they can only ever offer approximations of the future. Too much is unknown about the course of technological and structural change, with the key processes difficult to capture formally. Too much that is of value – such as people's health, the reduction of risk, the sustainability of the natural environment – is hard to quantify. John Maynard Keynes once said "it is better to be roughly right than precisely wrong". The report gathers the available quantitative evidence. But the Commission and its Economic Advisory Panel would warn against the search for false precision. It is judgement, informed by a range of perspectives and evidence, that will lead to better decisions. The report is intended to provide resources for such judgements.

The structure of the report is as follows. Chapter 1 sets out the joint challenges of economic growth, poverty reduction and climate change, in the context of the rapid structural and technological transformations through which the global economy is now going. It examines the core question of whether the actions and policies which can reduce greenhouse gas emissions are inevitably damaging to growth and other economic goals, or whether better economic management could deliver growth and less climate risk at the same time. In doing so it introduces the core framework of analysis underpinning the report. This focuses on three key drivers of change within the economy – resource efficiency, infrastructure investment and innovation – and three key economic systems where

both growth and emissions are strongly occurring: cities, land use and energy.

Chapters 2 to 4 explore the three systems. Chapter 2: Cities shows how building better, more productive cities can boost economic prosperity. Chapter 3: Land Use examines measures to meet global food demand, restore degraded land and end deforestation. Chapter 4: Energy examines how increased energy demand can be met more sustainably through cleaner energy sources and increasing efficiency. Each chapter asks how it is possible to achieve economic goals in these areas at the same time as reducing climate risk, and sets out a series of conclusions, drawing on the evidence of what is already happening across the world today.

Chapters 5 to 7 then look at the wider economic drivers of growth, structural change and greenhouse gas emissions. Chapter 5: Economics of Change examines how resource efficiency can be increased through key areas of economic policy, including fiscal reform and regulatory and other approaches. It also discusses the vital measures needed to help economies and societies adjust to change. Chapter 6: Finance looks at how the risks and capital costs of investing in low-carbon infrastructure can be lowered, particularly in the energy sector, in both developing and developed economies. Chapter 7: Innovation discusses the processes of technological and business innovation, and how they can be encouraged to favour the development of low-carbon technologies that will also drive growth across the economy. Again, these chapters draw on evidence from across the world for their analysis and to make recommendations for action and policy.

Chapter 8: International Cooperation considers how action at national and sub-national levels to achieve lower-carbon and more climate-resilient growth and development can be enhanced through various forms of international cooperation. It discusses in particular how a strong and equitable international climate agreement can provide the economic framework for the transition to a low-carbon and climate-resilient global economy.

The final chapter brings together the Commission's principal recommendations to the international community of governments and economic decision-makers in the form of a 10-point Global Action Plan.

Each chapter of the report can be read as a stand-alone document. Each is intended to be particularly relevant to decision-makers in the subjects it covers.

In addition to the full report, the Commission has published a shorter Synthesis Report which summarises the core findings, argument and conclusions. This also includes the Executive Summary and summary of the Global Action Plan. Subsequent publications include a series of contributing papers and country reports for Brazil, China, Ethiopia, India, the Republic of Korea and the United States. These will provide fuller technical support for the work contained in the global Better Growth, Better Climate report.

This is a report for consultation. It is not intended as – and could not be – the final word on the many complex issues it explores. The Commission does not expect universal agreement with its conclusions. But the issues it examines are urgent and critical, and the Commission hopes it will stimulate both debate and action.

Chapter 1

Growth and Climate Change: THE STRATEGIC CONTEXT

Main points

- Rapid technological progress, a large rise in trade, and major structural changes have transformed the global economy in the last 25 years. Developing countries now account for more than two-fifths of world GDP. Poverty dropped at the fastest rate ever in the last decade. However, since the Great Recession of 2008–09, countries at all income levels have struggled to achieve fast, equitable growth in output, jobs and opportunities. Vigorous and deliberate reforms are needed to sustain broad-based long-term prosperity.
- The next 15 years are also critical for tackling climate risk. Global carbon dioxide (CO_2) emissions from energy use increased by about 3% per year in the 2000s, around twice the pace of the years 1981–2000. The choices made in the next 15 years will either lock in a future with growing pollution and worsening climate change, or help move the world onto a more sustainable, low-carbon development path.
- Many of the policy and institutional reforms needed to revitalise growth and improve well-being over the next 15 years can also reduce climate risk. Potential "win-win" reforms in urban, land use and energy system would involve correcting market and government failures that now make economies less efficient than they could be. These are not "easy wins", however; they will require real effort.
- Many actions to reduce greenhouse gas (GHG) emissions can yield multiple benefits, such as improved air quality. Health damage from air pollution averaged over 4% of GDP in the 15 largest CO_2 emitters in 2010. Measures that reduce GHGs and air pollution together in these countries would yield health benefits of US$73 per tonne of CO_2 abated.
- The climate benefits from economic measures considered in this report could be substantial: enough to achieve at least 50% and potentially up to 90% of the emission reductions needed to get onto a 2°C pathway. All these measures are compatible with goals of boosting national development, equitable growth and broadly shared improvements in living standards, and make economic sense even before considering future avoided climate damage.
- Countries at different stages of development will necessarily prioritise different actions. For low-income countries, key challenges include strengthening institutional capacity, improving agricultural productivity, and expanding modern energy access. Middle-income countries have greater institutional capacity and resources but face complex problems of structural change and urban development. The challenge facing developed countries is to accelerate innovation, renew infrastructure and modernize public finance in ways that strengthen growth and promote decarbonisation.
- Greenhouse gases already in the atmosphere will make 2016–2035 about 0.9–1.3°C warmer than 1850–1900, on average, even if drastic action to reduce emissions is taken immediately. Thus, adaptation is essential. Financial flows from developed to vulnerable low-income countries need to increase sharply to meet adaptation needs. Many institutional reforms to facilitate adaptation will also increase the development and carbon abatement options available to countries.

1. Introduction

The world economy has been transformed over the last 25 years. Computing, communications, biotechnology, materials science and other fields are in the midst of technological revolutions, greatly expanding humanity's productive capacity. World output has more than doubled since 1990,[1] accompanied by rising international flows of knowledge, trade and capital, as well as by enormous structural changes. Developing economies have grown in importance, their share of global GDP rising from just over a quarter to more than two-fifths over this period.[2] The number of people living in urban areas surged by two-thirds, to more than half the world's population.[3]

Developing countries – the poorest and most populous region of the world – have been at the heart of many of these changes. Middle-income countries' output has more than tripled since 1990, and low-income countries' has more than doubled.[4] Growth accelerated not only in large emerging economies such as China and India, but also in many smaller and poorer countries in Asia, Africa and Latin America. In developing countries, the number of poor fell by nearly 500 million just in the last decade – the fastest pace of poverty reduction for which we have data.[5] But 2.4 billion still live on less than US$2 a day.

There is now an opportunity to build on this experience to make further major gains in human well-being in the next 10–20 years and beyond. But progress cannot be taken for granted. There are major risks that overshadow this otherwise bright prospect.

First, in the wake of the Great Recession of 2008–09, countries at all income levels are struggling to restore or achieve fast, equitable growth in output, jobs and opportunities. Despite the rapid growth before the crisis, the world is not on track to eradicate extreme poverty by 2030, as envisaged in the Sustainable Development Goals that are now being drafted.[6] Improvement in broader measures of human development has also slowed since the crisis.[7]

Middle-income countries' output has more than tripled since 1990, and low-income countries' has more than doubled.

Climate risk, meanwhile, is an increasing concern. The strong growth performance before the financial crisis was accompanied by a surge in energy consumption and greenhouse gas (GHG) emissions.[8] This development model, if carried forward, would generate spiralling emissions and, ultimately, severe climate damage that would undo the very gains in well-being that we seek.[9]

Major recent natural disasters have inflicted significant economic and human costs, including Typhoon Haiyan in the Philippines, Hurricane Sandy in the United States, major droughts in China, Brazil and the Horn of Africa, and floods in Europe. Such extreme events are likely to increase in both frequency and magnitude with unchecked climate change. Nor are extreme events the only concern. Existing climate variability is already a major source of poverty and insecurity among the rural poor. For them even small increments to risk in the form of delayed rain, higher temperatures, slightly more intense or protracted drought can mean disaster.

Tackling the challenge of strong, equitable and sustainable growth will require huge new investments and shifts in resource use. Actions today and in the next 15 years will be critical to stabilising and then reducing emissions to try to meet the international target of keeping the average global temperature increase below 2°C.[10] They will either lock in a future with inefficient infrastructure and systems, growing pollution and worsening climate change, or help move the world onto a more sustainable, low-carbon development path that strengthens resilience and begins to slow and reverse the accumulation of climate risk.

A critical insight of this report is that many of the policy and institutional reforms needed to revitalise growth and improve well-being over the next 15 years can also be critical to tackling climate risk. There are many potential "win-win" reforms that can simultaneously energise development and grapple with climate risk, but they may not be "easy wins". Real-world economies are rife with market and government failures. Correcting these can generate multiple benefits that transform the cost-benefit calculus of reforms. For example, we illustrate the very large co-benefits that can arise from policies to cut GHGs and local air pollution.

The report highlights three fundamental drivers of change that these reforms will draw upon: more efficient resource use, infrastructure investment, and innovation. And it focuses on three socio-economic systems that hold the key to yield multiple economic, social and environmental benefits: cities, land use, and energy systems. These systems are crucial for change in the next 10–20 years, because they are so important for the global economy and emissions, are already undergoing rapid change, and usually possess some institutions and policy frameworks that render them capable of reform and contributing to improved outcomes.

The Commission estimates that at least 50% and – with broad and ambitious implementation –potentially up to 90% of the actions needed to get onto a 2°C pathway could be compatible with goals of boosting national development, equitable growth and broadly shared improvements in living standards.

Reforms will entail costs and trade-offs, and will often require governments to deal with difficult problems of political economy, distribution and governance. But an argument that tackling climate risk is simply too costly, whether in terms of growth, competitiveness, jobs or impact on the poor, can be overstated, especially when the multiple benefits of climate action are fully taken into account. Complementary social protection and adjustment policies can help vulnerable groups and sectors make what is often a difficult transition.

Reforms will entail costs and trade-offs, and will often require governments to deal with difficult problems of political economy, distribution and governance.

There is no simple reform formula or agenda that will work for all countries. Each will deal with development and climate challenges differently, based on levels of economic, human and institutional development, social and political structures, history, geography and natural endowments. Countries will need creative experiments, to "learn by doing" and thus to find the right path for their own circumstances.

This introduction lays the foundation for the rest of the report. It begins by examining the growth and climate risks that could overshadow the global economy in coming years. It then looks at ways for countries to advance both economic and climate goals together, including "no-regrets" reforms, critical sectors and drivers of change, and the potential economic and GHG impact of reforms and actions discussed in the report. The differing challenges in low-, middle- and high-income countries are then examined. The chapter ends by showing why actions in the next 15 years are particularly critical.

2. Growth risks and climate risks

The world has made tremendous gains in human well-being over recent decades. Yet there are signs that countries could downshift to a weaker growth and poverty reduction trajectory in the aftermath of the Great Recession of 2008–09. Understandably, policy-makers are now focused on how to craft reforms to spark renewed growth and development – but they are also aware of growing climate risks.

The current model of development carries with it a growing risk of locking in a high pollution path. Current economic and poverty reduction gains may then prove unsustainable in the long run, as rapidly rising GHG emissions result in serious climate damage. Continued, rapid economic progress cannot be taken for granted. There is thus an urgent need for sustained policy and institutional reforms to revitalise growth and poverty reduction, strengthen resilience, avert lock-in and begin to slow and ultimately reverse the accumulation of climate risk.

2.1 Growth risks

The world economy may struggle to resume its strong performance before the Great Recession. Global annual growth averaged about 4% in the 2000s, before the crisis.[11] A more volatile and uncertain landscape has emerged in the years since, however. World growth did rebound to 5% in 2010 but has steadily decelerated since, falling to only 2.8% in 2013.[12] Forecasters expect a slight pickup in 2014, but there is high uncertainty around these projections.

Growth risks in developed countries

Developed countries were at the epicentre of the financial crisis and have also underperformed in the years since. After a modest rebound in 2010, growth in countries in the Organisation for Economic Co-operation and Development (OECD) has decelerated, falling to 1.3% in 2013.[13] The large gap between actual and potential output that opened up during the crisis has fallen much more slowly than in previous recessions. Output gaps in 2013 remained as high as 3.5% of potential output in the United States and the Euro area, according to OECD estimates. Potential output itself has deteriorated relative to pre-recession trends.

Unemployment in the OECD was 7.9% in 2013, only slightly below a peak of 8.3% in 2010.[14] Stagnating median incomes, high youth unemployment and rising inequality are a source of disquiet in many developed countries. In the longer run, there are concerns about the fiscal impacts of ageing populations, exacerbated by the steep increase in public sector debt as a consequence of the crisis.

The causes of the crisis and its weak aftermath are intensively debated. Theories include shocks to aggregate demand; overly tight fiscal and monetary policies; financial sector risk-taking coupled with weak regulation; too much private debt and protracted deleveraging; and excessive government intervention and uncertainty caused by unpredictable policies.

This report does not attempt to resolve these debates. However, extended cyclical downturns can cause adverse structural changes that reduce the economy's long-term potential output. Prominent analysts are concerned that developed countries may fall into an extended period of "secular stagnation".[15] Broad programmes of policy and institutional reforms are needed to modernise and buttress public finance, enhance innovation, and boost growth and employment opportunities in the developed world today.

Figure 1
Countries at different stages of development

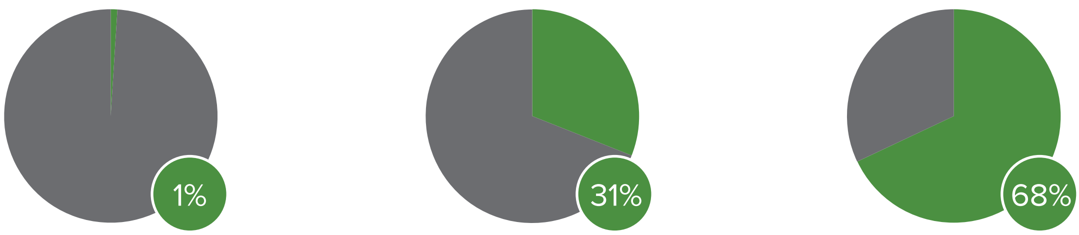
LOW-INCOME COUNTRIES	MIDDLE-INCOME COUNTRIES	HIGH-INCOME COUNTRIES
US$1,035 or less GNI / capita	**US$1,035-12,616** GNI / capita	**US$12,616** or more GNI / capita
36 countries	**103** countries	**74** countries
~ **0.9** billion people	~ **4.9** billion people	~ **1.3** billion people

TOP 10 MOST POPULOUS, ORDERED BY GNI PER CAPITA IN 2012

CURRENT US$

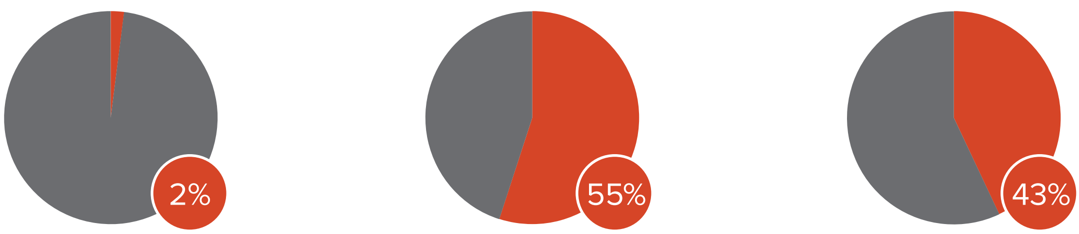
Country	GNI per capita	Country	GNI per capita	Country	GNI per capita
Kenya	860	Brazil	11,630	US	52,340
Bangladesh	840	Mexico	9,640	Japan	47,870
Nepal	700	China	5,720	Germany	45,170
Afghanistan	680	Indonesia	3,420	France	41,850
Tanzania	570	Egypt, Arab Rep.	2,980	UK	38,500
Mozambique	510	Philippines	2,500	Italy	34,720
Uganda	480	Nigeria	2,490	Spain	29,340
Madagascar	430	India	1,550	S.Korea	22,670
Ethiopia	380	Vietnam	1,550	Russia	12,700
Congo, Dem. Rep.	230	Pakistan	1,260	Poland	12,660

SHARE OF WORLD GDP IN 2012



SHARE OF WORLD GHG EMISSIONS IN 2010

EXCLUDING LUCF



Note: GNI per capita is using the World Bank Atlas Method, in current US$. GHG emissions exclude land use, land use change and forestry (LULUCF). Source: The World Bank, 2014.[16]

Growth risks in developing countries

Developing economies are also finding it difficult to regain their growth momentum in the wake of the crisis. Developing country growth averaged close to 7% annually in 2001–07, but slipped below 5% in 2013–14.[17]

The causes of the slowdown in developing countries are diverse. They include more difficult global conditions, including slow post-crisis growth in developed world imports, volatile foreign capital flows and lower prices for many primary commodities, as well as the need to curb overly expansive macroeconomic policies, and deeper structural and institutional impediments to growth.

There are also some general reasons why the growth boom in developing countries in the 2000s could turn out to have been a temporary episode. Empirically, high growth that is sustained over several decades is extremely rare. China and Korea are two outstanding examples in this select group. It is much more common for developing countries to experience "spells" of both high and low growth lasting 10–15 years, sometimes characterised as "growth miracles" and "growth failures".[18]

Developing economies are also finding it difficult to regain their growth momentum in the wake of the crisis.

There are good theoretical reasons why high-growth spells in developing countries might not be sustained. "Catch-up" growth is a basic mechanism of economic development, in which poor countries grow by importing advanced ideas and technologies, but it does not occur automatically. Achieving sustained growth requires developing countries both to strengthen fundamentals such as human capital and institutions, and to foster structural change, which sees labour, capital and entrepreneurs move from traditional to new, higher-productivity sectors. Achieving structural change is fraught with both government and market failures. Examples of the former might include a lack of key public infrastructure, and of the latter knowledge failures that lead to inadequate investment in importing foreign technologies. Overcoming such failures requires a constant, high-level engagement by government to experiment with reforms, learn from mistakes, and implement what seems to work at a given time. Such reform capacity may not exist, or be present only fitfully, according to changing political conditions.[19]

We thus have good reasons to think that if developing countries are to regain and sustain the fast growth of the 2000s into the next decades, they will need to undertake intense and sustained reform over the long term. These reforms will both build up fundamental capabilities and promote structural change.

It is important to remember the particular development challenges faced by middle- and low-income countries, as well as by countries with abundant natural resources – a group that cuts across income lines.

Low-income countries are marked by high poverty. Three-quarters of their population live on less than US$2 a day.[20] In sub-Saharan Africa extreme poverty is not only widespread but deep: large numbers live well below the absolute poverty line of US$1.25 a day. Health, education and other human development outcomes are weak. Low-income countries generally have low institutional capacity, relatively low (though fast-increasing) urbanisation, and a high reliance on agriculture and other primary sectors.

The key challenge in these countries is to overcome poor governance and low institutional capacity, and so spark rapid and widely shared economic growth and poverty reduction. These countries comprise 11% of the world population[21] and are exceptionally vulnerable to climate change and variability.[22] They are responsible for only 2% of world primary energy consumption and 1% of carbon dioxide emissions from energy use.[23] Changes in agriculture and land use could yield significant gains in terms of development and build climate resilience while curbing GHG emissions. Ensuring modern energy access for the poor is also a key development challenge.

Middle-income countries comprise 70% of the world population and were central to the boom in developing country growth, globalisation and urbanisation in the 2000s.[24] They account for around half of world energy consumption and carbon emissions from energy use, proportions which are rising rapidly. These are countries with a large and growing middle class. Many are grappling with complex problems of structural change and institutional modernisation. They are critical players in a transition to a resource-efficient, low-carbon global economy. Major development challenges include tackling dysfunctions and inefficiencies in urbanisation, industrialisation and energy use, where there is a high potential both to improve productivity and abate GHG emissions.

China and India stand out among middle-income countries by virtue of their size. Despite China's tremendous development over the last 30 years, its political leaders have remarked that the country's previous economic model is likely to prove "unbalanced, uncoordinated and unsustainable".[25] New approaches will be needed if the country is to avoid the "middle income trap" and reach high income levels in the next 15–20 years. The previous model entailed rapid growth in capital accumulation, exports, energy-intensive industry, and high levels of fossil fuel use (particularly coal); it also brought urban sprawl and severe local air pollution. A new direction will include a shift towards growth driven by innovation, more efficient resource use, cleaner energy sources and reduced coal consumption, cleaner air to breathe, more compact and productive cities, and greater reliance on growth in domestic consumption and services. These structural changes offer notable "no-regrets" opportunities for decarbonisation as part of the country's efforts to achieve national economic and social goals.

In India, meanwhile, where growth has fallen below 5% for two consecutive years,[26] a new government has a strong mandate to accelerate development by boosting infrastructure, improving the business climate and strengthening public service delivery.

Countries that have abundant natural resources occur in all income groups. They saw a significant rise in revenues during the 2000s as a result of major new mineral discoveries and higher international commodity prices.[27] If well managed, these resources could accelerate growth and poverty reduction. If not, they could generate dysfunctional outcomes.

Global CO_2 emissions from energy use increased by about 3% per year in the 2000s, around twice the pace in 1981–2000.

However, these countries also face particular challenges. First, in the absence of strong governance, natural resource abundance tends to foster problems such as corruption, social strife over rents and other effects – collectively labelled the "natural resource curse" – that lead to worse development outcomes. In practice, faster growth associated with mineral booms has often had only weak links to job creation and poverty reduction. Second, many of these countries are not saving enough to replace the depletion of their natural assets with human capital, through skills development, health improvements and new infrastructure, for example. In such cases, the total stock of wealth is falling, and present prosperity masks the likelihood of a poorer future.[28] Third, if the rest of the world credibly commits to curbing fossil fuel use, these resource-rich countries face the prospect of reduced demand and lower prices for fossil fuels in the future. It is therefore crucial that they make the most of the boom they are enjoying today to build up their human and other capital and prepare for the transition that they will surely have to undertake in the coming decades.

2.2 Climate risks

While achieving rapid economic growth and poverty reduction in the run-up to the financial crisis, the world has also been accumulating immense climate risks. Global CO_2 emissions from energy use increased by about 3% per year in the 2000s, around twice the pace of the years 1981–2000.[29] CO_2 emissions from energy use are the largest component of global GHG emissions, accounting for two-thirds of total emissions in 2010.[30] A growth rate of 3% means that emissions increase by 55% in 15 years and double in 25 years.

Recent emissions trends differ strongly between developed and developing countries, decelerating in the former but accelerating in the latter. Figures 2a and 2b explain changes in CO_2 emissions according to three drivers: real GDP, energy intensity of GDP, and carbon intensity of energy. (Energy intensity is the energy consumed per unit of real GDP. Carbon intensity of energy is the carbon emissions per unit of energy.)

Figure 2a shows that in the developed world, CO_2 emissions began to decouple from economic growth, contracting by 0.3% per year in the 2000s. This decline partly reflects the recession and slower economic growth, but there were also more promising reasons. The annual decline in energy intensity reached nearly 2% per year. Carbon intensity also fell, reflecting a continued gradual shift towards cleaner sources in the energy supply mix.

There was, however, no such decoupling in developing countries, where CO_2 emissions rose by 6.5% annually in the 2000s, in line with economic growth (see Figure 2b). Among other factors driving emission growth, the pace of decline in energy intensity slowed compared with the 1990s. Most seriously, the carbon intensity of the energy mix in developing countries, which was flat in the 1990s, rose by over 1% per year in the 2000s, reflecting a greater reliance on coal to meet rapidly growing demand for electric power generation.

Importantly, these carbon emission trends in developed and developing countries have not evolved independently. They reflect growing international trade in an increasingly integrated global economy. The 1990s and 2000s saw a shift in production of energy- and carbon-intensive goods from developed to developing countries, accompanied by a sharp rise in imports of such goods by developed countries from developing countries.[31] Key metrics for understanding this trend are "production emissions", which refer to the carbon dioxide (CO_2) emissions within a particular country's borders, and "consumption emissions", relating to the CO_2 embedded in the goods consumed by a country, regardless of the country where this CO_2 was originally emitted.

In developing countries, the fraction of production emissions which were ultimately exported rose from about 4% in 1990 to 11% in 2010.[33] Conversely, in developed countries, consumption emissions have grown faster than production emissions, reflecting rising carbon-intensive imports. High-income OECD countries saw

Figures 2a and 2b

Changes in CO_2 emissions, by key drivers, in high-income and developing countries

Source: Brahmbhatt et al., 2014 (forthcoming).[32]

Box 1

Climate change – concentration pathways, "lock-in" and impacts

Greenhouse gas emissions cause climate change. Carbon dioxide (CO_2) is the main greenhouse gas, and is emitted principally from the burning of fossil fuels for energy in the electrical power, transport, industry and residential sectors, and from deforestation and land use change. Other powerful GHGs include nitrous oxide (N_2O) and methane (CH_4), which are emitted from various agricultural and industrial processes and from waste. Fluorinated greenhouse gases such as hydrofluorocarbons (HFCs) are used as refrigerants and are less abundant but far more powerful than CO_2.

A broad definition of GHG concentrations includes so-called "Kyoto" GHGs (CO_2, CH_4, N_2O and three fluorinated gasses HFC, PFC and SF6) as well as "Montreal" GHGs (ozone-depleting substances such as chlorofluorocarbons, or CFCs). The concentration in the atmosphere of Kyoto GHGs is currently around 446 parts per million (ppm) of CO_2 equivalent (CO_2e), while including Montreal gases raises this to 470 ppm. Atmospheric CO_2e concentrations are rising by around 3 ppm per year, and that rate is accelerating.[34] A century of "business as usual" development might take us to a concentration of 1,000 ppm of CO_2e. Climate models suggest that such a rise could lead to a median temperature increase over the next century of 4°C or more compared with pre-industrial levels (see Figure 3).[35]

Action to reduce carbon emissions is made more urgent by long lag effects, both in atmospheric physics and human infrastructure, which mean that decisions today have their major impact on the climate for future generations.

First, there is a long atmospheric time lag, because it can take 25–30 years for CO_2 molecules to reach the upper atmosphere, and cause the "greenhouse effect" of trapping heat. Thus, moderating climate change in 2040–50 requires cuts in GHG emissions today and over the next 10 years. Note that CO_2 remains in the atmosphere for several centuries, and so avoiding emissions in the first place is the only sure way to limit their impact.

Second, GHG emissions come largely from long-lived assets. Once a power station, building, factory or car has been built, it will generate emissions at about the same rate through its life. This can be 40–50 years for a power station and even longer for some buildings (assuming constant use, and no "retrofitting" of new technology). This gives rise to the phenomenon of "lock-in". Once capital assets are built, their lifetime emissions are potentially irrevocable for decades.

The implications for climate action are profound. The infrastructure and technologies we install today will affect emissions both today and through this century. The next 15 years will be decisive in influencing the future climate. That is because of the greenhouse gas-emitting capital stock which already exists, plus the US$90 trillion worth of new infrastructure investment expected during this period across the cities, land use and energy systems where emissions will be concentrated.[37]

One way to understand the implications of lock-in for climate policy is through the concept of "carbon budgets". The Intergovernmental Panel on Climate Change (IPCC) calculated that for a two-thirds or better probability of limiting global average warming to 2°C, cumulative GHG emissions could not exceed 3,670 billion tonnes of carbon dioxide equivalent (Gt CO_2e).[38] Around half of that (1,890 Gt CO_2e) had been emitted by 2011. If the capital stock built over the next 10 years generated emissions at the same rate as that built over the last 25 years, the world would almost certainly exceed this carbon budget.

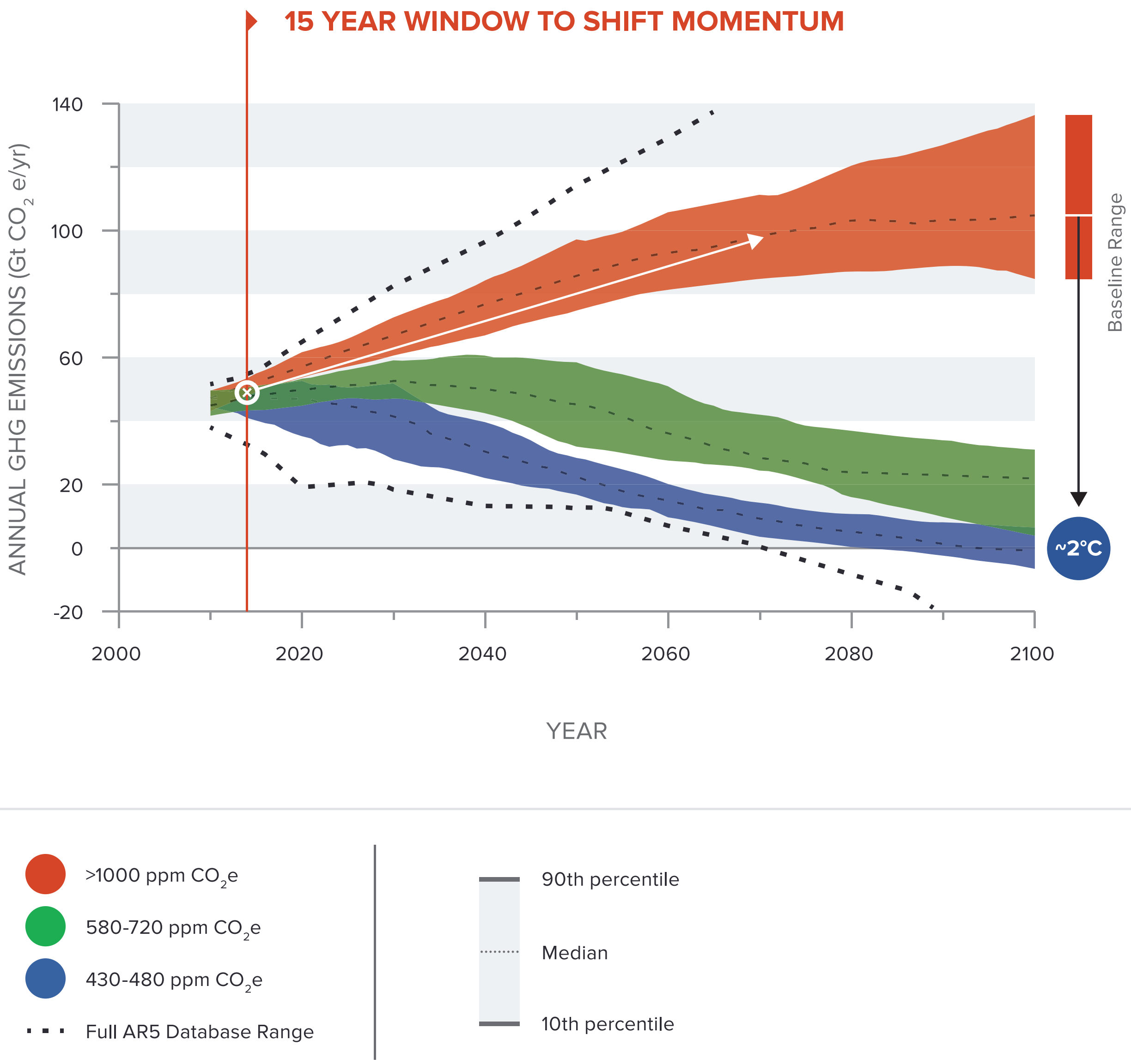
The IPCC's review of recent emission projections suggests that if current trends continue, global emissions in 2030 will be around 68 Gt CO_2e, compared with around 50 Gt CO_2e today, with cumulative emissions breaching the 2°C carbon budget by a significant margin in the long term.[39] There are several conceivable emission pathways consistent with a two-thirds probability of keeping warming below 2°C by 2100. A core 2°C scenario used in this report looks for a reduction in GHG emissions to 42 Gt by 2030 – an average decline of about 1% a year, with further reductions thereafter, including (in line with IPCC scenarios) a transition to negative emissions in the second half of the century.[40]

Such calculations show that delay in taking action makes it increasingly difficult to meet a 2°C target, raising climate risk. Delay is dangerous. Climate scientists have estimated how rising temperatures will affect different regions of the world over time, showing how warming above 2°C will lead to more dangerous effects.[41] In general, the frequency of extreme weather events, such as heat waves, droughts, floods, hurricanes and storm surges, will increase. Rising and more variable temperatures and changes in precipitation patterns will also take a toll, particularly in developing countries which depend on agriculture. Arctic sea ice and global glacier volume will shrink further, while sea-level rise and ocean acidification will continue. Ecosystems and "biomes" (biologically productive regions) will move polewards as temperatures rise.

Put in economic terms, the impact of about 2°C of warming could lead to global aggregated losses of 0.2–2.0% of income, the IPCC has said, synthesising the results of various studies.[42] Impacts and damages were likely to be significantly more severe in tropical regions and developing countries. Within developing countries, the poor are inevitably the most vulnerable group.

The IPCC reports that very few studies have examined economic impacts beyond a 3°C increase, which would represent an average global temperature not experienced

Figure 3
The world is currently on track for warming of around 4°C



Source: IPCC, 2014.[36]

for millions of years. While such studies have arrived at a very wide range of damage estimates, it is well understood that higher temperatures in this range increase the likelihood of reaching "tipping points" or "thresholds" in natural systems, setting off powerful, self-reinforcing climatic impacts and irreversible changes with severe economic and human costs. For example, the thawing of permafrost could lead to a large release of methane, which would drive additional temperature rises, risking runaway and catastrophic climate change and economic damages.

net carbon imports in 2010 rise to the equivalent of 18% of production emissions, from about 2% in 1990. Nevertheless, some OECD countries have managed to reduce both production and consumption emissions.

The comparison with financial risk

Climate risk can be usefully compared with financial risk before the 2008–09 financial crisis. Such comparisons include the steady accumulation of risk over time, the systemic nature of that risk, and its underlying incentives.

Before the crisis, financial risks increased as leverage and the use of high-risk instruments grew and spread through a globalised financial system. Climate risk is similarly cumulative, determined by the growing stock of GHGs in the atmosphere, rather than any one year's emissions. Such accumulation of risks creates the danger of a more severe outcome, especially since it is hard to know how close the system is to a tipping point. Even if most analysts thought a global financial crash was unlikely, there was clearly a possibility that it could happen, as transpired. Similarly, there is a clear possibility that climate impacts and damages could be even greater, or come earlier, than scientists' central scenarios, with very severe effects.

The financial risks that accumulated in the pre-2008 period were "systemic", in that all major financial institutions were exposed, making the entire global financial system vulnerable. Climate risk is also systemic: it cannot be isolated in one part or region of the world economy. Damage from warming above 2°C will affect all parts of the global economy.

Climate risk is large, systemic and accumulating, just as financial risk was before 2008.

Climate and pre-crisis financial risk also exhibit similar incentives. Financial firms and households had incentives to take on excessive debt and risk, because of higher near-term profits and utility. Regulators and governments had little short-term incentive to stop the excess, since the credit boom was evidently boosting economic growth and voter satisfaction. Similarly, firms emitting carbon and consumers enjoying the benefits of fossil fuels have every incentive to enjoy their low costs today. Governments with short-term political considerations hesitate to get in the way.

These parallels are both disturbing and instructive. Climate risk is large, systemic and accumulating, just as financial risk was before 2008. However, climate risk is arguably much better understood, having been the subject of vast international research collaboration and discussion for decades. And, unlike financial risk, failing to act could have consequences that are irreversible. The Commission believes that the world's governments, businesses and citizens at large possess an overwhelming case to act while they are still able to defuse the risks, if not to eliminate them.

Managing climate risk under uncertainty

One of the factors that makes climate change such an unusually difficult problem is that it entails policy-making under large scientific and economic uncertainties. While there is little doubt that climate change is occurring and that human activity is contributing significantly, there remain many large scientific uncertainties about the timing and scale of climate changes. The IPCC exhaustively documents these uncertainties in its latest major report reviewing the physical evidence, published last year.[43] As Box 1 notes, little is known about the scale of economic damages beyond a warming of 2–3°C, although the range of outcomes includes the possibility of very severe, long-run damage.

Uncertainty is not a reason for inaction given the evidence that climate change will inflict significant costs on average across the range of uncertainties. In addition, it is a standard assumption that decision-makers are risk-averse, and should therefore put even greater weight on the loss of welfare under a less optimistic outcome. The rational course of action is to manage climate risks, to take climate action today as an insurance premium against the real, but difficulty to quantify, possibility of severe or catastrophic outcomes.

Broadly speaking, there are two strategies to manage climate risk:

- **Mitigation** of climate risk aims to reduce the likelihood and extent of climate change by reducing GHG emissions. In risk management language, this can be called a self-protection strategy. The challenge facing the world is how to mitigate emissions substantially while maintaining rapid economic development and poverty reduction. In the remainder of this report we explore the potential for mitigation in terms of three drivers of change: improvements in efficiency in resource use; strategic investments especially in infrastructure; and, perhaps most important in the long run, innovation.
- **Adaptation,** on the other hand, is defined by the IPCC as "the process of adjustment to actual or expected climate effects", which "seeks to moderate or avoid harm or exploit beneficial opportunities" from climate change.[44] This is sometimes referred to as a self-insurance strategy. There is growing interest in broader strategies for transformative adaptation that help communities increase productivity, seek out lower-carbon methods and strengthen resilience to climate change. Box 2 notes some key aspects of adaptation. (See also Box 4, which describes transformative adaptation in sub-Saharan Africa.)

In conclusion, there is an urgent need for a development

Box 2
Adaptation

Any sensible approach to managing climate risk will involve some investment in adaptation, alongside mitigation. GHGs already in the atmosphere will mean that 2016–2035 will be 0.9–1.3°C warmer than 1850–1900, on average, even if drastic action to reduce emissions is taken immediately.[45] Adaptation to at least that level of climate change will therefore be essential. Furthermore, without mitigation, emissions and temperatures will continue to rise, and so will the costs of adaptation, as the impacts of climate change become increasingly harsh. Beyond a certain threshold, climate change would overwhelm capacity for adaptation – for example, extreme heat and sea-level rise.

Adaptation is likely to be highly context-specific, but will in general involve complementary actions across all levels, from individuals to governments. Changes in patterns of resource allocation, investment and innovation will be needed to sustain and improve well-being in response to actual and expected climate changes. Increased investment will be needed in such areas as more resilient infrastructure and water supplies; stronger coastal defences and flood protection; new techniques in agriculture, forestry, fisheries and other sectors to maintain output under changing weather conditions; improved meteorological forecasting and early warning systems; and better risk management, insurance, social protection and health services.

Taking adaptation seriously further underlines the importance of efforts to strengthen institutions for public investment management, to ensure that public spending is well planned, carefully implemented and efficiently managed.

Initial estimates have indicated that the costs of adaptation to 2°C warming might be US$70–100 billion per year from 2010 to 2050, or about 0.2% of global GDP in 2009, but a much more significant cost relative to GDP in low-income countries, which are likely to suffer more from climate change.[46] Limitations in the evidence base also suggest that these estimates are incomplete.[47] Regardless, estimates of adaptation financing needs in vulnerable low-income countries, such as in sub-Saharan Africa and Small Island Developing States, far exceed actual flows. Improving financing for adaptation must be an important element in international cooperation to tackle climate change.

Alongside public investment, adaptation also requires institutional and policy reforms that facilitate adaptation by businesses and individuals. Rational, forward-looking individuals will normally undertake adaptation actions in their own self-interest, but such autonomous adaptation may be hampered by market and policy failures. For example, farmers in low-income countries may fail to shift to new, more resilient seeds and farming techniques due to some combination of credit market and information failures, and weak property rights. Solving such problems to promote more resilient farming methods can have multiple benefits by raising agricultural productivity as well as curbing emissions, by promoting more sustainably intensive farming methods.

As these examples suggest, many of the reforms needed to facilitate adaptation are also likely to increase the development options and carbon abatement choices available to individuals and countries. A systematic use of cost-effective adaptation measures could increase resilience and reduce losses from climate change by up to two-thirds through 2030, while also making insurance more cost-effective for the remaining third, according to one study.[48]

model, across all types of countries, that first slows and ultimately reverses the accumulation of climate risk, while continuing to yield rapid gains in human well-being.

3. Opportunities to tackle growth and climate challenges

3.1 Some strategic considerations

A central insight of this report is that many of the policy and institutional reforms needed to revitalise growth and improve well-being over the next 15 years are also key to tackling climate risk. There is considerable scope for countries to press forward with reforms that both energise development and grapple with climate risk.

Market and policy failures, multiple benefits and the scope for "win-win" reforms

The potential for countries to make immediate progress on both development and reducing climate risk rests partly on what the Commission sees as the substantial scope for what are sometimes called "win-win" or "no-regrets" reforms.

"Win-win" reforms arise because real-world economies are rife with market and policy failures. In contrast to the theoretical economic model of competitive general equilibrium, where the demanding conditions for a welfare optimum are satisfied, real economies are typically operating well below their potential to improve welfare. Correcting these failures can generate multiple benefits, including gains in economic efficiency and the environment. Such reforms still entail costs and trade-offs. But the case for vigorous reform is substantially strengthened by taking proper account of the full range of market and coordination failures, and the potential multiple benefits (and costs) of correcting them.

Box 3 lists some of the more important market and coordination failures that are relevant to this discussion.

This report documents numerous opportunities for reforms which deal with both development and climate risk. These reforms yield both significant near- to medium-term net improvements in welfare, economic efficiency and development, as well as mitigation of GHGs. One important example we illustrate here is reform to reduce the negative environmental externalities from burning fossil fuels to reap multiple benefits, including both lower global climate risk and reduced local air pollution.

Climate change itself is, of course, the biggest of all global externalities. The economic case for undertaking some immediate action to mitigate climate change is well established.[50] But actual action has been limited. One concern among policy-makers is that while the costs of climate interventions are incurred today, they will produce benefits mostly over the long term. In addition, the size of these benefits is uncertain. And the climate benefits produced as a result of actions by any individual country will largely accrue to other countries, in the absence of a global agreement.

There is considerable scope for countries to press forward with reforms that both energise development and grapple with climate risk.

The benefit-cost calculus of climate action can change substantially when fuller account is taken of the multiple benefits that arise as a joint product of actions to reduce emissions of GHGs.[51]

The classic example of multiple benefits is the reduction in local air pollution associated with climate mitigation policies that reduce the use of fossil fuels.[52] Fossil fuel burning generates not only greenhouse gases but also local air pollution that has an immediate harmful impact on the emitting country itself. The most important type of air pollution involves tiny particles called particulate matter (PM). These particles are defined according to their size; the smallest, $PM_{2.5}$, which often come from burning fossil fuels, are the most dangerous. They increase they prevalence of lung cancer, chronic obstructive pulmonary disease, ischemic heart disease (from reduced blood supply) and stroke.[53]

Box 3
Anatomy of market failures – a world of imperfections and opportunities

Externalities occur when a product or activity affects people in ways that are not captured in its price. A firm burning coal as an input in manufacturing creates local air pollution, which damages the health of people nearby. This damage is not captured in the price of the final product, which is then over-consumed, reducing overall welfare. The firm's activity also creates a global externality in the form of climate change, which will adversely affect people all over the world.

Network effects occur when the value of a product or activity depends upon its wider adoption. Electric cars are less valuable if there are only a few users, because it is unprofitable to create a network of charging stations. And without charging stations, the number of electric car users remains low. As a result, electric cars may fail to take off and achieve an alternative possible equilibrium with many users and a profitable charging network. Extension of recycling initiatives and the electricity grid provide other examples.

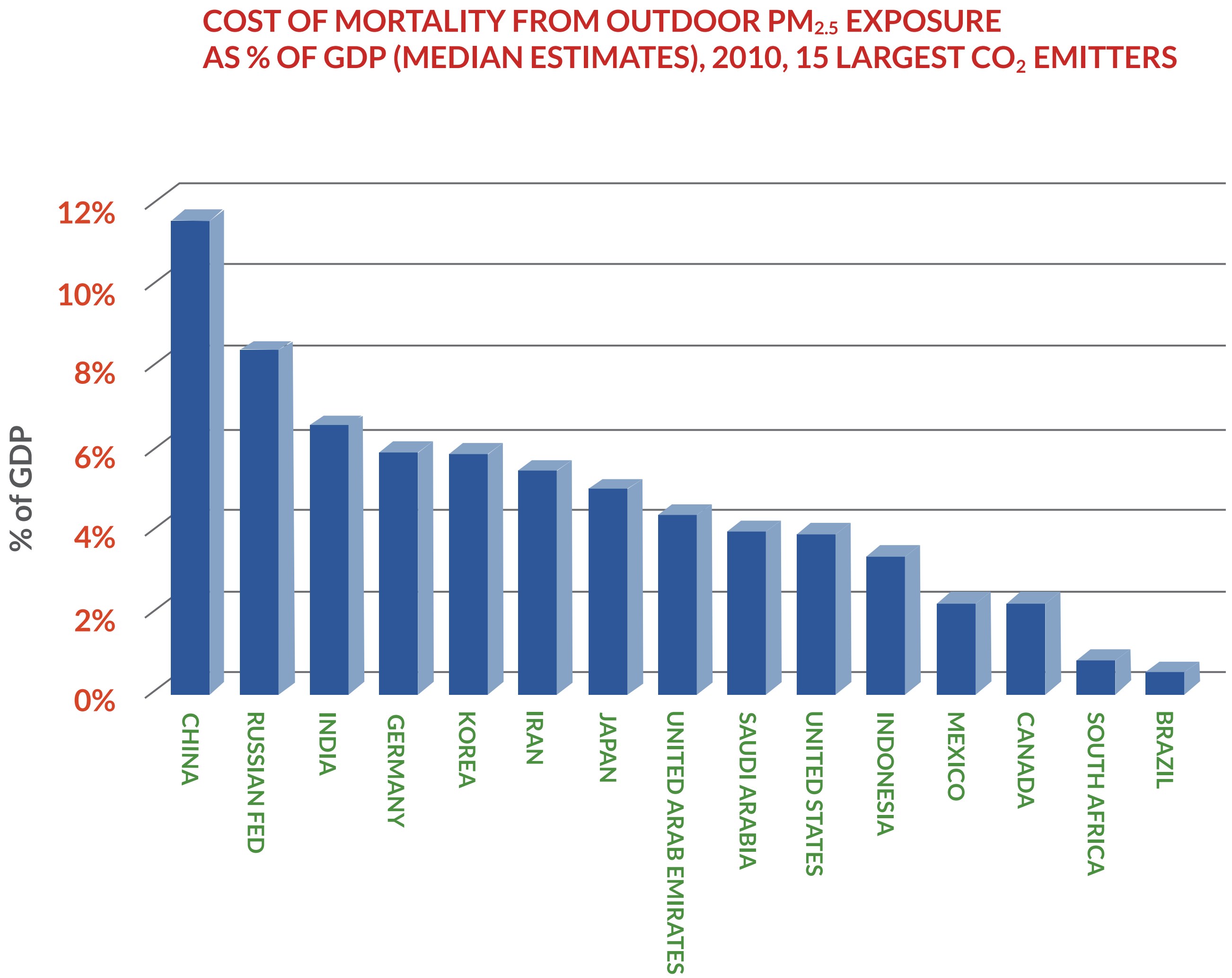
Agglomeration effects are close cousins of network effects, and are important in the economics of cities, where the value of deciding on a particular location depends on the number of other people deciding the same.

Innovation externalities occur where an inventor is inadequately rewarded for the time and resources invested to create a superior product or process. For example, once developed, the innovation's advantages may be relatively cheap to copy. Knowing this, the inventor may simply not take the trouble to innovate. Similarly, firms may under-invest in education and training, as trained workers can be "poached" by other companies. Network externalities and asymmetric information effects also hinder the creation, diffusion and financing of innovations.

Imperfect information. Many imperfections in capital markets and financial systems, such as moral hazard, adverse selection and principal-agent problems, result from imperfect information. In addition, firms and consumers do not have complete information about available goods and services – for example, the energy efficiency of appliances or cars – and so may not recognise their economic benefit.

Behavioural aspects. Economies may also perform inefficiently because of the psychological features of economic agents, whether consumers, workers, savers, managers or policy-makers, reflecting various biases and constraints in human decision-making.[49]

Figure 4
Cost of mortality from outdoor air pollution, 2010



Note: The estimate is for mortality from particulate matter ($PM_{2.5}$) exposure in particular Source: Hamilton, 2014.[55]

The health damages caused by local air pollution are often very large. In China, $PM_{2.5}$ pollution has been linked to 1.23 million premature deaths in 2010 (median estimate) – or, put in monetary terms, damages equivalent to 9.7–13.2% of China's GDP. The problem is so severe that curbing local air pollution has become one of the major items on the government's policy agenda, driving plans to curb China's coal consumption.

In India, $PM_{2.5}$ pollution is associated with more than 627,000 premature deaths in 2010 (median estimate), equivalent to 5.5–7.5% of GDP. Figure 4 shows median estimates of the costs of mortality from $PM_{2.5}$ exposure for the 15 largest emitters of CO_2 from energy use.[54]

It is sometimes useful to express the monetary value of health damages from local air pollution per tonne of CO_2 emitted from fossil fuel combustion. With some caveats, this indicator also provides an estimate of the potential health benefits per tonne of CO_2 abatement. A recent study calculates the median value of such health benefits for the 15 largest CO_2 emitters at US$73 per tonne of CO_2 abated in 2010.[56] Illustrating the significance of these numbers, they are more than double US government estimates for the climate benefit of reducing CO_2 emissions. The US Interagency Working Group on Social Cost of Carbon estimated this climate benefit at US$32 per tonne of CO_2 abatement in 2010.[57] Adding the median US$73 benefit from reduced air pollution in the 15 largest emitters would triple the overall benefit from cutting carbon emissions. Furthermore, and importantly from the perspective of policy-makers, the air quality benefits are enjoyed in the near term; accrue locally, mostly to the country itself; and are more certain compared with climate change benefits.

This discussion of avoided local air pollution provides a specific example of the importance of accounting for multiple benefits when evaluating climate actions. In practice, it would be important to look carefully at how the size and time paths of the various benefits and costs differ across countries. Many aspects of the links between greenhouse gases and local air pollutants, including synergies and trade-offs, need to be better understood.

From the perspective of policy-makers, an important complication is that there may be alternative policies that generate a different set of benefits. For example, a significant volume of local air pollution can be mitigated by so-called "end of pipe" methods that do not reduce GHG emissions, such as sulphur scrubbers fitted to the smokestacks of power plants. If countries pursued more ambitious air pollution reduction targets, however, then "end of pipe" methods are unlikely to be enough. It would still then be necessary to adopt methods that also reduce GHG emissions.

One of the few model-based studies to estimate the scale of GHG reductions from ambitious air pollution policies considered an illustrative scenario in which countries sought to reduce premature air pollution-related deaths in 2050 by 25% compared with 2005. This ambitious air pollution target also yielded large GHG reductions by 2050, falling by 38% in the OECD, 61% in China and 42% in India, compared with a baseline without mitigation policies.[58]

Fossil fuel combustion, especially from coal, is the major source of PM pollution in China, causing severe smog and haze problems in major cities. In 2013 only three Chinese cities met a so-called "Grade II" air quality standard (equivalent to less than 35 micrograms of PM per cubic metre). Research for the Commission suggests that even with the most advanced end-of-pipe technologies, only 50% of Chinese cities would be able to achieve the Grade II air quality standard by 2030. Instead, it will be necessary to adopt upstream methods which replace fossil fuels to ensure that most Chinese cities meet these air quality standards. Such transformational policies would also generate GHG reductions and help China peak its emissions by around 2030.[59]

In a full cost–benefit analysis, policy-makers could compare the total multiple benefits (net of costs) of a GHG mitigation policy against those of an air pollution reduction policy. An optimal policy would seek a combination of GHG and air pollution measures, to maximise total multiple benefits net of costs. One study finds that an optimal, combined policy achieves air quality benefits as large as an air pollution-only policy, while also achieving climate benefits larger than in a GHG-only mitigation policy.[60] The net total benefits of the combined policy are larger than either of the separate policies. Clearly, this is an important policy theme which deserves to be explored more thoroughly going forward.

Scope for reforms: some qualifications and limitations

We have used the term "win-win" to refer to the potential for reforms which tap multiple benefits by tackling numerous market and policy failures. It is important to describe some qualifications and limitations.

First, such reforms still entail costs and various trade-offs. To illustrate, consider a common example of a "win-win" reform, to reduce fossil fuel consumer subsidies. Such a reform can reduce fiscal pressures, improve economic efficiency, and yield multiple benefits in reduced local air pollution and GHG emissions. However, it also entails costs, including human costs and loss of output that occur as workers and equipment in some sectors become unemployed for some time, before finding employment in rising sectors. Costs and trade-offs exist in all cases, and need to be carefully examined and dealt with in undertaking reforms.

In developing countries, an important concern is that attempts to tackle climate change will derail their immediate and overriding objective of rapid economic growth and poverty reduction.

Second, there is the "problem of the second best". In an economy with multiple imperfections, an attempt to correct one imperfection could reduce rather than increase overall welfare.[61] Here there are no easy formulas. Each situation would need to be analysed carefully on its merits, and policy might need to proceed through step-by-step experiment and learning-by-doing to discover the right combination of instruments to advance overall welfare over the course of time.

Third, there are often deep political economy or institutional reasons why governments do not undertake reforms to eliminate a market or policy failure. Government failure can lead to reforms themselves introducing new distortions or inefficiencies that leave the country worse off than before. Such failures can occur, for example, when governments are mainly responding to influential special interests or rent-seekers; lack credibility with the public; or are mainly driven by short-term political objectives. As a result, the hard and poorly understood problem of improving governance and institutions is an essential element of reform strategies to tackle development and climate objectives.

Some of these limitations may represent daunting challenges for reform. But this should not discourage a well-considered, bold and persistent effort to act, given the potential for immense gains in human welfare and poverty reduction, and the severe climate losses that could accompany inaction.

Is climate action too costly?

There is never a good time for major change, especially one which involves complex political dynamics and deep institutional reform. To make progress, it is crucial to examine the many thoughtful and reasoned concerns about potential adverse effects of climate action. Here we briefly discuss some of the main concerns that are sometimes raised against taking immediate action on climate.

The most widely held concern is that climate action is simply too costly. In developing countries, an important concern is that attempts to tackle climate change will derail their immediate and overriding objective of rapid economic growth and poverty reduction. In all countries there are concerns about potential effects on employment and competitiveness in the global economy.

In evaluating such concerns, it is important to take into account the full costs and benefits of all available options. Sometimes a policy may appear too costly because not all its benefits are accounted for. The appropriate metric for judging an economic policy is its impact on overall welfare. In this report, we have tried to focus on policies and reforms which improve overall national welfare, productivity and efficiency, and which also help reduce climate risk.

Developing countries may worry that environmental policies will hinder their industrialisation. They may argue that it is better to "grow dirty and clean up later".

Often the analysis focuses only on the costs to a particular sector – for example, the pollution or carbon-intensive industries in the economy – while ignoring broader effects on the welfare of the public at large, such as improvements in health from reduced local air pollution. A lack of environmental regulation is in effect a form of subsidy to highly polluting firms at the expense of a less healthy public, and less polluting firms. Environmental policy improves overall economic efficiency and welfare by removing the implicit subsidy for polluting firms, and by causing a reallocation of resources towards cleaner activities.

The exclusive use of GDP as a yardstick to measure the welfare effects of reform can also be misleading. The effect on GDP might include a potential loss in measured output of goods and services, but not other types of changes in welfare, for example in improved health. Policy-makers should supplement GDP effects with estimates of broader welfare gains, which can also be estimated in monetary terms, albeit sometimes only roughly.[62]

If policy-makers do want to focus solely only on GDP effects, however, several points are relevant. First, the assumptions of models used to make such estimates need to be carefully scrutinised. Models often start from the assumption of an economy where resources are already efficiently allocated, for the good reason that we do not yet know how to model the real world of multiple imperfections and numerous inefficiencies. The effects of reform are therefore judged against the assumed starting point of an efficient economy. Such results, while interesting, need to be used cautiously as a guide to policy, when one is judging the results of reform versus non-reform in a highly imperfect and inefficient world.

Second, as Chapter 5: Economics of Change discusses in more detail, the estimated global costs of efficient climate policy, such as a carbon tax, are usually rather limited, perhaps in the order of 1–4% of global consumption in 2030, with a median value of 1.7%, according to the IPCC's review of recent studies.[63] Such costs are fairly small in relation to the much larger underlying increase in consumption that would occur by 2030. Assuming consumption growth of 3% in 2015–30, a little less than average world GDP growth since 1980, a median 1.7% cost would represent a delay of about six months in achieving the level of consumption that would have been reached in 2030 without climate policies. This does not seem an excessive insurance premium to pay to start reducing the possibility of dangerous climate change. Note that the cost estimates discussed here do not include the kinds of multiple benefits discussed above, nor the benefits of averted climate damages. Such model-based cost estimates can also be significantly reduced by optimal recycling of revenues from a carbon tax – for example, to cut labour and capital taxes.

Third, adopting a somewhat costlier option today may make sense in a highly uncertain world where there is a value in keeping options open and avoiding getting locked into courses that might turn out to be very expensive in the future. This point is especially relevant when building large, long-lived infrastructure such as transport networks or power systems.

Fourth, the cost–benefit ratio for climate action depends greatly on the international context. There is a disincentive for governments to undertake reforms with climate trade-offs, because climate action creates a global public good. The benefits from a single country's efforts to reduce GHG emissions will accrue to all countries. But if countries act together to reduce emissions, then the climate benefits for each country are much larger. Chapter 8: International Cooperation explores approaches for enhancing global cooperation on climate action, including the need for climate finance to help developing countries make progress.

Will climate action lead to loss of competitiveness?

The particular focus here is the potential harm caused by climate action to the international competitiveness of a country's industries. The concern is that higher costs relative to foreign competitors will cause a shift in pollution-intensive industries to other countries with less strict regulation.

Empirical studies have found this relocation effect to be small, where it is found at all, reflecting the fact that pollution abatement costs are only a small proportion of total costs in most industries. In addition, environmental regulations can induce firms to increase innovation as a way to offset such higher costs. Governments may nevertheless consider providing carefully designed transitional assistance to vulnerable sectors.[64]

Developing countries may worry that environmental policies will hinder their industrialisation. They may argue that it is better to "grow dirty and clean up later". Developing countries indeed face numerous coordination and market failures that may hamper structural change and the success of tradable goods industries, which, even if they are polluting, might well be important for long-term growth and structural change. As noted earlier, "growing dirty" implies subsidising polluting industries at the expense of less polluting firms and the public at large, who suffer from pollution and ill-health. Lack of environmental regulation can then be a form of industrial policy to support polluting tradable sectors, one that is relatively easy to implement, as it does not make heavy demands on institutional capacity. Developing countries should, however, be able to reach a better outcome if they combine tighter environmental policy with more focused government interventions in support of structural change, backed by a sustained effort to strengthen institutional capacity. To encourage such approaches, developed countries could consider providing greater flexibility under international trade rules to accommodate well-managed industrial policy interventions by developing countries.[65]

Will climate action hurt the poor?

Whether climate actions such as removing fossil fuel subsidies or a carbon tax are regressive (having a greater relative negative effect on the poor) depends to some extent on country circumstances. There is some evidence that they tend to be regressive in developed countries, but less so in developing nations, where the upper and middle classes may be the major consumers of energy.[66] Regardless of this relative impact, policy-makers are concerned about the absolute impacts of higher energy prices on the poor. Well-designed and targeted safety net measures to help vulnerable groups are an essential element in the political economy of reforms.

Will climate action cost jobs?

Linked to concerns about competitiveness are fears that environmental policies will significantly increase unemployment. Others have argued that such policies will, on the contrary, be a source of "green jobs".

A good starting point is to note that the aim and effect of environmental and climate policies is to induce a substitution between different types of production and consumption, away from more polluting to less polluting activities. There is no special reason to expect any overall net job gains or losses from this adjustment. While there is a clear finding in the research that any overall employment effects of environmental policies are small, there is no consensus whether those small effects would be positive or negative.[67] (See Chapter 5: Economics of Change for further details.)

Investment in infrastructure is a fundamental mechanism to expand the productive capacity of the economy.

There will, however, be changes in the numbers and types of jobs across and within economic sectors, and there could be significant adjustment issues, as workers need to move from declining to expanding sectors, firms and job types. This will require specific policies to shape a just transition. The amount of such "churn" or job destruction and job creation linked to climate mitigation is expected to be about 0.5% of total employment – quite small compared with the overall "churn" that normally occurs in a market economy. Job effects may be larger in economies with larger labour market imperfections. The recycling of revenues from carbon taxes or emissions trading schemes can mitigate job impacts. For example, studies suggest that recycling of carbon tax revenues to reduce labour market taxes could offset or more than offset all adverse impacts of climate action on employment.[68]

3.2 Enabling change through resource efficiency, investment and innovation

Policy efforts to promote rapid development and tackle climate risk will draw upon and work through three fundamental mechanisms or drivers of change that affect every sector of the economy: efficiency of resource use; investment, particularly in infrastructure; and innovation.

Figure 5
Three critical economic systems and three key drivers of change

Note: Cities include urban transport, and land use includes forests; innovation includes economy-wide innovation.

Resource efficiency

The discussion in the preceding section has stressed the presence of numerous market and policy failures which result in an inefficient allocation of resources and lower levels of welfare. Fossil fuel consumer subsidies are an important example. They result in multiple resource misallocations, including excessive capital and labour employed in pollution-intensive sectors. Within sectors, firms use more fossil fuel- and pollution-intensive methods of production. Consumers' shopping baskets are biased towards fossil fuel- and pollution-intensive goods and services. There is too much local air pollution, damaging citizens' health and productivity, and too high GHG emissions, storing up climate risks for the future.[69]

> *Innovation and technological progress are by far the most important drivers of long-term growth in productivity and output.*

Reforms of fossil fuel subsidies, discussed in more detail in Chapter 5: Economics of Change, can stimulate improvements in efficiency of resource use in all these dimensions. Various instruments can improve resource efficiency by tackling market failure, including price-based instruments such as carbon taxes or emission trading schemes, as well as regulations and standards, and information-based instruments, among others.

Infrastructure investment

Infrastructure refers to the large interconnected physical networks – transport, communications, buildings, energy, water and waste management – that provide critical services to and raise the productivity of the economy as a whole. Investment in infrastructure is a fundamental mechanism to expand the productive capacity of the economy.

Recent economic research has provided much evidence on the high, economy-wide returns to efficiently allocated and well-managed infrastructure capital.[70] As Chapter 6: Finance indicates, almost US$90 trillion infrastructure spending (in constant 2010 dollars) is projected to be needed in 2015–30 across the cities, land use and energy systems, especially in developing countries. Ensuring that this new infrastructure does not lock countries into a high-carbon path, but rather supports the transition to a low-carbon economy, is expected to have a net additional cost of about US$4 trillion. The latter does not include longer-term operational savings in a low-carbon transition, as a result of burning less fossil fuels.

Increased investment is a means of increasing consumption in the future. When the economy is operating at full capacity, it will, in general, demand some sacrifice of present consumption. But that is hardly the case in large parts of the world today, which are continuing to operate at below their potential output in the wake of the Great Recession. Investment is hardly constrained by a shortage of savings, as suggested by low long-term real interest rates. Yet world gross fixed investment relative to GDP has fallen to around 21% in the years since the crisis, the lowest level in 50 years, entirely due to a fall in developed countries, to around 19%.[71] The present macroeconomic context thus provides a particularly favourable opportunity for policies to foster stronger global growth through increased infrastructure investment, including in low-carbon systems.[72] Chapter 6: Finance further explores policy approaches to boosting infrastructure spending on low-carbon assets, in particular through institutional innovations to encourage private-sector financing and engagement.

Innovation

Innovation and technological progress are by far the most important drivers of long-term growth in productivity and output.[73] It is also becoming clear that innovation is likely to be the most important long-term driver to mitigate climate change, in particular by fostering new technologies that can supply energy that is not only clean but also cheap and abundant. The latter condition is critical if the world is to satisfy rapidly growing energy demand in developing countries while also abating GHG emissions and climate change.

> *The clustering together of individuals and firms in urban areas facilitates innovation, productivity increases and economic growth through a variety of agglomeration economies.*

A broad definition of innovation includes not only cutting-edge research and development (R&D), but also deployment, diffusion and adoption of existing technologies, the latter being especially important in developing countries. It includes not only development of new products and production processes, but also institutional innovation and new methods of business organisation, marketing and distribution. Relatively simple innovations can have enormous impacts: the introduction of the humble shipping container revolutionised global freight transport and is estimated to explain a 700% increase in industrialised country trade over 20 years.[74]

There is a large role for public policy to foster innovation. As Box 3 indicates, innovation is subject to its own specific market failures, such as knowledge spillovers, network externalities and asymmetric information. These failures mean that private incentives alone are generally

Box 4
African agriculture – a case for transformative adaptation and multiple gains[80]

High poverty makes Africa's rural populations acutely vulnerable to climate risk. It also closes down opportunities for productive investment and reinforces land use policies that contribute to climate change.

Low productivity is at the heart of the problem. Grain yields are between one-third and one-fifth of those in South Asia. Much of Africa's agricultural output growth over the past half-century has come from land and labour increases. Crop-intensification, minimum tillage and agroforestry projects could all boost yields. Farmers in Malawi have doubled maize output per hectare through more intensive cropping. However, climate risk is itself a barrier to investment, one which is gradually ratcheting higher. Studies show that inability to manage risk is a major deterrent to the adoption of new technologies and investment in crops offering higher (but more variable) returns.

Transformative adaptation strategies could help change this picture. For example, support for social protection and the development of insurance can provide a safety net that reduces the threat of severe losses. Investment in infrastructure can have a similar effect by strengthening resilience.

African governments themselves could do much to reduce risk and raise productivity. On one estimate, Africa's farmers typically receive around 20% of the value of food crops, reflecting the poor state of rural roads and the operation of transport cartels. Some 10–20% of food staple production is lost through post-harvest losses. Non-tariff barriers restrict opportunities for participation in regional trade. One effect is to decouple agriculture from fast-growing urban markets. Currently, intra-regional trade accounts for less than 10–15% of the US$35 billion in food imports.

Ethiopia is exploring a more ambitious approach to adaptation. The 2011 Climate Resilient Green Economy strategy provides a single funding mechanism and institutional framework linking all government departments. The strategy combines public investment in infrastructure with incentives for private investment to mitigate climate risks and raise productivity.

inadequate to generate an optimal amount of innovation. Market incentives for climate-friendly innovation are further reduced by the failure to price externalities related to GHG emissions, which boost the profitability of polluting relative to clean technologies. The introduction of environmental pricing on fossil fuels would improve the price incentives for innovators to seek out new cleaner technologies, in addition to improving the efficiency of existing resource allocation.

Chapter 7: Innovation discusses various public policy responses, including public-sector R&D, fiscal incentives, public procurement, intellectual property rights and other instruments. Innovation market failures also provide a rationale for policies tailored to promote innovation in clean technologies more specifically. That is because market failures affecting innovation also promote path dependence.[75] The large existing base of research in fossil fuel technologies, for example, has given them a large "head start", and favours further innovations on that path. This path dependence, or bias in favour of existing dirty technologies, could hinder or prevent the creation of a clean energy innovation complex and path that might otherwise generate new clean technologies that are ultimately even cheaper than their dirty competitors.

3.3 Opportunities to tackle growth and climate challenges in three critical systems

The Commission has focused on three socio-economic systems that hold the key to yield multiple economic, social and environmental benefits: cities, land use and energy systems. These systems are crucial for change in a meaningful 10- to 20-year horizon because they are so important for the overall economy and emissions, are already undergoing rapid change, and generally have institutions and policy frameworks that can support reforms and contribute to improved outcomes. Other sectors such as heavy and light industry and services are also enormously important, of course, and are examined throughout the rest of the report, for example in the discussions of energy, innovation, competitiveness and restructuring.

Building more productive and cleaner cities

As Chapter 2: Cities discusses, urbanisation and economic development are mutually reinforcing. The clustering together of individuals and firms in urban areas facilitates innovation, productivity increases and economic growth through a variety of agglomeration economies. Such effects include spillovers and diffusion of knowledge between firms; increased productivity due to a wider variety of specialised inputs and types of labour; better risk-sharing; better matching of workers to firms; and greater feasibility of infrastructure projects with economies of large scale.

The geographic density of economic activity is found to be a powerful influence on productivity, broadly confirming the role of agglomeration economies, and showing that more compact cities can have economic development advantages. Employment density is found to explain over half of the variation in labour productivity across US states, for example.[76] At the same time, cities are also drivers of energy consumption and GHG emissions, generating about 70% of the global total of each.[77] Crucially, more compact, more connected city forms allow significantly greater energy efficiency and lower emissions per unit of economic activity.

> *In developing countries, especially, the traditional model of agriculture and land use is under pressure due to growing land and water scarcity, deforestation, over-grazing and soil degradation.*

Unfortunately, there are few automatic guarantees that urban form will necessarily evolve in ways that maximise agglomeration economies and productivity while curbing GHG emissions, local air pollution and congestion. The dominant growth pattern in many urban areas is characterised by unmanaged sprawl and increasing car use. The fact that individuals and firms do not take into account the collective benefits of density creates a bias towards more urban sprawl. Other market failures also contribute, such as the lack of pricing for air pollution, congestion, or road traffic accidents (a major source of death and injury, particularly in developing countries[78]). Lack of city-level institutional and planning capacity tends to work in the same direction. Policy failures include infrastructure financing or urban tax models that implicitly subsidise sprawl, and motor fuel taxes that are too low to fully cover the cost of building and maintaining roads. Once a city starts to sprawl, it creates its own logic for further sprawl, by shaping household expectations about dwelling space and commute time; and building up a political economy of property developers and transport providers. Beside climate change, urban sprawl is one of the biggest examples of a market failure worldwide.

The Commission concludes that the type of urbanisation that unfolds in the next 15 years will have a major bearing on whether the world can exploit the opportunity for achieving economic growth while managing climate risk. How urban planners shape urban form and long-lived infrastructure in these coming few years will largely determine whether the world gets locked into a traditional model of sprawl and conventional motorisation, with lower productivity and spiralling emissions, or moves onto a better path, with more compact, connected and liveable cities, greater productivity and reduced climate risk.

Improving land use

Agriculture and land use systems will play an important role in dealing with development and climate risk challenges, as elaborated in Chapter 3: Land Use. These systems are central in meeting rising demand for food, driven by fast-rising incomes in developing countries and a still growing world population. They remain a major source of employment and income in low- and lower-middle-income countries, where they are also highly vulnerable to climate change.

In developing countries, especially, the traditional model of agriculture and land use is under pressure due to growing land and water scarcity, deforestation, over-grazing and soil degradation. These are also regions where agricultural productivity is already being affected by existing climate variability and will be most seriously reduced by climate change.

Chapter 3: Land Use argues that there are significant reform opportunities that raise farmers' incomes, strengthen resilience to climate change and abate GHG emissions. Such gains can be achieved by the application of modern agricultural technologies and practices that boost crop and livestock productivity, and that economise on inputs such as land, water and fertilisers. Landscape approaches to land and water management, which look beyond individual farms to improve resource use and protect ecosystem services, and often involve planting trees, can increase productivity and help stop and reverse land degradation. This, in turn, can reduce pressure on adjacent forests.[79]

> *Developing countries need to re-evaluate traditional assumptions about the inevitability of fossil fuels and coal and to study the full range of options that are now becoming realistic.*

Exploiting such opportunities will require policy reforms, coordination and institution-building to overcome market failures that hinder farmers from pursuing them individually. One key problem to address is weak property rights, which create "tragedy of the commons" problems, contributing to overgrazing, deforestation, overuse of water resources and soil degradation. Weak property rights, credit market failures, imperfect information and other market failures contribute to inadequate uptake of new agricultural technologies, products and logistics capacity, which together could improve living standards, reduce food losses, and create greater flexibility and resilience to climate variability. Government failures, including inadequate provision of public goods such as roads, human security, information and agricultural extension services, also contribute.

Transforming energy systems

Energy is a crucial enabler of development. World energy use has increased by more than 50% since 1990,[81] and it is clear that developing-country demand for energy services will continue to increase as these countries industrialise and as hundreds of millions more people move out of poverty. Many of these people will be gaining access to electricity for the first time. Securing access to abundant energy services will remain a major preoccupation for policy-makers everywhere.[82]

Important approaches for meeting energy demand and reducing climate risks will include boosting energy efficiency, and exploiting rapid changes in energy supply technologies, as discussed in Chapter 4: Energy.

First, there is substantial scope to meet demand for energy services by increasing energy efficiency. Numerous low-cost ways already exist to increase energy efficiency in transport, power, heating, lighting, buildings and industry, a potential which is growing rapidly as a result of innovation. Uptake of these solutions is hampered by energy subsidies, lack of environmental pricing and market failures such as innovation externalities, learning-by-doing effects, imperfect information, credit market failures and principal-agent problems, as well as behavioural effects such as inattentiveness and myopia.

Policy interventions such as subsidy reform, carbon pricing, product efficiency standards, better information and behavioural "nudges" can significantly boost energy efficiency and, in particular, prevent inefficient energy models being locked into long-lived infrastructure.[83] Such interventions can also prevent lock-in of a high-carbon mix of fuels, in particular excessive use of coal. Section 3.1 above has explored the large health and economic benefits of curbing local air pollution from fossil fuel burning. The most effective way to reduce these damages is through corrective fuel taxes. A recent study by the International Monetary Fund (IMF) finds that fuel taxes would also raise substantial fiscal revenues that could be used to cut other distorting taxes, or to raise other development spending.[84]

Second, global energy supply technology is changing rapidly. Renewable energy has seen unexpectedly fast cost declines. These changes are overturning many previous assumptions about relative energy costs and broadening the set of cost-effective low-carbon energy options available to countries, as Chapter 4: Energy elaborates.

Developing countries need to re-evaluate traditional assumptions about the inevitability of fossil fuels and coal and to study the full range of options that are now becoming realistic. Middle-income countries that want to absorb new technologies and become technology leaders should avoid locking themselves into coal-based pathways. Broadly speaking, high-income OECD countries have been the pace-setters in exploring low-carbon paths, through research and development, deployment, and policy and institutional innovation. Innovation market failures mean that there is a clear rationale for a strong public sector role to support overall energy R&D and deployment. A major, expanded push on fundamental energy research, development and innovation should be a priority in all developed countries, both individually and through international cooperation.

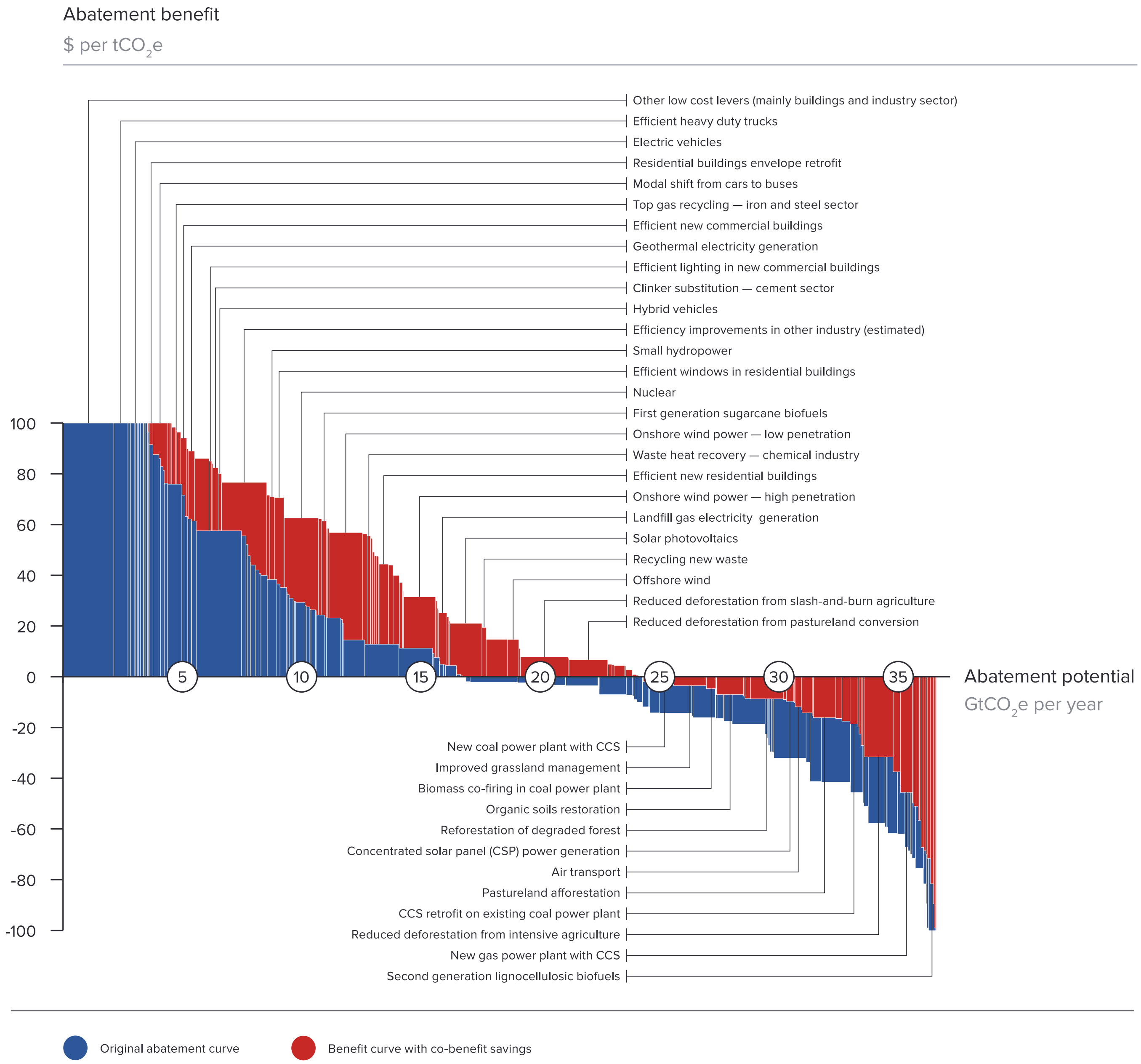
3.4 Quantifying multiple benefits and emissions reduction potential from low-carbon actions

Analysis for the Commission has developed preliminary estimates of the value of multiple benefits likely to result from the reforms and investments discussed in this report. The analysis focuses on actions in the three key economic systems discussed in the preceding section: cities, land use and energy systems. Surveys of relevant technical literature were used to make monetary estimates of the multiple benefits per tonne of CO_2 abated.[85]

The focus is on multiple benefits from the following actions: reduced coal use, leading to lower local air

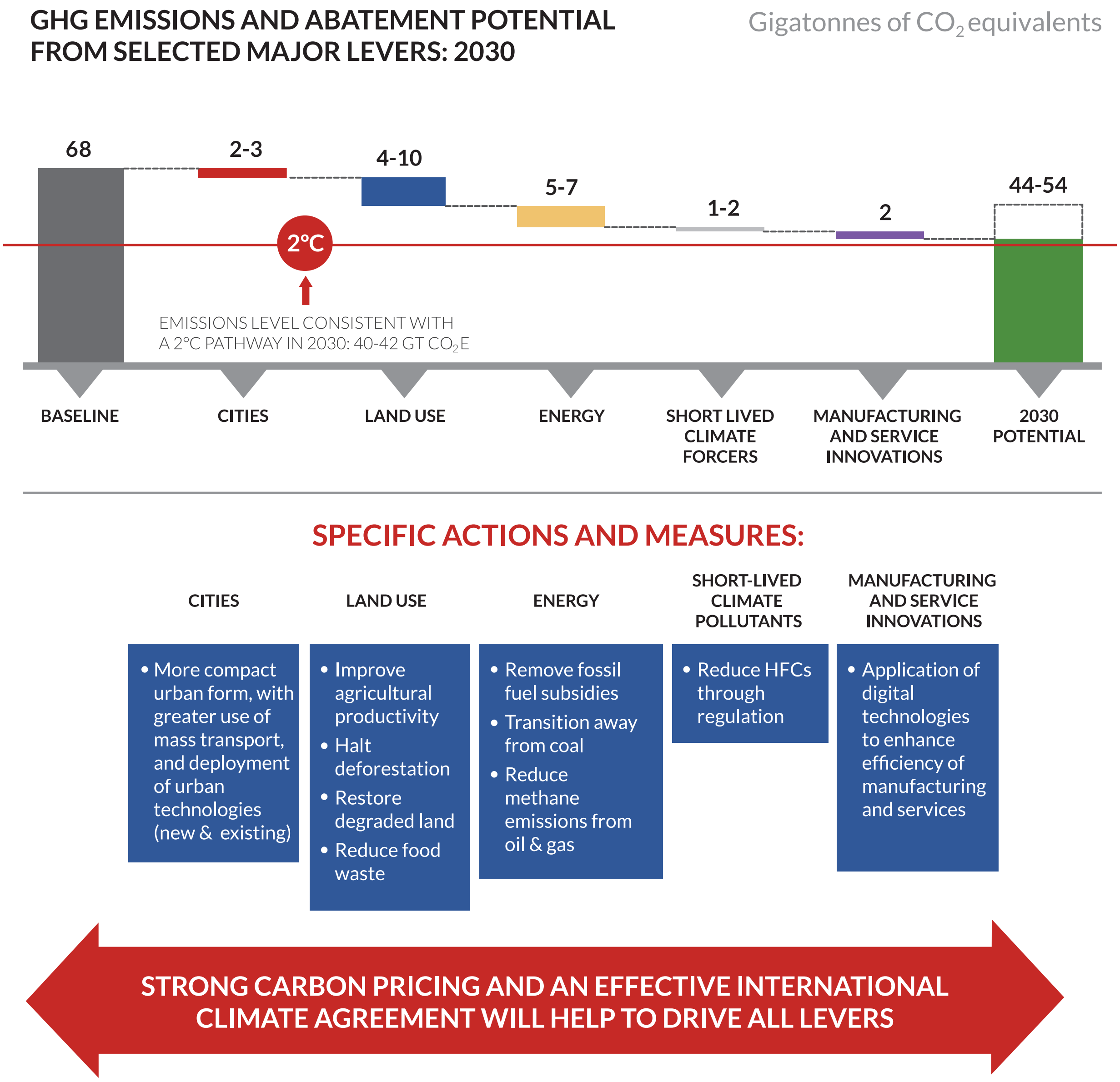
Figure 6

Marginal abatement benefits curve for 2030



New Climate Economy project analysis.[87]

Figure 7
Abatement potential of measures proposed in this report up to 2030



Source: New Climate Economy analysis.[90]

pollution and improved health; rural development arising from better land management and the restoration of forests and degraded land, linked with policies reducing emissions from deforestation and forest degradation (REDD+); reduced volatility of energy prices as a result of less reliance on fossil fuels; and reduced air pollution, avoided accidents and lower congestion due to shifts in transport modes, including greater use of bus rapid transit.

The results are illustrated with a version of the Marginal Abatement Cost Curve (MACC) developed by McKinsey & Company.[86] Each of the blue bars in Figure 6 shows the estimated incremental cost in 2030, relative to the high-carbon alternative, of abating an extra tonne of CO_2 through a specific technique or action, and the total technical abatement potential it offers. The incremental cost estimate per tonne in 2030 is based on the difference in operating and annualised capital costs between the low- and high-carbon alternatives, net of any potential savings associated with the shift to low carbon. The original McKinsey cost curve is inverted, so that methods with net benefits appear above the axis and those with net costs below, and the value of the multiple benefits is included where relevant. Thus, the chart becomes a "marginal abatement benefits curve". The red bars in Figure 6 show the additional co-benefit associated with various abatement options, such as the health benefits from reduced local air pollution.

Figure 6 shows that many abatement options have a positive benefit even in narrow financial terms, which become substantially larger and more numerous once multiple benefits are included. A number of options with net costs swing to net gains when multiple benefits are taken into account, for example reduced deforestation, recycling of new waste or offshore wind. For energy efficiency options, the inclusion of multiple benefits could as much as triple their overall benefit.

This quantification of co-benefits is exploratory. On one hand, the coverage of co-benefits does not incorporate all possibilities, and, on the other, the proposed reforms do not include various potential programme and transaction costs. Nevertheless, this analysis clearly strengthens the case that countries have available a broad array of reform and investment options to improve the well-being of citizens while abating GHG emissions.

This analysis raises the question of the extent to which the actions discussed in this report would contribute to significant cuts in greenhouse gas emissions. As noted in Section 2.2, on current trends, with no climate action, GHG emissions could reach around 68 gigatonnes (Gt) by 2030, from around 50 Gt CO_2e today. While a number of emission pathways are consistent with limiting warming to below 2°C by 2100 with over 66% probability, a core scenario used in this report looks to reduce emissions to 42 Gt by 2030.[88] In other words, the world would have to cut GHG emissions by 26 Gt by 2030, compared with a baseline of no climate action. Further reductions would be needed after 2030, including negative emissions in the second half of the century.

Analysis for the Commission shows that the most significant measures and actions set out in this report relating to cities, land use and energy systems, plus specific forms of innovation in manufacturing and services, would yield some 14 Gt CO_2e of emission reductions. That is at least 50% of the median level of emissions reductions needed in the core 2°C scenario.

In the best circumstances, with early, broad and ambitious implementation, with rapid learning and sharing of best practice, these reforms and actions could achieve as much as 24 Gt of emissions reductions, or 90% of what is needed for a 2°C path.[89] That, in turn, would require decisive policy change and leadership, combined with strong international cooperation, particularly to support developing countries' efforts.

These actions would deliver multiple economic and social benefits. As a result, governments have good economic reasons to implement these actions even without accounting for their climate change benefits.

Calculations of this kind cannot be precise, which is why the figures come with a broad range. They depend on assumptions about what happens in the "base case" scenario, how far specific kinds of measures can be implemented and at what cost, the level of emissions they will generate, the underlying economic conditions (including growth rates and energy prices), and how rapidly technological changes may occur. They also depend on judgements of how the multiple economic benefits of these measures and actions should be valued. But with all these caveats, the figures do provide an indication of the scale of reductions potentially available.

On their own, these measures would likely not be enough to achieve the full emission reductions needed by 2030 to put the world on a 2°C path. The additional low-carbon measures needed would likely have net economic costs. For example, buildings will have to be more deeply retrofitted with energy efficiency measures than could be justified otherwise. Coal- and gas-fired power stations will have to be retired early, or fitted with carbon capture and storage (CCS) technology whose sole purpose is the reduction of GHGs. Industrial, agricultural and transport emissions will need stronger curbs. The likelihood that these more costly actions will also be required suggests that investment in research and development on key technologies such as CCS should be scaled up significantly today.

The low-carbon transition will not end in 2030. Deeper reductions will be required after that, to achieve near-zero or even net-negative emissions in the second half of the century. The measures in this report would nevertheless begin to put in place the institutions and policies – in terms of urban design, land use patterns, energy systems, environmental pricing and technological innovation – that would lay the foundation and create options for the more ambitious low-carbon policies and actions needed throughout this century.

4. Addressing growth and climate challenges in different country realities

The best approaches for dealing with development and climate challenges will depend on countries' vastly different realities and circumstances. Differences in levels of economic, human and institutional development, in social and political structures, in history, geography and natural endowments, profoundly shape the development and climate challenges that countries face, the capacities they can bring to bear, and the manner, timing and speed with which they can make progress on tackling these challenges. In this section we briefly consider the differing realities and challenges in low-, middle- and high-income countries.

4.1 Low-income countries

Low-income countries are characterised by high absolute poverty and low levels of human development and institutional capacity; limited industrial development; low access to energy; and a high reliance on foreign aid and concessional financing to support infrastructure investment and the public budget. As noted earlier, they account for negligible proportions of world energy consumption and GHG emissions.[91] Large fractions of the population are typically rural and derive their livelihoods from agriculture. Along with geographic issues that may expose them to more natural hazards, socio-economic conditions in these countries make them particularly vulnerable to climate risks.[92] The key challenge in these countries is to overcome poor governance and low institutional capacity, to spark rapid, widely shared and sustainable economic growth and poverty reduction.

Cities: Urbanisation is still in its early stages in low-income countries, with only 28% of the population living in cities, compared with 39% in lower-middle- and 60% in upper-middle-income countries.[93] Cities are growing rapidly, but still at an early stage of development. City authorities in low-income countries have a great opportunity to shape urban development in a desirable direction at relatively low cost, although they tend to lack the institutional capacity to use more sophisticated instruments of urban planning. Basic infrastructure choices can nevertheless fundamentally shape a city's character and footprint even at this stage; for example, they can ensure that scarce infrastructure resources go to smart choices such as bus rapid transit (BRT) rather than "business-as-usual" choices such as urban motorways (see Table 1).

Agriculture and land use, including forests, are much more important for people's livelihoods and well-being in low-income countries, and they are vulnerable to pressures of land and water scarcity, deforestation and soil degradation. Agricultural productivity will be more seriously reduced by climate change than in other countries, in part because of lower capabilities and investment in preparedness and infrastructure ranging from weather forecasting to irrigation.

In most cases, agriculture, forestry and land use are the biggest contributors to GHG emissions in these economies.[94] Carbon emissions related to energy are relatively unimportant because of limited industrial, power and transport development. Methane (CH_4) and nitrous oxide (N_2O) emissions related to livestock digestion and waste and various agricultural processes are far more important, as are carbon emissions related to deforestation, which is driven by expansion of agricultural lands, consumption of wood for cooking fuel and logging.

As Chapter 3: Land Use argues, there are substantial opportunities for low-income countries to intensify agriculture and to adopt "climate-smart" practices that can achieve "triple wins": higher farm incomes, increased resilience to climate change, and reduced GHG emissions

Table 1
Addressing growth and climate challenges in low-income countries

	Cities	Land use	Energy
Resource efficiency	Reduce incentives and hidden subsidies for embryonic urban sprawl in smaller towns	Reform tax and other policy distortions	Reform fossil fuel subsidies, with well-designed safety nets to protect the poor. Strengthen power sector management
Investment and finance	Use smart infrastructure such as mass transit to guide early-stage city development. Improve tax administration and public investment management	Strengthen rural credit and risk markets. Boost investment in rural infrastructure, including water management and agricultural logistics, together with forest protection	Boost concessional finance and domestic tax capacity to support rapid expansion of grid and distributed electricity capacity
Innovation		Strengthen property rights and extension services to speed diffusion of modern farming technology and practices	Support diffusion of distributed solar and other cost-effective new low-carbon technologies

(including greater carbon storage in soil, plants and trees).[95] From a policy perspective, this requires not a single technological solution, but rather a broad range of reforms and investments to promote better soil and water management, more efficient use of inputs, and the use of agroforestry techniques and other practices, and, more generally, to promote widespread diffusion and adoption of modern agronomic knowledge.

Reforms should improve incentives for farmers to adopt new technologies and practices, and tackle supply constraints that arise because of inadequate rural public goods and infrastructure. Reforms should strengthen farmers' property rights; boost rural credit and risk markets to increase adoption of new technologies by poor farmers; and increase rural extension services to provide better information and technical support. Public investments in rural transport and logistics infrastructure can vastly strengthen incentives by linking farmers to international markets and supply chains. The specific mix of reforms and investments will depend on the circumstances of the country. Ethiopia, for example, has adopted an "Agricultural Development Led Industrialisation Strategy". The country has also initiated a Climate Resilient Green Economy strategy, with measures to boost yields, improve soil management, curb agricultural GHG emissions and curb deforestation.

Energy: Ensuring modern energy access is a major development challenge in low-income countries. About 1.3 billion people or 26% of the population in developing countries still lack access to electricity. The International Energy Agency (IEA) defines modern energy access as "a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time".[96] The thresholds for electricity access in this definition are low: 250 kilowatt-hours per year for rural households and 500 kWh/year for urban households; for comparison, the average US household uses about 11,000 kWh/year.[97]

Rapid expansion of public and private investment in power-generating capacity is key to improving energy access. Such scaled-up finance will come both from international sources – for example, concessional lending from development banks, and strengthened domestic taxation and financial capacity. Support for cost-effective, low-carbon energy sources will be an important part of long-term, external, concessional financing. Nevertheless, given the overriding priority for rapid growth and poverty reduction in these economies, there will undoubtedly be trade-offs between low-carbon and fossil fuel options. Given the relatively small size of low-income economies, a push to achieve minimum energy access levels in these countries would have a negligible impact on global CO_2 emissions.

In addition to efforts to scale up power generating capacity, demand-side, efficiency measures and opportunities will also play an important part in helping to satisfy energy needs in low-income countries – aided, for example, by reforms of fossil fuel subsidies.

Drivers of change: In addition to reforms in these three key systems – cities, land use and energy – it is also important to pursue broad, economy-wide reforms that can enhance or stimulate resource efficiency, infrastructure investment and innovation.

Regarding innovation, the rapid spread of mobile phones shows the potential for low-income countries to achieve widespread adoption and diffusion of appropriately adapted and priced new technologies. A similar rapid diffusion of appropriate new technologies should be encouraged in agriculture, energy, the digital economy and financial services, among others. Governments in low-income countries can facilitate rapid and continuous absorption of new technology by maintaining low barriers to foreign trade and investment, including through "South–South" interactions with middle-income countries which may have invested in adapting high-income technologies to developing country conditions. A business-friendly investment climate encourages local entrepreneurs to take on the risks of adapting imported technologies. Strengthening education broadly increases the capacity of the population to absorb new technologies. Financial support and technical assistance from foreign partners are also important.

Regarding investment, a key priority in low-income countries is building and strengthening the basic institutions of public financial management, such as tax administration, budgetary management and execution, accounting and auditing. There is an urgent need to improve public investment management capacity, given that there is little point in mobilising resources if new investments have poor returns because of mismanagement. External finance from multilateral development banks and other development partners for major infrastructure projects needs to be substantially expanded. This will also help encourage private capital flows.

4.2 Middle-income countries

Middle-income countries account for about 70% of the world population[98] and are at the heart of global development and climate challenges. Poverty is less widespread than in low-income countries, but still substantial, with 38% overall living on less than US$2 a day. Rapid growth and poverty reduction thus remain central development objectives, implying rapidly rising demand for energy services and, with it, continued GHG emissions growth.

Growth itself, however, is creating new pressures in middle-income countries. Industrialisation and urbanisation are generating substantial local air

Table 2
Addressing growth and climate challenges in middle-income countries

	Cities	Land use	Energy
Resource efficiency	Tax congestion and air pollution damage from auto use. Eliminate incentives for urban sprawl	Reduce subsidies that waste fertiliser, water and power; increase spending on key public goods	Reform fossil fuel subsidies; increase fuel taxes to reflect local pollution damages. Recycle tax revenues to boost development
Investment and finance	Secure major infrastructure savings by re-orienting spending to promote compact urban forms	Strengthen rural credit and risk markets; boost investment in rural infrastructure and logistics	Develop medium-term plans to peak coal consumption and boost investment in lower-carbon energy portfolios
Innovation	Develop strong, city-level governance to guide urban development	Strengthen domestic agricultural R&D, in particular to adapt modern agricultural technologies to local conditions	Boost domestic R&D to facilitate integration of low-carbon energy technologies; strengthen efficiency standards

pollution, congestion and other stresses. Expanding middle-class populations are becoming more vocal in demanding solutions to these problems. But these countries also have institutional advantages that differentiate them from low-income countries: more effective governance, more educated populations, more diverse economies and greater private-sector capacity, on average. Thus, they have a growing capacity to tackle complex and institutionally challenging economic and environmental reforms.

Cities: Middle-income countries are at the heart of a global urbanisation trend. The decisions that these cities make today about their size, shape, density, land use and infrastructure will effectively lock in – for better or worse – the potential pathways for economic prosperity, and emissions for decades and even centuries to come. For example, some 70–80% of the built infrastructure that India will have in 2050 is not yet built.[99] Already many middle-income countries are suffering the unintended costs of a "business-as-usual" model of urbanisation, at the heart of which are urban sprawl and conventional motorisation. These costs include lost productivity and innovation as a result of squandered agglomeration economies, as well as excessively costly transport infrastructure, air pollution and traffic congestion.

With their greater institutional strength, middle-income countries can adopt a variety of more sophisticated urban planning instruments. Strong city-level governance with financial autonomy, control, transparency and accountability is an important pre-requisite. Strong metropolitan authorities can deliver strategic infrastructure such as mass transit systems, for example, and can impose motor fuel taxes or congestion charges to help price the pollution and congestion damages caused by private vehicle use (see Table 2).

Industrialisation and urbanisation are generating substantial local air pollution, congestion and other stresses.

Agriculture and land use: Lower-middle-income countries, in particular, share many agricultural and land use characteristics with low-income countries. Around 70% of the population of India, for example, is still based in rural areas, with 50% relying on agriculture for their livelihoods.[100] As a result, these economies share the same problems of land and water scarcity and soil degradation as low-income countries. Many of the reforms to achieve so-called "triple wins" remain relevant here.

Given their greater institutional capacity, education levels and resources, however, middle-income countries also have the opportunity to undertake more ambitious initiatives – for example, to strengthen domestic agricultural innovation. Brazil's Agricultural Research Corporation (Embrapa)[101] has shown how a strong research and development (R&D) capability can boost the adaptation of foreign farm technologies to local conditions, for improving crop and livestock yields and making better use of degraded lands. Sometimes the greater resources of middle-income countries are also put to wasteful uses, such as in agricultural input subsidies that cause excessive use of fertilisers, irrigation and electricity. Countries like China and India can improve resource productivity in agriculture by cutting input subsidies and using these savings to strengthen rural public goods including transport and other services.

Energy: Middle-income countries have been the driving force behind the sharp acceleration in global energy consumption and energy-related CO_2 emissions in the 2000s.[102] This acceleration has been driven by rapid economic growth and a greater share of coal in the fuel mix of these countries.

There are many self-interested reasons for middle-income countries to shift their energy strategies towards a greater focus on energy efficiency and low-carbon sources. Such a shift can avoid large health and economic damages from local air pollution and congestion, and growing energy insecurity as a result of rising net imports of coal and other fossil fuels. In China, air pollution has become so severe that the National Action Plan on Air Pollution in September 2013 banned construction of new conventional coal-fired power plants in major economic areas such as Beijing-Tianjin-Hebei (JingJinJi), the Yangtze River Delta and the Pearl River Delta, requiring them to sharply reduce coal consumption by 2017.[103]

The most efficient way to implement such reform is to eliminate fossil fuel subsidies and end the under-taxation of fossil fuels, to reflect local air pollution and other local damages, and recycle the resulting taxation revenues for poverty reduction and development. Recent estimates suggest that such corrective fuel taxes would generate revenues in the range of 6–8% of GDP in China and India, and cut pollution-related deaths in these countries by 50–70%.[104]

Institutional reforms and regulatory measures can also improve the adoption of energy efficiency. India's power transmission and distribution losses are around 20% of production, compared with 5–7% in the United States.[105] More ambitious standards to promote the uptake of existing low-cost energy-efficient products and technologies could reduce such losses and associated energy-related carbon emissions dramatically.

Countries can learn from one another. For example, the emergency measures to slash coal consumption in China could have significant economic adjustment costs. Other middle-income countries could take steps to prevent their economies becoming as coal-intensive in the first place, drawing on available policies and emerging low-carbon energy technologies.

Drivers of change: Middle-income countries have a much greater capacity to undertake innovation, compared with low-income countries, both in absorbing and adapting frontier technologies from abroad, and undertaking innovation themselves. This capacity can help middle-income countries adopt a more proactive approach to promote innovation and efficiency in key sectors such as electricity and energy, transport, buildings, manufacturing, agriculture, and the digital economy. The Republic of Korea provides a model example of a middle-income economy which was able to make a transition to high-income status through an unwavering focus on strengthening domestic human capital and technological capability.[106]

Middle-income countries can also access a deeper pool of resources to pursue development and climate challenges, as a result of their greater institutional capacity. They have more sophisticated systems of public finance, deeper domestic capital markets and engage more extensively in international private capital markets. Such institutional capacity is important to reshape domestic public finance, using environmental taxes to reduce labour and capital taxes and boost productive investment.

4.3 High-income countries

Developed economies are still struggling in the aftermath of the Great Recession. Five years after the crisis, unemployment and output gaps remain high. Medium- to longer-term problems loom, including the impact of ageing populations on public finances and growth, as well as problems of rising income inequality and climate change.

The challenge facing developed countries is to modernise public finance, enhance innovation and boost growth and employment in ways that accelerate progress on decarbonisation.

The challenge facing developed countries is to modernise public finance, enhance innovation and boost growth and employment in ways that accelerate progress on decarbonisation. The OECD argues that policies will need to focus on four key areas in the decades ahead: accelerating global integration; making institutions more resilient to shocks; curbing emissions; and exploiting a knowledge economy, which will be the main driver of global growth.[107]

Cities: In developed countries, the strategic focus is the re-densification and revitalisation of existing urban cores, alongside a shift from industry to services and innovation in megacities and mid-sized cities. London, Brussels and Tokyo are examples of cities that are reversing urban sprawl and re-densifying. Strong, well-established city governments are important to drive adoption of more sophisticated high-tech infrastructure and energy-efficient buildings, and to use more sophisticated spatial planning and regulation instruments such as urban growth boundaries and maximum density standards. Sophisticated multimodal metropolitan transport authorities can be established, like "Transport for London",[108] which can drive productivity of the whole transport system through both pricing (e.g. congestion charging) and capacity allocation mechanisms (e.g. bus lanes, downtown parking capacity).

Agriculture and land use: Developed economies are at the forefront of agronomic research and development and innovation. Further public support should be provided for fundamental research and development, under a general high-income country strategy for economic revitalisation through increased innovation. Support should also be increased for multinational institutions and partnerships, such as the Consultative Group on International Agricultural Research (CGIAR),[109] among others, that specifically focus on agricultural innovation and dissemination targeted at developing countries. Forestry and land use in developed countries are now a net sink for CO_2 emissions, and this trend can be enhanced. The Republic of Korea provides an outstanding example of a country that has dramatically increased its forests, increasing from about one-third to two-thirds of its land area since the mid-1950s.[110]

Energy: High-income countries are the pace-setters in developing paths to a low-carbon future, both in research, development and innovation, and in policy and institutional innovation, including efforts at international coordination. A resolute push to introduce carbon pricing will yield multiple benefits, in terms of reduced local air pollution, as well as generate significant revenues that can play an important role in facilitating pro-growth fiscal reforms. A major push on fundamental energy research and development and innovation should also be a priority in developed countries both individually and through international cooperation. Institutional experimentation and learning from trial and error will also be crucial, especially around power system reform where more distributed generation technologies challenge traditional utility business models. Some developed countries are facing significant fiscal and other problems related to support for and integration of renewables. Careful study of lessons from these experiences and redesign of institutions as appropriate will be an important contribution in developed countries.

5. Conclusion: Why now?

Decision-makers will never have all the information they would want to make perfect decisions about the future. However, they do have three vital pieces of information that can guide their choices now.

First, the world is only halfway through its urbanisation journey. The next 15 years will hugely increase the footprint of urban infrastructure and shape the consumption patterns of about 1 billion new urban dwellers.[111] Choices over the pattern of urban development and associated energy and transport systems will shape how future societies function. These choices will also disproportionately affect the speed with which nations move from low- to middle-income status and from middle- to high-income status. The expected infrastructure investment of about US$90 trillion per year in cities, buildings, energy and transport systems over the next 15 years provides an unparalleled opportunity to build the world we want.

Second, deferring decisions for another decade will mean locking into high-carbon infrastructure. This will significantly increase the probability that future generations will have to contend with global warming of 4°C or more. Without immediate action, we will soon be committed to a minimum of 2°C warming, with adaptation costs likely to increase non-linearly beyond that point.

Third, many "no-regrets" opportunities exist to improve economic growth and climate risk performance together. Our economy is not operating at the "efficient frontier". Tackling multiple market failures and policy distortions will create both more growth and less climate risk, through integrated reform. Driving productivity in land use, by bringing degraded land back into production, meets the goals of increased rural incomes, greater food security and better climate risk management. The same is true for driving energy efficiency, cutting wasteful resource subsidies and tackling urban air pollution. Many of these opportunities are available with today's technologies, but need policies to encourage investment in better management systems and business models. We are just at the start of an innovation journey where advances in digitisation, energy technologies and biological and materials sciences can create new industries and reinvent old ones, generating new jobs while reducing greenhouse gas emissions.

There is also a crucial role for international cooperation on climate action. While this chapter and report stress opportunities for self-interested national action, it is well understood that – given the nature of the climate problem – countries working cooperatively will have incentives to accomplish a good deal more than the sum of uncooperative national actions.

Table 3
Addressing growth and climate challenges in high-income countries

	Cities	Land use	Energy
Resource efficiency	Congestion pricing and other fiscal reforms to remove subsidies for urban sprawl	Reform inefficient bioenergy policies; eliminate remaining input subsidies	Modernise public finance systems, drawing on carbon pricing to facilitate pro-growth tax reform.
Investment and finance	Infrastructure and systems investments to promote densification and revitalisation of urban cores	Scale market-based instruments for green infrastructure and ecosystem services	Develop short- and medium-term plans to peak coal consumption and boost investment in low-carbon energy; drive regulatory reform especially in the power sector
Innovation	Institutional innovation to strengthen city governance, including through greater digitisation. Multimodal transport authorities to promote mass transit. Deregulation to support new asset-sharing business models	Boost funding for international agricultural R&D, advanced bioenergy, and diffusion to developing countries	Boost fundamental energy R&D including "game changers"; create market-pull mechanisms; strengthen public-private risk-sharing partnerships (e.g. for CCS) including IPR models

As Chapter 8: International Cooperation argues, future cooperation will benefit from an approach that promotes development while helping countries to steadily move away from carbon dependence onto low-carbon trajectories. Such an approach would focus on agreed common norms and standards, and developing institutions that promote investment, trade, technology and expertise to support decarbonisation, both from richer to poorer countries, and among developed and developing countries. The Commission recognises that international cooperation is required not only for a transition to a low-carbon economy that is dynamically efficient, but also for one that is just.

Building the new climate economy will not be an easy journey. It is certainly not the "path of least resistance", and will require constant adjustment of policies, economic structures and institutions. But it is our opportunity to choose and shape a better economy, where equitable growth and a safer climate are not in opposition. This report also highlights actions that create flexibility and increase countries' options in an uncertain future through 2030 and beyond. The Commission is well aware that the transition to an economy which delivers better growth and climate performance is a 30- to 50-year journey. It is also a journey on which path dependencies mean that steps taken over the next 5–15 years may prove to be disproportionately important.

As finance ministries, central banks and the world's leading companies know, good growth and good risk management go together. Growth that takes no account of climate risk is unlikely to be sustainable for investors who know that their future assets could be adversely affected. Climate risk reduction that comes at the expense of growth or that hurts poor households will never be politically sustainable. The trick, and central purpose of this report, is to learn how to put the two sides of the equation together.

Endnotes

1 World GDP in 2012 was US$73.3 trillion, up from US$36.3 trillion in 1990, in constant 2005 international dollars, purchasing power parity (PPP).

See: The World Bank, 2014. World Development Indicators 2014. 11 April 2014 release. (An updated release, not including constant 2005 international $ PPP figures, is available at http://data.worldbank.org/data-catalog/world-development-indicators.)

2 The World Bank, 2014. World Development Indicators 2014. Data cited are for GDP (constant 2005 international $ PPP), 1990–2012. In 1990, middle-income countries' share of global GDP was 27%; in 2012 it was 42%. Share of global GDP calculated by the authors.

3 United Nations (UN), 2014. World Urbanization Prospects, the 2014 revision. UN Department of Economic and Social Affairs, Population Division. Available at: http://esa.un.org/unpd/wup/.

For detailed data, see: http://esa.un.org/unpd/wup/CD-ROM/Default.aspx.

4 The World Bank, 2014, World Development Indicators 2014. Data cited are for GDP (constant 2005 international $ PPP), 1990–2012. Middle-income countries' GDP increased from US$9.7 trillion in 1990 to US$30.7 trillion in 2012; low-income countries' GDP rose from US$396 billion to US$1.02 trillion.

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Specifically, the estimates are that actions with multiple economic benefits to improve transport and building efficiency in cities could deliver 2–3 Gt CO_2e. In land use, a combination of forest protection, restoration of degraded landscapes for forestry and agricultural purposes, improved yields and lower food waste could deliver 4–10 Gt CO_2e. In the energy system, phasing out fossil fuel subsidies, combined with cost-effective reductions in coal use and more effective measures to tackle methane emissions, could deliver 5–7 Gt CO_2e. Phasing out of hydroflurocarbons (HFCs), chemicals used largely for refrigeration and air-conditioning, could deliver the equivalent of a further 1–2 Gt CO_2e. Finally, innovations in the manufacturing and services sectors could generate a further 2 billion tonnes.

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Chapter 2

CITIES

Main points

- Building better, more productive cities can boost economic prosperity and help tackle climate change. On current trends, fewer than 500 cities in three key groups – Emerging Cities, Global Megacities, and Mature Cities – will account for over 60% of global income growth and half of energy-related greenhouse gas emissions growth between now and 2030. Action in these cities, particularly Emerging Cities, will have disproportionate benefits for the global economy and climate.
- Growth today typically involves poorly managed, unstructured urbanisation whose economic, social and environmental costs outweigh the benefits. Urban sprawl costs the US economy alone an estimated US$400 billion per year.
- A shift to more compact urban growth, connected infrastructure, and coordinated governance could boost long-term urban productivity and yield environmental and social benefits. Such an approach has the potential to reduce urban infrastructure capital requirements by more than US$3 trillion over the next 15 years. New analysis suggests that the world's 724 largest cities could reduce greenhouse gas emissions by up to 1.5 billion tonnes of carbon dioxide equivalent (CO_2e) annually by 2030, primarily through transformative change in transport systems.
- All cities can improve resource productivity in the short term through cost-effective investments in building energy efficiency, waste management, transit and other measures. However, these benefits will typically be overtaken by economic and population growth within seven years without a broader, structural shift in the model of urban development.
- We are already seeing many cities shifting towards better-managed urban growth, particularly in transport. Over 160 cities have implemented bus rapid transit systems. China's urban rail networks will total 3,000 km in length in 2015. Nearly 700 cities have implemented bike-sharing schemes, and a range of smarter transport systems, such as car-sharing, have taken off in numerous cities.
- Scaling and accelerating the shift to compact, connected, coordinated growth will require countries to put urban areas at the heart of their economic development strategies, and consider greater fiscal autonomy for cities. Only 4% of the 500 largest cities in developing countries are deemed creditworthy in international financial markets. The international community should redirect and scale up multilateral development bank financing for smarter urban infrastructure, and help cities build creditworthiness.

1. Introduction

Cities are engines of national and global growth. Urban areas account for half the world's population, but generate around 80% of global Gross Domestic Product (GDP).[1] They are also associated with around 70% of global energy consumption and energy-related greenhouse gas emissions.[2]

The world is now experiencing a new, different type of urbanisation. By 2030, around 60% of the global population will live in urban areas. Cities and urban areas[3] will house nearly all of the world's net population growth over the next two decades: 1.4 million people are being added to urban areas each week, roughly the population of Stockholm.[4] By 2050, the urban population will increase by at least 2.5 billion, reaching two-thirds of the global population.[5] This urban transition is being driven by cities in the developing world, where 90% of urban growth is projected to take place.[6] In 2030, China's cities will be home to close to 1 billion people or 70% of the population.[7]

The stakes for growth, quality of life and carbon emissions could not be higher. The structures we build now, including roads and buildings, could last for a century or more, setting the trajectory for greenhouse gas emissions at a critical time for reining these in.

City administrations are often acutely influential, with sharper local powers than national policy-makers.[8] But climate risk is rarely near the top of their priority list. They face other pressing issues: public safety, delivery of basic services, housing, chronic traffic congestion, municipal budgets.

> *The structures we build now, including roads and buildings, could last for a century or more, setting the trajectory for greenhouse gas emissions at a critical time for reining these in.*

Planning for more compact, better-connected cities with strong mass transit systems will help policy-makers tackle these pressing challenges. Such cities are more productive, socially inclusive, resilient, cleaner, quieter and safer. They also have lower carbon emissions, showing that the goals of economic growth and climate change can work together. The lessons are being learned. South American cities such as Curitiba and Bogota are flagships for the benefits of bus rapid transit systems. But these are not typical. In the last 10 years, population densities in Chinese cities have declined on average by 25%, for example.[9]

This chapter begins by charting the growing contribution of cities both to the world economy and carbon emissions. Next, it reviews the most common form of urban expansion across countries today, and examines an alternative growth pathway, giving special attention to urban form, transport, and initiatives which boost short- to medium-term resource productivity. Next, it discusses the kinds of urban policy frameworks needed to scale up that alternative pathway, through planning policy, pricing instruments, fiscal and finance mechanisms, governance, and legal powers. It concludes with recommendations.

While the chapter is targeted at a wide readership, it is particularly pertinent for countries which have a significant portfolio of rapidly growing cities. Several other chapters also address urban issues, including Chapter 4: Energy (particularly urban air pollution); Chapter 5: Economics of Change (how mass transit systems can help reduce the distributional effects of fuel taxes and carbon pricing); Chapter 6: Finance (unlocking funding for smarter infrastructure); and Chapter 7: Innovation (improving energy efficiency in buildings).

2. Cities, global growth and carbon emissions

Cities are engines of national and global growth, accounting for around 80% of global economic output.[11] Some 150 of the world's largest metropolitan economies produce 41% of global GDP with only 14% of the global population.[12]

Most successful high-income countries have economically dynamic cities at the heart of their regional and national economies, from Tokyo in Japan to London in the United Kingdom. Cities are also rapidly transforming the economic landscape of emerging markets. Already the 90 largest Chinese cities account for over US$6 trillion – the size of the national economies of Germany and France combined.[13] And cities in India generate two-thirds of GDP, 90% of tax revenues, and the majority of jobs, with just a third of the country's population.[14]

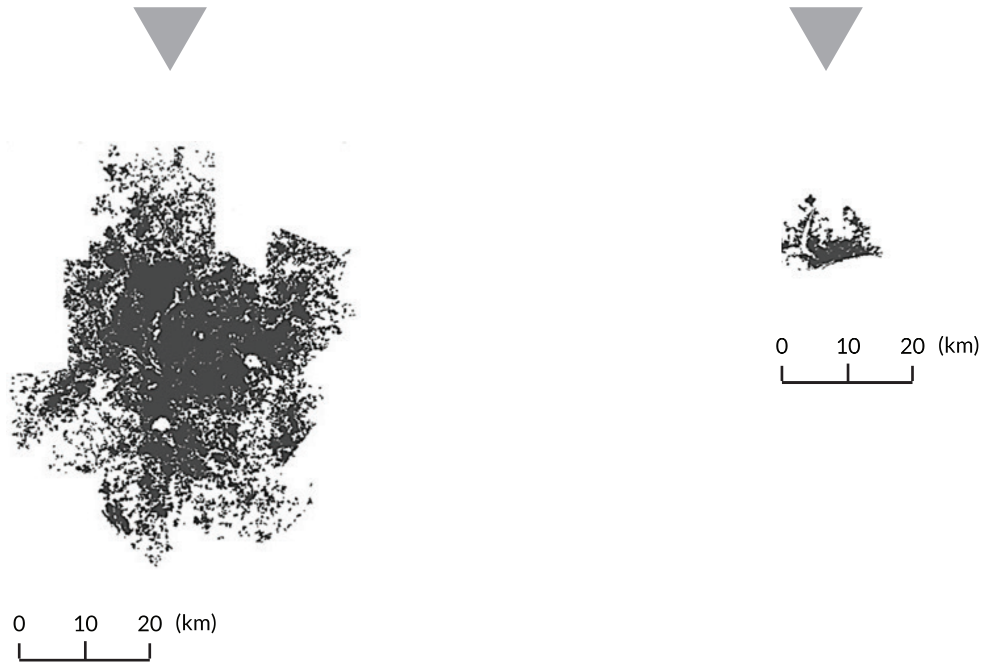
Cities are also key drivers of global energy demand and greenhouse gas emissions, accounting for around 70% of both, according to the International Energy Agency (IEA).[15] Urban emissions from emerging economy cities are already converging with those of developed cities.[16] Beijing, Shanghai and Tianjin, for example, have per capita emissions comparable to those of large European and some North American cities.[17]

Research for the Commission used a database of the world's largest cities to identify three groups that are particularly important in terms of impacts on the global economy and climate out to 2030. The three groups

Figure 1

Atlanta and Barcelona have similar populations and wealth levels but very different carbon productivities

ATLANTA'S BUILT-UP AREA | **BARCELONA'S BUILT-UP AREA**



	Atlanta		Barcelona
POPULATION:	5.25 MILLION	POPULATION:	5.33 MILLION
URBAN AREA:	$4,280 KM^2$	URBAN AREA:	$162 KM^2$
TRANSPORT CARBON EMISSIONS: TONNES CO_2 PER PERSON (PUBLIC + PRIVATE TRANSPORT)	7.5	TRANSPORT CARBON EMISSIONS: TONNES CO_2 PER PERSON (PUBLIC + PRIVATE TRANSPORT)	0.7

Source: Bertraud and Richardson, 2004.[10]

were defined based on their population, income level and growth. The analysis shows these 468 cities will account for over 60% of global income growth between 2012 and 2030, under business-as-usual economic growth assumptions. They will account for nearly half of all growth in energy-related greenhouse gas emissions. In 2030, they will account for 60% of global GDP and around 45% of global energy-related emissions.[18]

The groups are classified as Emerging Cities, Global Megacities, and Mature Cities, defined below.[19]

- **Emerging Cities** are 291 rapidly expanding middle-income, mid-sized cities in China, India and other emerging economies, with populations of 1–10 million, and per capita incomes of US$2,000-20,000. These cities are likely to account for over a quarter of global income growth and over a third of energy-related emissions growth over the next two decades. Given the rapid change expected in these cities over the next few decades, action by this group represents the most significant short- to medium-term global opportunity for avoiding lock-in to long-lived, high-carbon urban infrastructure.[20]

- **Global Megacities** are 33 major cultural centres with populations above 10 million and per capita incomes over US$2,000, including capital cities such as London, Beijing and Tokyo. This comparatively small number of cities will account for approximately 15% of global income growth and over a tenth of emissions growth out to 2030, with considerable diversity in the pace of economic and demographic change between them. Some of these cities are already exhibiting signs of relative decoupling of economic growth from emissions growth.[21] This presents an important opportunity to explore how these cities can continue to attract talent and capital while managing growth in emissions.

Figure 2

Emerging Cities will play a significant role in growth of the global economy and carbon emissions to 2030

URBAN GROUP	PROJECTED BASE GDP GROWTH FROM 2012-2030, USD TRILLIONS	PROJECTED BASE CASE EMISSIONS GROWTH[1] FROM 2012-2030, MEGATONNES OF CO_2	PROJECTED POPULATION IN 2030, BNS	PER CAPITA IN 2030, TONNES OF CO_2 PER PERSON
Emerging Cities e.g. Bangalore, Kunming, Pune, Puebla	16	3230	~1.3	~7
Small Urban Areas Inc. villages, small towns, peripheral industrial areas pop. < 0.5 million	16	1220	~2.2	~4.6
Established Cities e.g. Stuttgart, Minneapolis, Stockholm, Hiroshima	11	390	~0.4	~12.1
Global Megacities e.g. Beijing, New York, London, Rio de Janeiro	10	1050	~0.6	~7.1
Total growth	~ 52	~ 5,890	**Total population in 2030** ~ 4.5	
Share of world growth	~ 87%	~ 65%	**Share of world pop. in 2030** ~ 55%	

Note: Energy assumptions are consistent with the IEA's Current Policies scenario. GDP figures are based on 2012 prices and exchange rates. Small urban areas are a highly diverse segment covering cities in both developed and developing countries. Estimates for this segment, especially for per capita emissions, are subject to significant levels of uncertainty and should be treated as indicative.

Source: Analysis by LSE Cities and Oxford Economics; data from the Oxford Economics Global 750 Cities database. Small Urban Areas include 26 cities in the Oxford Economics database with populations under 500,000 and those areas classified as urban in the UN World Urbanization Prospects database.

- Mature Cities are 144 prosperous, established, mid-sized cities in high-income countries with per capita incomes above US$20,000, such as Stuttgart, Stockholm and Hiroshima. These cities – which often form part of a regional economic network – will drive close to 20% of income growth out to 2030 and have the highest per capita emissions of any city group, averaging 12 tonnes of carbon dioxide equivalent (CO_2e) per capita in 2030. Growth in emissions is expected to be relatively modest, and a number of cities within this category show signs of decoupling of economic growth from emissions growth.

In addition, a less-noticed story of urbanisation is unfolding in Small Urban Areas. Over a quarter of global income growth and around a sixth of GHG emissions growth will take place in small cities, towns, peripheral industrial zones, and other urban areas of less than half a million people. This is where much of the urbanisation will take place in Least Developed Countries.

Given the significant lock-in risks associated with urban infrastructure investments, the choices all these groups of cities make now about their future model of urban expansion will play an important role in determining the global economic and emissions pathway for decades and even centuries to come. This is particularly the case for rapidly growing Emerging Cities and Small Urban Areas (see Figure 2). The stakes could not be higher.

3. The rising costs of unmanaged, unstructured global urban expansion

In much of the world, urban growth is now characterised by poorly managed, unstructured expansion and conventional motorisation. Business-as-usual development may see the number of privately owned vehicles increase from 1 billion today to 2 billion in 2030.[22] Meanwhile, the area of urbanised land could triple globally from 2000 to 2030.[23] This is equivalent to adding an area bigger than Manhattan every day.

China illustrates this trend. Over the last 10 years, population densities in Chinese cities have declined on average by 25%, and are now lower relative to benchmarks in advanced countries.[24] Despite some signs of the inverse trend in Beijing over the last decade, the continuation of such a model of urban expansion would require developing an area equivalent to the Netherlands over the next decade, and a tripling of urban land in China by 2030.[25]

Although this sprawled pattern of urban development has real and perceived benefits,[26] the Commission's analysis shows that on balance, the future costs will significantly outweigh the benefits.[27] Already today, this growth model is starting to break down. In China, Prime Minister Li Keqiang described the smog in Chinese cities as a warning "against the model of inefficient and blind development", with the rush to develop spreading into rural areas and leaving municipal governments with mounting debt.[28] In other emerging markets, informal settlements are growing as urbanisation increases, with the provision of infrastructure and services unable to keep pace with population growth.[29]

The challenges also apply to developed countries. In the United States, sprawling urban areas were hit hard by a speculative real estate market and high energy prices in the run-up to the financial crisis. Sprawling suburbs such as Victorville, outside Los Angeles, proved unviable when fuel prices rose from $2 early in the decade to $4 in 2008.[30] The significant increase in transport costs reduced the demand for housing, contributing to over 70% of new homes for sale being in foreclosure by July 2009.[31] In Europe, urban economies characterised by a pre-crisis real estate boom, for example in Spain, are still struggling to recover from the downturn.

The business-as-usual pattern of urbanisation is imposing a range of significant economic and social costs. These include:

1. **Greater required investment, leading to a funding gap and the failure of many cities to deliver basic urban infrastructure and services:** The Organisation for Economic Co-operation and Development (OECD) and the IEA estimate that around US$50 trillion is required for investment in transport, building energy efficiency, telecommunications, and water and waste infrastructure over the next 15 years.[32] The Boston Consulting Group, meanwhile, calculates an infrastructure investment shortfall of over US$1 trillion per year[33], a significant share of which is due to the additional investment required for roads and traffic management in sprawling cities. Urban sprawl significantly reduces the resources available for investment in basic urban infrastructure and services, as well as public transport. In India, the gap in urban infrastructure investment is estimated at US$827 billion over the next 20 years,[34] with two-thirds of this required for urban roads and traffic support. New analysis for the Commission shows urban sprawl in the United States adds costs of around US$400 billion per year, mostly as a result of greater infrastructure, public service delivery and transport costs (see Box 1).[35]

2. **Growing financial and welfare costs related to traffic congestion:** Congestion is already imposing costs as high as 3.4% of GDP in Buenos Aires and 2.6% in Mexico City.[36] Even in the higher-density European Union, congestion costs average 1% of GDP.[37]

In Beijing, the total social costs of motorised transport, including air pollution and congestion, are estimated at 7.5-15% of GDP.

3. **Escalating economic and social costs due to air pollution:** Urban air pollution is projected to become the top environmental cause of premature mortality by 2050.[38] In Beijing, the total social costs of motorised transport, including air pollution and congestion, are estimated at 7.5–15% of GDP.[39] Analysis for this report, covering 311 cities and close to a billion people, shows that the business-as-usual pattern of urban development is responsible for 86% of these cities exceeding World Health Organization (WHO) air quality guidelines for outdoor air pollution. By tipping air pollution above safer thresholds, this pattern of development has therefore contributed to an estimated 730,000 premature deaths, a significant proportion of which are related to motorised transport.[40] Other studies show that pollution-related health costs reach as high as 5% of GDP in some cities in developing countries, over 90% of which can be attributed to vehicle emissions.[41] The OECD estimates that the social costs of road transport in OECD countries, China and India combined are US$3.5 trillion per year, including the value of health impacts and lives lost.[42]

4. **Lock-in of inefficiently high levels of energy consumption:** A study of 50 cities worldwide estimates that almost 60% of growth in expected energy consumption is directly related to urban sprawl, surpassing the impact of GDP and population growth.[43] This leaves many cities vulnerable to volatility in energy prices.

5. **Increasing social exclusion:** The combined effects of urban sprawl and motorisation are linked to the growth of both slums and gated communities, which are creating socially divided cities.[44]

6. **A wide range of other economic and social costs:** These include costs related to road safety, divided communities, low levels of physical activity (with significant health implications), reduced ecosystem

Box 1
The global cost of urban sprawl [47]

Urban sprawl, defined here as the uncontrolled and excessive spatial expansion of cities, is one of the world's most significant – and least well documented – market failures, leading to inefficient use of land, capital and other resources.

As noted above, new analysis for this project puts the external costs of sprawl at about US$400 billion per year in the United States alone. Around 45% of those costs are due to the increased cost of providing public services such as water and waste; one-fifth is due to increased capital investment needs for infrastructure such as roads, and the rest is due to the costs of increased congestion, accidents and pollution not borne directly by private individuals. The total costs amount to about 2.6% of US GDP at current prices. If the United States followed an alternative growth pattern without urban sprawl, the savings could cover the country's entire funding gap in infrastructure investment.

Such cost estimates indicate the potential savings from pursuing smarter growth policies based on more compact, mixed, multi-modal, infill development. This is a lower bound estimate, as it excludes over US$323 billion in higher personal/household transport costs, climate change impacts, the impacts on agricultural productivity and ecosystems, and social costs related to the creation of more divided communities and degradation of urban centres – which can, for example, increase crime. Although the costs of urban sprawl may be lower in absolute value in developing countries, due to lower wages and property values, they are likely to be similar in magnitude as a proportion of the national economy.

Despite a range of real and perceived benefits of more sprawled development to private individuals and developers, such as larger house sizes and some cost efficiencies in house-building, a review of the evidence for the Commission report suggests inefficient sprawled development at least doubles land used per housing unit, increases the costs of providing utilities and public services by 10–30% and sometimes more, and increases the costs associated with travel by 20–50%.[48] These costs can be higher in fast-growing low- and middle-income countries, where sprawled patterns can double or triple many costs due to the increased costs of importing construction equipment, for instance.

Sprawl also tends to be unfair, since lower-income people, who rely more on walking, cycling and public transport, are less likely to benefit from the additional road infrastructure, for example, but still pick up the bill in higher utility and public service costs. Although there is some evidence to suggest that sprawl can increase housing affordability, this is typically more than offset by the increase in transportation and public service/infrastructure costs (e.g. water, waste and sewage).[49]

A degree of urban expansion is inevitable, particularly in Emerging Cities, driven by a range of factors, including income and population growth, the falling costs of private vehicle travel, and reductions in the value of rural land as economies undergo structural transformation. However, urban expansion often goes far beyond what is economically efficient.

At the heart of sprawl are a range of interlocking market failures, such as the failure to account for the higher costs of providing public infrastructure in sprawling cities; the failure to price the significant and rising costs of traffic congestion, vehicle-related accidents, carbon emissions and air pollution; and the failure to take into account the public infrastructure costs generated by more dispersed developments. Excessive spatial growth is also driven by a range of governance failures, strong vested interests, and weak revenue bases (which encourage the sale of land for new development). Chapter 5: Economics of Change provides detailed analysis of markets failure in the pricing of energy and carbon emissions.

services and risks to food security. Urban road accidents in developing-country cities alone can cost as much as 2% of GDP.[45] And Chinese urban expansion is already adversely affecting food security due to the impacts on land use.[46]

In addition to these economic and social costs, a business-as-usual pattern of urban expansion will lead to a significant increase in global carbon emissions.

First, urban infrastructure uses materials, including concrete and steel, which have significant embedded emissions as a result of their carbon-intensive manufacture. These materials are heavily used in the early phases of urbanization in particular. If developing countries expand their infrastructure to current average global levels, the production of infrastructure materials alone would generate around 470 billion tonnes of CO_2 emissions by 2050,[50] much of this in sprawled cities. The continued expansion of infrastructure could produce cumulative emissions of 2,986-7,402 billion tonnes of CO_2 over the remainder of this century.[51]

Second, poorly managed urban development could lock in higher operational emissions for decades and centuries to come. The IEA estimates, for example, that under business-as-usual patterns of urbanisation, carbon emissions from urban transport will almost double by 2050.[52]

Box 2
The rising costs of unmanaged, unstructured urban expansion in India [53]

India is on the brink of an urban revolution. Over the last two decades India's urban population increased from 217 million to 377 million, and this is expected to reach 600 million, or 40% of the population, by 2031. The current pattern of urbanisation is largely taking place on the fringe of cities, much of it unplanned and outside the purview of city codes and byelaws, and is already imposing high costs. Unprecedented growth is leaving municipal governments with critical infrastructure shortages and service gaps.

Urban pollution caused 620,000 premature deaths in 2010, up more than sixfold from 2001, and a recent survey of 148 Indian cities by the Indian Central Pollution Control Board found onlty two cities with passable air quality. Recent estimates show that the cost of environmental degradation, largely driven by sprawling cities, is enormous, reducing India's GDP by 5.7%, or about US$80 billion annually. Some 44% of India's rapidly growing carbon emissions have urban origins, emanating from transport, industry, buildings and waste. This highlights the potential benefit of a new model of urban development.

4. A new wave of urban productivity

Cities can follow a different growth pathway to unlock a new wave of urban productivity. This alternative approach should be based on boosting resource productivity, to improve the efficiency of energy use and resilience to energy price volatility. And it would involve a broader shift to more compact, connected and coordinated urban growth.

4.1 Boosting resource productivity

Even under a business-as-usual pattern of urbanisation, all groups of cities have significant short- to medium-term opportunities to save energy and reduce inefficiencies associated with unstructured, poorly managed urbanisation. New analysis reviewed by the Commission shows significant economic opportunities in the next 5–10 years for all cities to improve resource efficiency, generate wider economic benefits, and reduce carbon emissions. Potential measures include smarter buildings and transport, efficient waste management, and investments at the district level. These are outlined in further detail in Box 3.

These relatively accessible, "no-regrets" options could play a critical role in helping cities overcome some of the key barriers to change, and so avoid becoming locked into higher-cost, higher-carbon development trajectories.

They could help secure commitment to creating cleaner cities, and could build capacities, stimulate investment, build momentum for change, and create opportunities for learning. All of these could be critically important benefits, as many cities, and particularly those in the developing world, may not yet have the technical, financial and institutional capacities needed for fundamental shifts to more energy-efficient and low-carbon development paths.[59]

However, it is also clear that the economic and climate benefits of measures to boost urban resource productivity can be quickly overwhelmed by continued economic and population growth under business-as-usual patterns, unless they are accompanied by broader structural shifts in urban form and public transport infrastructure. That was a key finding of the five city studies described in Box 3, and is especially the case in rapidly growing, Emerging Cities. The study calculated that it took only a few years for energy consumption and carbon emissions to reach business-as-usual levels (dubbed energy or emissions "TREBLE points"),[60] after exploiting all cost-effective energy efficiency and carbon reduction options. For example, GHG emissions returned to levels expected without the green technology investments in less than seven years in Kolkata, Lima, Palembang, and Johor Bahru, as a result of economic and population growth.

These findings highlight the importance of combining investments in efficiency with deeper structural changes in urban form and transport infrastructure. Another priority is to decarbonise the energy supply – a topic discussed in depth in Chapter 4: Energy. While sector- or district-level investments that boost resource productivity can help improve urban efficiency and build capacity for further change, they are not sufficient to ensure long-term resource efficiency, sustained emission reductions, and wider social and economic benefits. Cities operate like networks. Fixing one node at a time, on a patchwork basis, can create strong positive local effects at the node, but it does not systematically boost productivity across the whole urban network. A more coordinated approach is essential.

4.2 Compact, connected, coordinated urban development

To unlock a new wave of sustained, long-term urban productivity improvements, cities will need to shift to compact, connected and coordinated urban development, termed the "3C" model of urban development. This alternative model is briefly defined.

- Compact urban growth refers to managed expansion which encourages higher-density, contiguous

Box 3

Economic returns from boosting resource productivity

A synthesis of studies examining the economic case for investment in low-carbon development strategies in five cities – Leeds, UK; Kolkata, India; Lima, Peru; Johor Bahru, Malaysia, and Palembang, Indonesia – identifies numerous opportunities for cost-effective investments, for more efficient vehicles, transport systems and buildings, and for small-scale renewables.[54] The review shows that savings in the range of 13–26% in energy use and GHG emissions are possible relative to business-as-usual trends in the next 10 years through investments, with payback periods of less than five years, assessed on commercial terms.

In the buildings sector, opportunities include improved building design practices; insulation; more efficient heating/cooling, lighting technologies and appliances, and the adoption of small-scale renewables. For residential buildings in the Leeds City Region, it was calculated that £1.1 billion (US$1.7 billion) could be profitably invested in domestic energy efficiency measures, generating annual savings of £400 million (US$626 million), paying back the investment in less than three years and reducing total emissions from the domestic sector by 16% relative to business-as-usual trends. These investments could also achieve multiple other benefits, including reduced fuel poverty and improved public health.

In the transport sector, the studies emphasise the potential for cost-effective investments in more efficient vehicles, cleaner fuels and a range of public transport initiatives. In the Lima-Callao region, for example, it was projected that cost-effective investments could reduce transport-related GHG emissions by 26% by 2025 relative to business as usual. An investment of PEN7.4 billion (US$2.8 billion) would generate annual energy savings of PEN2.9 billion (US$1.1 billion) – meaning a payback in 2.6 years. These investments would also have other benefits – particularly relating to urban air quality and public health.

In the waste sector, the studies found that cities could make significant cost-effective investments in waste-related GHG emissions through measures such as improved recycling, landfill gas capture and enhanced composting of waste. In Kolkata, for example, waste-related greenhouse gas emissions could be cut by 41% by 2025, relative to business as usual, through investments of INR13.1 billion (US$224 million) that would generate annual savings of INR1.1 billion (US$18.8 million), paying back the investment in 11.8 years. Again, these investments could achieve multiple other benefits.

These findings are supported by other studies and assessments:

- The Intergovernmental Panel on Climate Change (IPCC) found that recent developments in technology and know-how made it possible to build or retrofit very low- and zero-energy buildings, often at little marginal investment cost.[55] Efficiency measures typically paid back well within the building's lifetime, and generated significant energy savings in both new (50–90% savings) and existing buildings (50–75%). The IPCC found that well-designed building codes and appliance standards were the most cost-effective ways to unlock these benefits, although numerous market and non-market barriers often hinder market uptake.
- Siemens identified 30 market-ready low-carbon technologies such as light-emitting diode (LED) street lighting, new building technologies and electric buses. Adopting these across 30 of the world's megacities could create more than 2 million jobs,[56] and avoid 3 billion tonnes of cumulative GHG emissions and 3 million tonnes of local air pollution between 2014 and 2025, with an investment value of US$2.5 trillion.[57]
- McKinsey & Company examined the economic benefits of developing new green technology districts in the United States, China and the Middle East.[58] Technologies included efficient building design and lighting, energy-efficient street lighting, efficient waste management, rooftop solar power, and combined heat and power. McKinsey estimated annual operating savings of US$7–21 million, or US$250–1,200 per resident, for incremental capital costs of US$35–70 million per square kilometre. The investment could break even after three to five years, and generate an internal rate of return of 18–30%. The green technologies could reduce annual energy costs by 24–36% and reduce GHG emissions by 28–49%. Extending the same technologies (analysed here for greenfield development) to brownfield sites would have higher costs associated with remediation, but likely still drive net savings.

development, with functionally and socially mixed neighbourhoods, and walkable, human-scale local urban environments.[61] Denser development is complemented by public green spaces to maintain liveability.[62] In rapidly expanding cities, compact urban development is achieved through planned accommodation of population expansion and anticipation of infrastructure needs. Compact urban growth can also be achieved through redevelopment of brownfield sites.[63]

- Connected infrastructure refers to investment in innovative urban infrastructure and technology, with a focus on smarter transport systems to connect and capture the economic benefits of more compact urban forms. These transport systems would connect mixed-use, employment, housing and commercial clusters. They include bus rapid transit (BRT), bicycle "superhighways", car- and bicycle-sharing, smarter traffic information systems, and electric vehicles with charging point networks using renewable energy sources. Transport systems can be complemented by smarter urban utilities to deliver more connected, resource-efficient public services such as efficient energy, waste and water systems, street lighting technology, and smart grids. Smarter, more efficient buildings (both via retrofits and new builds) complete the fabric of the urban system.
- Coordinated governance refers to effective and accountable institutions to support coordinated planning and implementation across the public and private sectors and civil society, particularly for land use change and transport. The existence of organisations dedicated to coordinating policies within entire urban agglomerations, for example, has especially positive effects, ranging from lower levels of particulate matter air pollution to a reduction in urban sprawl.[64]

4.3 The benefits of compact, connected, coordinated urban pathways

Encouraging more compact, connected and coordinated cities is ultimately about harnessing cities' growth potential by reinforcing a central function, facilitating access to people, goods and services, and ideas. Throughout history, cities have been dynamic centres of economic specialisation and cultural expression. By enabling density – the concentration of people and economic activities in a small geographic space – these economic and social interactions create a vibrant market and fertile environment for innovation in ideas, technologies and processes, spurring innovation and productivity.[65]

More compact urban growth can significantly reduce the cost of providing services and infrastructure, and the rate of development of new land. It also significantly increases the viability of public transport and other urban infrastructure, by attracting more intensive use, and creates a deeper labour market that can achieve faster and better job matches. Moreover, the components of this system are self-reinforcing, generating a virtuous circle: more compact urban centres concentrate urban innovation and job creation, helping to attract talent and capital for investment in smarter infrastructure and technology, and widening the skilled labour pool.

In the medium to long term, the economic and social benefits of a large-scale shift to a compact, connected and coordinated urban pathway include:

1. **Unleashing productivity and growth through agglomeration effects:** Firms and workers in dense urban agglomerations are more productive. The World Bank estimates that in China, for example, a compact urban development pathway would lead to higher economic growth, greater productivity, and a larger share of the high-value services sector by 2030.[66] There are also productivity benefits from policy coordination. Empirical evidence suggests that productivity is lower in cities with a high degree of administrative fragmentation, a cost that is almost halved by the presence of a well-functioning governance body.[67]

More compact, connected urban development could reduce global urban infrastructure requirements by more than US$3 trillion over the next 15 years (2015–2030).

2. **Improving the efficiency of capital deployment and closing the infrastructure gap:** New analysis for the Commission suggests that the United States could save $200 billion per year if it pursued smarter, more compact growth policies, primarily due to savings in the cost of providing public services and capital investments such as roads.[68] According to the World Bank, China could save up to US$1.4 trillion in infrastructure spending up to 2030 if it pursued a more compact, transit-oriented urban model – equivalent to around 15% of China's GDP in 2013.[69] Analysis for the Commission suggests that more compact, connected urban development could reduce global urban infrastructure requirements by more than US$3 trillion over the next 15 years (2015–2030).[70]

3. **Delivering substantial cost savings in the transport sector:** Estimates for the United States suggest that transit-oriented urban development could reduce per capita car use by 50%, reducing household expenditures by 20%.[71] In 1995, transport costs in transit-oriented Singapore were US$10 billion less than in car-oriented Houston, a city of similar population size and wealth.[72] At significantly lower fuel prices, sprawling Houston spends about 14% of its GDP on transport, compared with 4% in relatively compact Copenhagen and about 7% typically in many Western European cities.[73] In New York, density-related transport cost savings amount to about US$19 billion per year.[74]

4. **Delivering a wide range of benefits related to public-transport, walking and cycling infrastructure:** These benefits include greater access to jobs and low-cost transport, reduced congestion, improved public health and safety, and greater energy security[75] – all of which are particularly valuable to low-income urban residents. Regarding health, substantial benefits arise from improved air quality and physical activity. A study of Ho Chi Minh City, for example, found that a compact urban model would reduce transport-sector fine particulate matter (PM2.5) emissions by 44%, as well as indirect PM emissions by 16% as a result of reduced electricity use.[76]

In addition to the economic and social benefits, more compact, connected and coordinated urban development will also have significant climate benefits, by lowering GHG emissions from transport, buildings and other operations. New analysis for this report using a global database of city-level carbon emissions estimates that adoption of more compact, connected development models by the world's largest 724 cities could reduce global GHG emissions by 800 million to 1.5 billion tonnes of CO_2e per year by 2030. Those savings are achieved primarily through transformative changes in transport, reducing personal vehicle use in favour of mass transit.[77]

Another analysis for the Commission found that compact, transit-oriented cities could reduce annual GHG emissions by about 0.6 billion tonnes of CO_2e in 2030, rising to 1.8 billion tonnes CO_2e by 2050.[78] The savings would be achieved through reductions in personal vehicle use (shifting to public transport) and smaller housing units with lower energy demand. Further research is needed, however, to fully assess the potential impact on emissions of these and other compact, transit-oriented urban development strategies.

Box 4

Urban resilience: compact, connected and coordinated cities

With the rising incidence of climate-related hazards impacting urban areas, it is crucial that cities invest in enhancing their resilience to ensure they can withstand the shocks of future extreme events, minimise the damages, and recover quickly. A great deal is at stake: Hurricane Sandy in 2012 caused about US$19 billion in damages in New York City alone, left almost 2 million people without power, and flooded nearly 90,000 buildings.[80]

Coastal cities are at particularly great risk. The OECD analysed the climate risks faced by the 136 port cities globally with more than a million residents in 2005, and found they had about US$3 trillion worth of assets at risk in 2005, or about 5% of global GDP that year; by the 2070s, that is expected to rise to US$35 trillion, or 9% of projected global GDP.[81] The most exposed cities as of 2005, the study found, were Mumbai and Kolkata in India; Guangzhou and Shanghai in China; Miami, Greater New York and New Orleans in the US; Ho Chi Minh City in Vietnam; Osaka-Kobe in Japan; and Alexandria in Egypt.

Sound urban management can reduce vulnerability to climate hazards – for example, through better planning to restrict development in the most exposed locations.[82] Transport systems, utilities (e.g. energy, water) and buildings also need to be made more resilient, and basic infrastructure such as sewers needs to be well maintained. Some measures can enhance resilience, reduce emissions, and boost jobs and growth at the same time. For example, investment in green space and efficient waste management bolsters climate resilience, absorbs carbon, and enhances the attractiveness of cities to global talent and capital.

While the benefits of economic density have to be balanced against the potential risks of increased exposure to shocks such as climate hazards, there is evidence that more compact, connected and coordinated cities can also be more resilient:

- They are more energy- and resource-efficient, providing resilience to resource price shocks.
- They may be more able to raise finance for investing in climate-resilient infrastructure and public services.
- They provide economies of scale in the provision of risk control measures.
- Dense, well-functioning urban centres can draw residents in from areas exposed to climate hazards.
- Strong, coordinated land management can prevent settlement in hazardous areas.

Table 1

Different cities, different choices

	EMERGING CITIES	GLOBAL MEGACITIES	MATURE CITIES
Compact	Design in compact city features from the start, including integration of industrial and residential areas e.g Chenggong (China)	Re-densification through regeneration of existing city cores and multiple hubs, brownfield re-development, and urban retrofitting e.g Beijing (China)	Re-densification through regeneration of existing city cores and supporting hubs, brownfield re-development, and urban retrofitting e.g. Hamburg (Germany)
Connected	Introduce surface-based public transport based on Bus and BRT systems and rapid rail where appropriate e.g. Bogota (Colombia)	Further expand existing public transport systems and increase share of public and non-motorised travel e.g Mumbai (India)	Major opportunities for introducing cycling and non-motorised travel e.g. Amsterdam (Netherlands)
Coordinated	Build capacity for integrated land use and transport planning e.g. Curitiba (Brazil)	Integrated land use and transport planning, including accessing international finance for smarter infrastructure, road pricing and land value capture mechanisms e.g. London (United Kingdom)	Integrated land use and transport planning, including use of regulations e.g. Barcelona (Spain)

Measures to improve compactness and connectivity at the city level can also significantly improve the effectiveness of national policies to reduce carbon emissions. A recent study of Paris, for example, found that the presence of dense public transport infrastructure significantly increases residents' willingness to pay carbon or fuel taxes.[79]

4.4 Different cities, different choices

The concept of supporting more compact, connected and coordinated urban development is relevant to all types of cities, but the strategies for achieving this will vary significantly.

In Emerging Cities and many Small Urban Areas, there will inevitably be some urban expansion. There is thus a unique opportunity to managing urban growth so it includes compact city features and smarter urban infrastructure from the start.[83] Emerging Cities can become real leaders in driving forward a compact, connected development model, given that much of their infrastructure is yet to be built, and essential aspects of urban form have yet to be locked in.

In Global Megacities, there is a growing imperative to retain and enhance attractiveness for talent and capital. This can be achieved through vibrant urban cores and world-class transit systems. Transit-oriented development at the periphery can complement the redevelopment of city centres, neighbourhoods and former industrial land. Road space and parking areas can also be reallocated to achieve a greater mix of alternative transport and non-transport uses. Many Global Megacities have a central core with multiple hubs, with opportunities for a two-track strategy to revitalise and improve connectivity within and between the urban core and multiple hubs.

Mature Cities may already be locked into substantial sprawl, as is the case in Sydney and Johannesburg. Concentrating new development in denser urban blocks can enable compact city pockets supported by mass transit, to create more efficient and connected urban networks, and diversification of their economies. This can be complemented by the regeneration and revitalisation of brownfield sites in urban cores. Existing development can also be retrofitted, and connectivity between the urban core and supporting hubs can be improved. As with many megacities, this type of strategy will become ever more important as many Mature Cities look to retain and enhance their attractiveness for talent and capital in increasingly globalised labour and capital markets (see Box 7).

In summary, every city has a unique economy, demographic and geography, so the strategy for achieving more compact, connected and coordinated urban development must be flexible and responsive to diverse demands: one size does not fit all.

Box 5

Innovation: a potential tipping point in urban transport? [87]

Few sectors are as inefficient as road transport. Roads can cover more than 20% of a city's surface, but operate at capacity only 5% of the time. Cars are in use only about 4% of the time, and much of that time is spent stuck in traffic or searching for parking.[88] Despite this, there remains a global trend towards increasing motorisation, with the number of privately owned motorcars potentially doubling from 1 billion today to 2 billion by 2030.[89]

However, new and alternative patterns of urban transport are emerging in cities around the world, driven largely by innovative use of existing technologies, which could start to reverse this trend.

Figure 3 below shows the explosion in new forms of urban mobility, as more and more cities adopt these solutions to enhance their efficiency, competitiveness, social equity and quality of life. BRT is a notable phenomenon, which redistributes road space in favour of buses through dedicated bus lanes, pre-boarding ticketing and custom-designed stations. But there has also been an explosion in other areas such as car- and bike-sharing and the use of car-free zones.

In 2000, five cities had bike-sharing schemes, with only 4,000 bikes between them.[90] There are now bike-sharing schemes in 678 cities in both developed and developing countries, with 700,000 bikes.[91] Some 186 municipalities around the world were building, planning or actively studying bike-sharing as of the end of 2013. The number of car-sharing members in North America has increased from 16,000 in 2002 to 1 million in January 2013.[92]

While the number of electric vehicles (EV) introduced in cities has been slower than anticipated, EV sales increased from 45,000 cars in 2011 to nearly 200,000 in 2012, and more than 400,000 EVs were registered in cities worldwide at the beginning of 2014. This is likely to rise markedly with further technological improvements, helping to reduce local air pollution and noise in cities. Digitisation, information and communications technology (ICT), and use of "big data" are also opening up possibilities for improving public transport efficiency and reducing the need for travel. Chapter 7: Innovation discusses these issues.

There are several reasons for this diversification of urban mobility, including increased congestion and the costs of maintaining a car, which are shifting new generations of urban dwellers to alternative transport options. A study of 23,000 respondents in 19 countries found that younger urban dwellers (the so-called Generation Y) are more likely to live in areas where amenities are within walking distance; to relocate to reduce their daily commuting time; and to use car-share or car-pool technologies.[93]

Urban transport in the next decades is thus likely to be marked by greater use of public options; smarter, cleaner vehicles, and digitally enabled car-sharing. However, it is unlikely that in the foreseeable future, technological innovation will change the co-dependence of compact urban form and public transport in enhancing productivity and accessibility in cities.

4.5 New urban development models in action

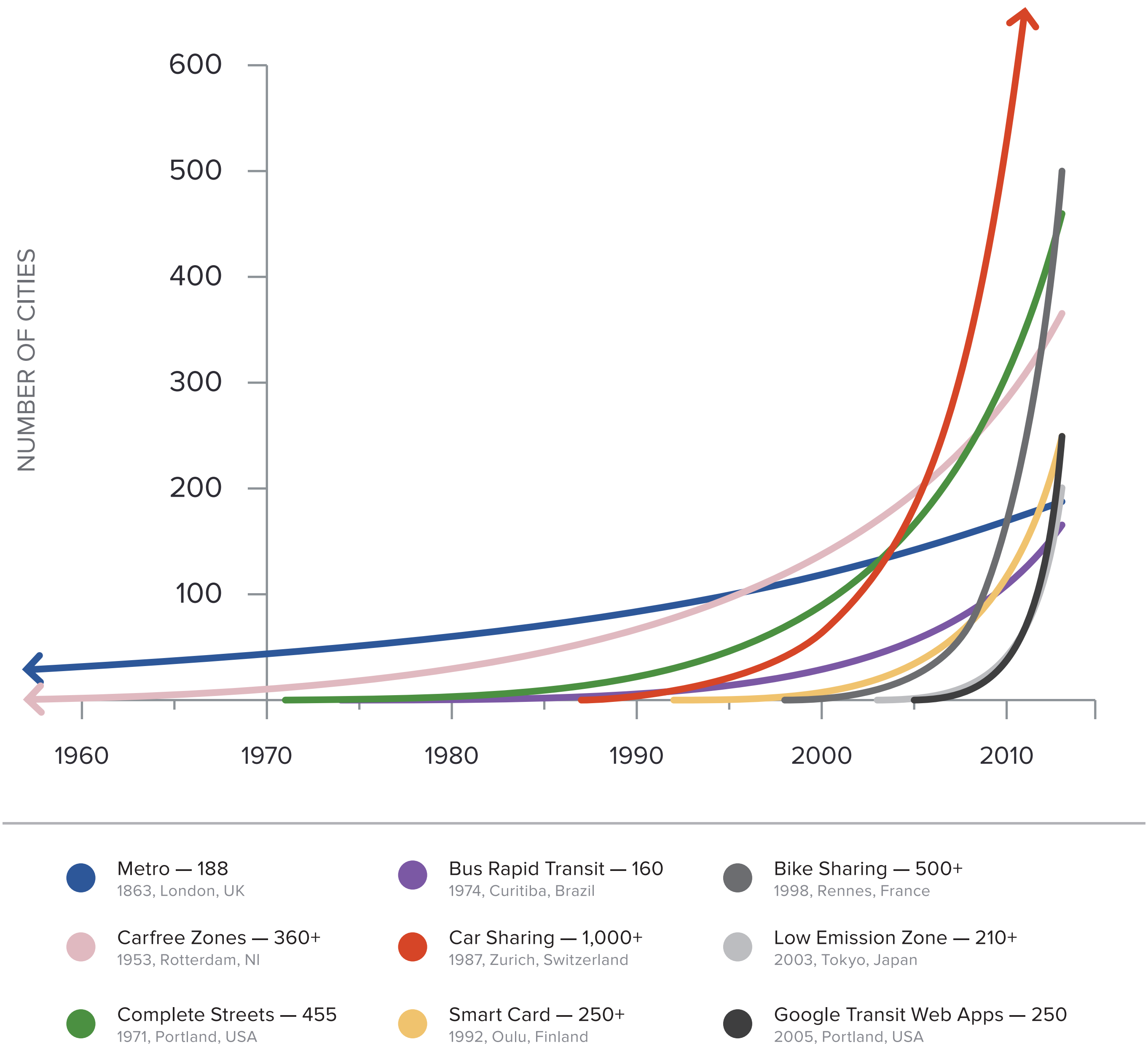
The Commission found remarkable consensus amongst urban development practitioners and prominent international organisations such as the World Bank, the OECD, the United Nations Human Settlements Programme (UN-Habitat), and the United Nations Environment Programme (UNEP) supporting the development of more compact, connected and coordinated cities. There is strong evidence that such cities are more productive, socially inclusive, resilient, cleaner, quieter, safer and lower-carbon.

There is less consensus on whether it is possible to develop cities in ways which arrest what some see as an inevitable expansion of existing patterns of urbanisation. Case study evidence suggests, however, that we are already seeing tipping points towards more compact, connected and coordinated urban pathways. The development of more compact urban forms and re-densification is an emerging trend in some leading, better planned cities, and in other cities as well.

Over the last decade, re-densification has been taking place in a range of Global Megacities and Mature Cities,[84] including London, Brussels, Tokyo, Hamburg and Nagoya. These cities have moved back towards more concentrated forms partly as a result of land use regulations and investment in public transport. Beijing is going against the trend of sprawling cities in China: population density in Beijing's core increased by 50% between 2000 and 2010.[85] The Sacramento region in California demonstrates how an urban area can swiftly reverse a trend towards urban sprawl, through land use and transport planning. Two years after a growth management plan was implemented, two-thirds of the housing growth in the region was achieved through infill in attached or small-lot detached housing, resulting in a significant rise in density for the region.[86]

The world is also seeing the seeds of a revolution in urban connectivity, through smarter urban infrastructure and new technology, particularly in transport, with the potential for transformative effects (see Box 5).

A range of smart transport systems have taken off in numerous cities worldwide since 2000



Source: Embarq, 2013[94]

BRT is transforming cities in many developing countries, increasing productivity and land value, while reducing traffic congestion, carbon emissions and air pollution. More than 160 cities have implemented BRT systems, which can carry large numbers of passengers per day at less than 15% of the cost of a metro.[95]

Bogota has been a trailblazer in BRT. The city is a globally recognised leader in transit-oriented urban planning and transport innovation, with strong leadership from successive city administrations and the embrace of integrated planning. Its headline project has been the TransMilenio BRT system, which has been replicated in several other cities, including Guangzhou (China) and Ahmedabad (India).[96] The BRT carries 2.1 million passengers per day and operates at a profit.[97] The city has complemented the BRT with a citywide network of bicycle paths that connect residents to public transport, community spaces and parks. Further innovations in the pipeline include the piloting of electric and hybrid buses, and an electric taxi fleet.

There are other signs of change around the world. In China, urban rail networks will total 3,000 km in length in 2015 and double that by 2020.[98] Bicycle infrastructure is also being upgraded in many cities, including citywide upgrades in Copenhagen, cycle superhighways in London, and hundreds of bike-sharing schemes that showcase the

Box 6
China's urban revolution [103]

Joseph Stiglitz, a Nobel laureate in economics, has said that technological innovation in America and urbanisation in China will be the "two keys" to human development in the 21st century.

China's urbanisation represents the biggest and fastest social movement in human history, with nearly 500 million people moving into cities in the past 30 years.[104] However, the dominant, business-as-usual model of rapid urbanisation has given rise to a growing range of economic, social and environmental costs. Urban forms developed over the past 10 to 15 years are starting to lock in dependency on private cars, resulting in more carbon-intensive, polluting and congested development. Urban sprawl has reduced productivity gains from agglomeration and specialisation and has led to much higher levels of capital accumulation than is necessary to sustain growth. Research from 261 Chinese cities in 2004, for example, suggested that labour productivity would rise by 8.8% if employment density doubled.[105]

China's leaders recognise that building better cities will help China to keep growing strongly for years to come.[106] Going in the wrong direction with cities will undermine growth, increase social inequality, and accelerate global climate change. Traffic congestion and air pollution are the top complaints by China's citizens. As a result, China is undergoing a potentially radical policy shift. In December 2013, for the first time in China's history, the Central Government held a national urbanisation conference, attended by President Xi Jinping and Prime Minister Li, which emphasised the need to shift towards more compact and mixed-use land development patterns to contain urban sprawl, maximise resource efficiency and curtail the negative externalities of pollution, congestion and CO_2 emissions.

China's New National Urbanisation Plan for 2014-2020 – overseen by the prime minister and published in March 2014 – places urban policy at the heart of Chinese decision-making and signals a strong shift towards an alternative urban pathway, highlighting the need to address urban sprawl, congestion and worsening pollution. This shift in direction is embedded in a new joint report by the World Bank and the Development Research Center of China's State Council recommending that China curbs rapid urban sprawl, with a focus on reforms to urban planning, urban finance and municipal governance.[107]

benefits of cycling for local economies, the environment and individual health. A range of smarter transport systems, such as car-sharing and electric vehicles, have also taken off in cities worldwide.[99]

The coordination of land use and transport planning is also improving in some countries and cities, with strengthened urban institutions. More than two-thirds of OECD cities now have a municipal body to coordinate programmes of public investment in urban infrastructure. These cities tend to be denser, have higher GDP per capita, and attract more skilled people.[100] Cities such as London are providing strong, replicable models for coordinating public transport investment. Transport for London, for example, is a single agency that oversees all urban transport modes, including non-motorised transport, public transport and road traffic, with the authority to take decisions across local administrative boundaries.[101] India and South Africa have also developed plans to help coordinate land use and transport decisions between the local, regional and national levels.

City policies supporting a shift towards compact, connected and coordinated pathways are being adopted in a growing number of developed countries, including France, Japan, the Czech Republic and Austria. Among emerging economies, China is shifting towards a similar pathway to boost urban productivity and reduce the escalating costs of urbanisation. China has established a programme of 100 low-carbon demonstration cities embedded in all major departmental plans. Cities such as Chenggong district in Kunming typify radical shifts towards higher-density, mixed-use, transit-oriented development.[102]

A broad range of cities are demonstrating that more compact, connected and coordinated urban pathways can strengthen the economy and deliver multiple other benefits:[108]

- Emerging Cities are demonstrating the economic, social, and broader benefits of investing in more compact, connected urban pathways. Sustained investment by Curitiba in its BRT system, bike paths, pedestrian ways and zoning policies has resulted in the city having one of the lowest accident rates in Brazil. Per capita GHG emissions are also 25% lower than the Brazilian urban average; gasoline consumption is 30% lower than the national average; and citizens spend only 10% of their income on transport, one of the lowest rates in the country. Curitiba has achieved this while seeing a threefold increase in population since the 1960s.[109] It is now one of the most affluent cities in Brazil, and its experience has been replicated in other cities, such as Bogota.

Box 7.
Houston: Overcoming sprawl through urban renewal and connectivity [117]

Even cities with significant lock-in to sprawled development patterns can start to forge alternative urban pathways. A striking example is Houston, one of the most sprawling, low-density, car-dependent cities in the United States, and the largest US city to lack zoning policies to manage private development. By 2035, if present trends continue, Houstonians are forecast to be spending 145% more time in their cars than they do today.

City leaders are making ambitious attempts to overcome the legacy of sprawl through urban renewal and sustained investment in transport systems. One programme, for example, offers developers up to $15,000 per unit for building multi-family housing in and around the city's core. Houston also launched a light rail system in 2004, and will be adding three new lines in 2014. Plans are in progress for a BRT line.

In addition, a third of Houston's bus fleet is now hybrid buses, and the city has created an online hybrid and electric car-sharing programme for municipal vehicles, enabling a 34% reduction in the municipal car fleet; more than half of its light-duty vehicles are hybrid or electric. Bike-sharing and car-sharing programmes are now up and running. The city and the private sector have also committed more than $200 million to a signature new Bayou Greenways initiative, adding 150 miles of new hiking and biking trails. These initiatives mark a potential shift towards planning Houston's future in a way that values improved transport connectivity as a viable alternative development model. (In addition, the city is converting traffic lights at 2,450 intersections to LEDs, as well as 165,000 streetlights.)

The case for action has been a simple economic one: Houston's leaders recognise that their firms are struggling to draw talent from leading US universities, because prospective employees want a city with an attractive, vibrant urban core and strong multi-modal transport networks. Recent survey evidence from the Rice University's Kinder Institute for Urban Research already suggests that more than half the residents of Harris County, of which Houston is part, would prefer to live in an area with mixed-use development, including homes, shops, and restaurants as opposed to single-family residential areas.

"At some point, it's not enough to keep grabbing the suburbs and roping them in," Houston Mayor Annise Parker has said, recognising the need for change. "You've got to make the system as a whole function, and you do things to bring people back to the inner core."

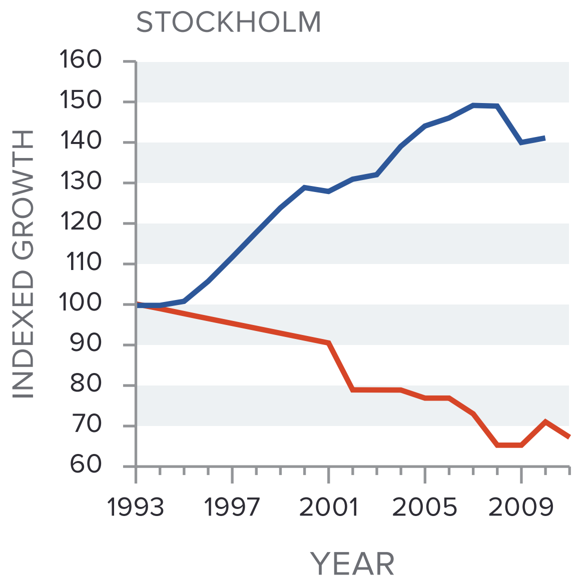
Houston's leaders have had to demonstrate leadership to make these investments and reforms. Stephen Klineberg of the Kinder Institute says: "The great Catch-22 for Houston is we want density, but you can't have density with a car and there's no density to support light rail. You build light rail on the faith that if you build it, they will come."

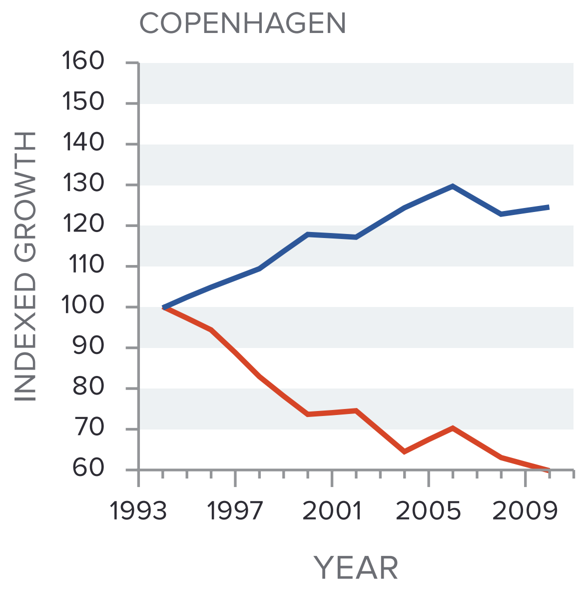
- Global Megacities are demonstrating how to remain competitive through more compact, connected and coordinated urban development. London, for example, remains one of the world's most dynamic cities, yet since 2000, population growth in London has been concentrated within a 10 km radius of the city centre, and 53% of all newly constructed floor area between 2004 and 2011 was within 500 metres of a rail or underground station.[110] Car ownership in London decreased 6% from 1995 to 2011, while the city's economy grew around 40%.[111] And the city has reduced air pollution to close to WHO guidelines, with a particular emphasis on reducing emissions from private vehicles through policy measures such as congestion charges and low-emissions zones.[112] More broadly, the members of C40, a global network of megacities committed to reducing GHG emissions, are collectively taking more than 8,000 actions, primarily in their economic self-interest. A significant share of these investments could be transformational, with a rising number of megacities reporting implementation of BRT systems, for example.[113]
- Mature Cities such as Stockholm, Copenhagen, Portland, Hong Kong, Hanover and Singapore have all shown, through efficient land use and sustained investments in public transport, that it is possible to grow prosperous economies while dramatically reducing externalities such as GHG emissions and air pollution. For example, Stockholm reduced emissions by 35% from 1993 to 2010, but grew its economy by 41%, one of the highest growth rates in Europe.[114] The city is now considering new measures, such as making the Stockholm Royal Seaport fossil fuel-free by 2030, to drive further economic and carbon benefits. Since 1990, Copenhagen has reduced its carbon emissions by more than 40%, while experiencing real growth of around 50%.[115] All of these cities consistently rate high in rankings of the world's most competitive cities.

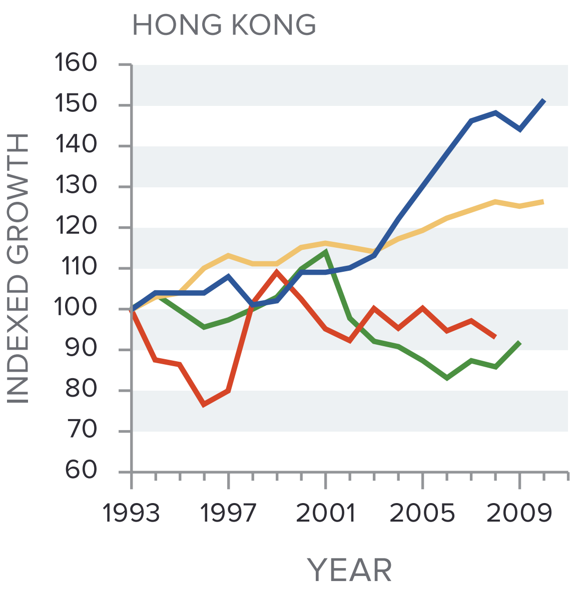
5. Scaling and accelerating change

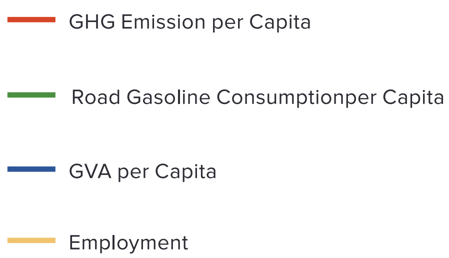
If the global economy is to capture the productivity benefits of more compact, connected and coordinated cities, analysis for the Commission suggests that policy-makers should prioritise four mutually reinforcing areas:

Some cities have shown that compact and connected urban pathways can go hand in hand with economic growth: Stockholm, Copenhagen, Hong Kong









SOURCE: Rode, Floater et al. 2013; Floater, Rode et al. 2013, 2014.[116]

- Strengthen the role of strategic planning and land use regulation at the national and city level, to provide the framework for more efficient and effective planning of land use, transport and urban infrastructure.
- Reform subsidies and introduce pricing to reflect the full costs associated with unstructured urban expansion, including inappropriate pricing of land, new development, carbon emissions and conventional motorisation.[118]
- Unlock financing for smarter, more resilient urban infrastructure and technology, to allow cities to redirect and invest capital in infrastructure which dramatically improves connectivity.[119]
- Build effective and accountable institutions to support the implementation and delivery of coordinated programmes and investment, particularly in relation to land use change and transport.

The importance of these issues to each city will differ. Cities will need to structure a mutually reinforcing package of reforms and investments suited to their own political, economic and social contexts, and their capacity for implementation. Moreover, the balance of responsibility between actions at the city, regional and national level will depend on the level of autonomy provided to urban areas.

The most significant opportunities for shifting the course of urbanisation are likely to be in fast-growing, mid-

Traditional vs. new citywide planning systems

Traditional approaches to planning	New approaches to planning
• Little integration with transport planning • Lack of thought for relationships with wider city region • Little attention paid to wider, social, environmental or economic factors associated with land use • Strict division of land uses with little mixed use • Low development densities to restrict pressure on existing infrastructure • Focus on neighbourhood-scale physical development rather than city-level spatial planning	• High degree of integration of land use, transport policy, and infrastructure investment with wider economic, social, and environmental objectives • Plan grounded in robust analysis of functional relationship with wider region • Plan fully costed and responsibilities for delivery clearly stated • Plans recognise that mixed use is part of a wider strategy for efficient land use, but not prescriptive on exact mix of uses • Flexibility built in to neighbourhood-level objectives, with high frequency of review

Source: Adapted from Atkins, 2014[126]

sized Emerging Cities and in Small Urban Areas, where administrative and technical capacities can be limited or weak. These cities can start by identifying relatively accessible, economically attractive options in the short- to medium term to boost resource productivity and build commitment and capacities for change. They can combine this with planning an adequate public transport network and basic public services. However, capacity constraints should not prevent cities from being ambitious and focusing on more challenging interventions. Consultations for this report have demonstrated that policy-makers are considering ambitious reforms even in some of the most capacity-constrained environments. Moreover, capacity is often best built through action-based learning in the process of policy implementation.

5.1 Strategic planning and regulatory reform

Spatial and infrastructure planning needs to be significantly strengthened at both the national and city levels.[120] According to the World Bank, only about 20% of the world's 150 largest cities have even the basic analytics needed for low-carbon planning.[121] A significant number of the world's most rapidly urbanising countries do not have national plans for managing urban expansion to achieve economic, social and environmental objectives. Traditional approaches to planning in countries such as India are proving ineffective at influencing the sheer scale and shape of urbanisation and infrastructure. Land use planning at the national and city levels is often conducted as separate exercises, leading to urban sprawl, social marginalisation and high demand for conventional motorisation (see Table 2).

Reforms to national- and city-level planning systems need to go hand-in-hand with regulatory reform. Such reform will include shifting from maximum to minimum density standards, and minimum to maximum parking requirements. It will also include introducing mixed-use regulation and density bonuses for developers in order to support compact city development with a hierarchy of higher-density, mixed-use clusters around public transport nodes. For example, Denmark's Planning Act on the "Station Proximity Principle" requires new offices over 1,500 m^2 to be located within 600 metres of a rail station, reinforcing Copenhagen's efficient, compact urban form.[122]

Careful introduction of urban growth boundaries (or selective protection of non-urban land) can foster urban compaction and incentivise the development of brownfield over greenfield land, while avoiding house cost inflation.[123] Here it is important to identify where there is scope for expansion and plan ahead for essential infrastructure, rather than simply try to contain sprawl, which can lead to unintended outcomes such as "leapfrog sprawl".[124] Complementary measures to boost development density, reduce parking requirements and promote more mixed-use development can offset the inflationary impact of growth boundaries on housing affordability, by reducing unit land costs and land requirements.[125]

5.2 Subsidy reform and new pricing mechanisms

Subsidy reforms and new pricing mechanisms can help reduce and reverse the perverse incentives supporting unstructured urban expansion and conventional motorisation. This would not only reduce negative externalities, but also strengthen the fiscal revenue base at the national and city levels, and provide revenue to reinvest in sustainable urban infrastructure. Nations and cities can develop different strategies according to their unique political, institutional, and cultural landscapes. Three types of instruments are of particular importance: fuel subsidies, congestion charges and land development taxes.[127]

Fuel subsidies and other pricing policies drive urban sprawl in many countries, directly against other national policy goals, such as addressing air pollution and congestion and promoting responsible macroeconomic policy management.[128] The under-pricing of transport fuels and motorised travel has locked-in inflated levels of automobile use in many urban areas. For example, commuters in the Netherlands are able to reduce their taxable income by up to €0.19 per kilometre of commute, resulting in 25% more commuting trips and 16% more car trips.[129] Research from US cities shows that a 10% increase in fuel prices leads to a 10% decrease in urban fringe developments with high commute times.[130]

Congestion charges and parking fees can steer commuters to public transport if viable options exist, and cities typically have the power to introduce such measures. Stockholm's congestion tax reduced traffic delays by a third, decreased traffic demand by more than a fifth,[131] and generated a net budget surplus of US$90 million per year.[132] A study in Paris showed that congestion charges would reduce the radius of the metro area by 34% and average travel distance by 15%.[133] Charging for on- and off-street parking based on market prices also reduce parking demand and release space for higher-value usage.

Land and development taxes are usually under the control of city authorities, and their greater use has recently been suggested by influential bodies such as the OECD and International Monetary Fund (IMF). Property taxes are typically the largest source of revenue for many cities, but often favour greenfield over infill development. Variants of property taxes include land taxes or split-rate taxes. These are underused and could be scaled up to promote compact urban form by levying a higher tax rate on the value of urban land, and a lower or zero rate on the value of buildings and other improvements. Such alternative taxes can increase the capital-to-land ratio – i.e. the intensity of development, with efficiency and equity benefits.[134] This type of taxation has been successfully used in countries such as Singapore, Japan and Korea, and parts of the United States, South Africa and Canada. Perverse incentives which favour single-family homes over multi-household developments should also be reconsidered. Development taxes can help to control urban sprawl at relatively low economic cost, and are the most direct way to price the externalities associated with new development beyond city boundaries.[135]

5.3 Finance mechanisms

An overwhelming body of evidence suggests that cities need greater access to financing for smarter urban infrastructure and new technology. A lack of financing can be the most significant hurdle of all.

Only 4% of the 500 largest cities in developing countries are deemed creditworthy in international financial markets, rising to 20% in local markets.

As a first principle, national, regional and city-level funding needs to be redirected away from business-as-usual urban infrastructure development, such as road-building. This would significantly reduce the investment gap and release funds for mass transit infrastructure, and is particularly important for countries with more limited budgets. China, for example, invested nearly US$200 billion in highway construction nationwide in 2012, with over US$1 trillion to accelerate the construction of urban public facilities during its 12th Five-Year Plan from 2011 to 2015.[136] India's main urban development fund – the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) – is skewed towards the construction of bridges and flyovers to support conventional motorisation.[137] Redirecting investment can be particularly effective for urban transport infrastructure.[138] Bogota's BRT system was partially financed by redirecting funds away from urban highway programmes.

Other steps for increasing city financing include greater budgetary control, enhanced creditworthiness, the use of land value capture, municipal bonds, reform of multilateral funding, and support for project preparation.[139] These are discussed in turn below.

A narrow revenue base induces many cities to convert publicly owned agricultural land to urban land for revenue generation. Providing cities with greater fiscal autonomy – backed up by appropriate fiduciary safeguards – would help them to leverage the significant co-financing often required for large-scale urban infrastructure investment, such as mass transit systems, rather than simply converting land to pay for basic public services.

Enhancing creditworthiness is one way to boost city finances. An inability to source financing for large-scale urban infrastructure projects is closely related to poor credit ratings. According to the World Bank, only 4% of the 500 largest cities in developing countries are deemed creditworthy in international financial markets, rising to 20% in local markets. Investing US$1 in raising the creditworthiness of cities can leverage more than US$100 in private-sector financing for smart infrastructure.[140] The World Bank's City Creditworthiness Initiative is demonstrating how cities can improve their credit ratings through an array of measures, such as increasing locally generated sources of revenue, better debt management, and developing multi-year capital investment plans.

Johannesburg recently issued a US$136 million green bond to finance a diverse range of investments, from hybrid buses to biogas energy and rooftop solar water heaters.

Such higher creditworthiness can unlock financing for low-carbon, climate-resilient infrastructure. Lima provides a good example of a city working with a range of international institutions, including the Public Private Infrastructure Advisory Facility (PPIAF), to gain a credit rating. This helped to unlock funding for its BRT project. In another example, Kampala in the space of one year managed to boost its locally generated revenue by 86%. With borrowing limits pegged to own revenue, this has almost doubled what the city can borrow for large-scale urban infrastructure.

Greater use of land value capture can also help finance large-scale urban infrastructure, while also driving more compact urban forms. Land value capture involves financing the construction of new transit infrastructure with the profits generated by the increase in land value stimulated by the presence of that infrastructure. For example, in Hong Kong, the government's "Rail plus Property" model captures the uplift in property values along new transit routes, ensuring efficient urban form while delivering US$940 million in profits in 2009 for the 76% government-owned MTR Corporation.[141] São Paulo has raised over US$1.2 billion in six years using related instruments, and Curitiba is funding the conversion of a highway into a BRT corridor, complemented by higher-density, mixed-use spaces and green areas – an investment of US$600 million.[142] Variations of land value capture include development impact fees, tax incremental financing, public land leasing and development right sales, land readjustment programmes, connection fees, joint developments, and cost/benefit-sharing. Cities such as Houston have created special Tax Increment Reinvestment Zones to help finance the cost of urban infrastructure.[144]

Cities can use municipal bonds to finance a group of infrastructure projects, whose collective assets underwrite the bond. Such bonds allow cities to attract large institutional investors which typically prefer not to invest in small, individual projects. For example, Johannesburg recently issued a US$136 million green bond to finance a diverse range of investments, from hybrid buses to biogas energy and rooftop solar water heaters. The bond was 1.5 times oversubscribed and will earn investors a return of 185 basis points above sovereign bonds.

The global climate-related bond market is currently estimated at US$503 billion.[145] Municipal bonds are a small share of this, less than US$2 billion, indicating significant potential for scaling up. Models such as the Qualified Energy Conservation Bond (QECB) used in the United States to allow local governments to borrow money to fund energy conservation projects could also be translated into other sectors to fund projects which generate economic returns and carbon savings. With public infrastructure investment falling in many countries, attracting private capital into smarter infrastructure is even more urgent. Institutional investors in the OECD alone have more than US$70 trillion in assets under management but face significant investment barriers related to the complexity of investments and transactions costs associated with smaller infrastructure projects.[146] To overcome these barriers, cities can set up exchanges or dedicated vehicles to match infrastructure projects with financial backers. For example, the mayor of Chicago set up the Chicago Infrastructure Trust in April 2012 to invest in transformative infrastructure projects. Smaller cities could set up pooled financing mechanisms between cities to aggregate the packaging, standardising, marketing and selling of urban infrastructure investments for the private sector.[147]

Existing multilateral development bank (MDB) funding in middle- and low-income countries could go further to support the development of more compact, connected and coordinated cities. The eight largest MDBs have committed to investing US$175 billion over the next decade for more sustainable transport. However, according to the MDBs' self-reported breakdown, only about 25% of current MDB financing for transport supports sustainable transport.[148] Less than a fifth of projects reported in 2012 focused on urban transport projects, except for road and urban highway construction.[149] This suggests that, for the foreseeable future, MDB financing will continue to provide incentives for business-as-usual urban growth rather than compact urban growth and connected infrastructure. Institutions such as the World Bank have established a set of tools to assess the carbon impacts of investment decisions. However, MDBs provide support to cities on a sector-by-sector basis rather than via holistic packages aligned to a strategic approach to managing urban growth. MDB funding could be reformed to ensure a more strategic, coordinated approach. Greater consideration should also be given to improving cities' access to MDB financing, in partnership with national governments.

Finally, cities need support to prepare infrastructure projects and financing deals, especially rapidly expanding mid-sized cities in emerging and developing countries. Many cities have good ideas and plans for smarter urban infrastructure, but often lack the necessary expertise to prepare and package these into bankable projects that can attract private-sector capital. While dedicated financing vehicles designed for this purpose can help (see municipal bonds above), international support is also valuable. For example, the Cities Development Initiative for Asia (CDIA)[150] provides assistance to mid-sized Asian cities to bridge the gap between their development plans and implementation. More than US$5 billion in large-scale urban infrastructure investments are under development due to CDIA's catalytic input, delivered at a cost of around 0.25% of the investments under preparation.[151]

5.4 Building effective and accountable institutions

Cities need to build effective and accountable institutions, to achieve the collective decision-making and integrated policy interventions required for efficient urban infrastructure development and spatial planning. While many megacities have the skills and resources to implement the shift towards a new urban development model, many other cities lack such capacity.

Institutional strengthening is particularly important in small and mid-sized cities in developing countries.[152] To underpin the institutions required to plan and finance a more compact and connected development model, five elements of urban governance should be given greater prominence:[153]

1. **Integrated transport and land use authorities:** Many urban agglomerations include multiple administrative levels, which can prove challenging to coordinate. To integrate policy programmes at the metropolitan level ("horizontal governance"), many countries have set up sector-specific, metropolitan-level agencies,[154] such as Transport for London, discussed earlier. Another option is to set up integrated multi-modal transport and land use authorities. Curitiba pioneered this approach through the Instituto de Pesquisa e Planejamento Urbano de Curitiba (IPPUC), which aimed to integrate all elements of urban growth.[155] The IPPUC prioritised mixed-use development and dedicated high-capacity bus lanes, the backbone of the city's successful BRT system. Key factors in IPPUC's success included an ability to leverage dedicated funding sources and a long-term vision which was followed by a succession of civic leaders.[156]

The next 10 to 20 years will be pivotal in the world's urbanisation journey

2. **Institutional structures for coordinating land use and transport planning:** Fragmented governance and a lack of coordination between national and local policy frameworks for urban planning and transport are common in many countries. Coordination between city departments and between city, regional, and national policy frameworks ("vertical" governance) is fundamental to effective strategic land use and transport planning. India, for example, has recently developed a National Urban Transport Policy, integrating transport and land use planning as a single strategic goal. The central government covers half the costs of preparing integrated transport and land use plans.[157] South Africa has used national legislation to create an Integrated Development Plan that coordinates national, provincial and local government policy.

3. **Information communication technology (ICT) and e-governance systems:** More advanced ICT systems can improve urban planning, revenue-raising, and transparency and accountability in government practices. Poor transparency and accountability have historically contributed to the unplanned conversion of undeveloped land into industrial or residential use in many cities, exacerbating sprawl.[158] Cities can now make use of new ICT and e-governance systems to improve urban planning, and protect a revenue base for infrastructure investments. On the "demand side", these systems can empower citizens to provide feedback on the quality of municipal service

delivery and boost citizen participation in shaping land use planning processes. City governments in India, for example, are starting to use geographic information system (GIS) mapping to develop spatial planning strategies and to ensure more effective revenue collection.

4. **Development of sound municipal accounts and data:** A crucial step in unlocking financing for urban infrastructure and new technology is to develop a coherent, consistent and integrated set of macroeconomic accounts, based on common standards similar to the Standard National Accounting system.[159] This helps private-sector financiers to assess creditworthiness and municipalities to identify and track performance improvements. If they face significant deficiencies in city-level economic, social and environmental performance data, cities can use ICT and social media to build effective metrics at low cost, and even use real-time data to monitor and improve the efficiency of service delivery. City-level GHG emissions data are particularly inconsistent, of poor quality and with no common baseline.[160] The Global Protocol for Community Scale GHG Emissions (GPC), an initiative to move towards a standard for city-level GHG accounting developed by ICLEI (Local Governments for Sustainability), the World Resources Institute and C40, and supported by the World Bank, UN-Habitat and UNEP, is helping to address this problem.[161]

5. **Building capacity to scale public-private partnerships:** Many city authorities do not have sufficient capacity or skills to identify and structure the right kinds of public-private partnerships required to plan, design, finance and deliver large-scale urban infrastructure. New models of engagement with the private sector can help cities to build that capacity. Examples include the 2030 Districts model in the US and Canada, and those spearheaded by the World Business Council for Sustainable Development through its Urban Infrastructure Initiative (UII). The 2030 Districts are urban public-private partnerships that bring together property owners, municipal governments and community stakeholders to ensure significant district energy, water and transportation emissions reductions and resiliency upgrades. There are six established Districts in major US cities (Seattle, Denver, Los Angeles, Pittsburgh, San Antonio and Cleveland), with 12 additional Districts in various advanced stages of development. The UII initiative brought together 14 world-leading companies in partnership with ICLEI and the Urban Land Institute to support 12 developed- and developing-world cities with new urban solutions. In Yixing (China), for example, UII recommended approaches for tackling urban sprawl, and the development of a citywide tram network is now being fast-tracked.

The next 10 to 20 years will be pivotal in the world's urbanisation journey. Building better, more productive cities could make all the difference for middle-income countries looking to become high-income, and for low-income countries looking to graduate to middle-income. Building better, more productive cities will also be crucial for the global climate. The measures identified in this chapter can support significant improvements in the economic and climate performance of cities and sow the seeds for unleashing a new wave of long-term urban productivity improvements by encouraging more compact, connected and coordinated urban development.

6. Recommendations

A strategic approach to managing urban growth at the national level

Countries need to prioritise better planned urban development and increased urban productivity as key drivers of growth and climate goals. This is especially the case for countries with rapidly urbanising populations. Current institutional arrangements often result in urban development being driven by other national priorities. Here, coordination and cooperation between national and regional governments and city leaders is essential. The Commission urges countries to:

- Develop national urbanisation strategies in conjunction with city governments, with cross-departmental representation and assigned budgets, overseen by the centre of government and/or Ministry of Finance.
- Provide greater fiscal autonomy for cities, potentially linked to economic, social and environmental performance benchmarks.
- Consider setting up a special-purpose financing vehicle at the national level to support cities to become more compact, connected and coordinated, with appropriate private-sector participation.
- Redirect existing infrastructure funding towards more compact, connected and coordinated urban infrastructure development, including existing national urban infrastructure funds and other relevant funding vehicles.

Stronger policies and institutions to drive compact, connected and coordinated urban development

Building better, more productive cities is a long-term journey. It requires persistence in several key areas to shift away from business-as-usual urban expansion, with countries, regions and cities working together. In addition to short-term measures and investments to boost resource productivity in sectors as diverse as buildings, transport and efficient waste management, priority areas for structural transformation include:

- **Strengthen strategic planning at the city, regional and national levels, with a focus on improved land use and integrated multi-modal transport infrastructure.** These efforts should be supported by regulatory reform to promote higher-density, mixed-use, infill development, and new measures such as efficient parking practices.
- **Reform fuel subsidies and introduce new pricing mechanisms such as road user charges to reduce and eventually eliminate incentives to fossil-fuelled vehicle use.** Also consider charges on land conversion and dispersed development, and measures that place a higher price on land than on buildings such as land taxes and development taxes. These reforms can raise revenue to invest in public transport and transit-oriented development.
- **Introduce new mechanisms to finance upfront investments in smarter urban infrastructure and new technology.** These may include greater use of land value capture mechanisms, municipal bonds, and the creation of dedicated national, regional, or city-level investment platforms to prepare and package investments to attract private-sector capital.
- **Build more effective and accountable city-level institutions.** Key measures include: (i) setting up integrated transport and land use authorities to plan urban growth and scale public transport, cycling, walking and spatially efficient use of low-carbon vehicles; (ii) working with the private sector to plan, finance and deliver smarter infrastructure and integrated technology solutions; and (iii) making enhanced use of ICT and e-government practices.

The role of the international community

The international community also has a key role to play in fostering better-managed urban growth. The Commission urges the international community to:

- **Develop a Global Urban Productivity Initiative to promote and assist in the development of best practices in boosting urban productivity and support countries' and cities' own efforts.** The initiative should:
  - Build on the existing work of the OECD, UN-HABITAT, the World Bank, Regional Development Banks, and city networks such as the C40 and ICLEI;
  - Involve rapidly urbanising countries and mayors of leading cities;
  - Include a global leadership group of CEOs of leading businesses already helping cities to plan, finance and deliver smarter urban infrastructure and integrated technology solutions.

  This initiative should review institutional options for systematic collection of city-level data; develop urbanisation scenarios and best practice guidance; create an international standard for integrated municipal accounting, and provide targeted capacity-building. It should also give priority to educating the next generation of urban planners and designers – as well as economists in key ministries – about the benefits of compact, connected and coordinated urban development.
- **Set up a global city creditworthiness facility to help cities develop strategies to improve their "own source" revenues and, where sovereign governments allow it, increase their access to private capital markets.** This should build on and scale-up the existing programme of the World Bank, and assist cities in both developing and developed countries.
- **Effective immediately, ensure that the multilateral development banks (MDBs) work with client and donor countries to redirect overseas development assistance and concessional finance away from investments which lock in unstructured, unconnected urban expansion.** Investment should support integrated citywide urban strategies and investment in smarter infrastructure and new technology. Greater consideration should also be given to redirecting overall MDB funding to account for the growing importance of cities in economic development in rapidly urbanising countries, as well as the scaling-up of support to help cities prepare and package urban infrastructure investments.

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Chapter 3

LAND USE

Main points

- Rapid population growth, urbanisation, rising incomes, and resource constraints are putting enormous pressure on agriculture and forests, which are crucial to food security and livelihoods. Agriculture and land use change also account for 24% of global greenhouse gas emissions. These factors, together with attractive opportunities to boost investment in well-managed land use systems, make agriculture a top-priority sector for both economic and climate policy, particularly in developing countries.
- Agricultural productivity needs to sharply increase to keep up with food demand. The Green Revolution boosted grain yields through widely applicable technological improvements, but many of the measures needed today are location-specific, addressing issues such as drought, pests, and salt resistance. Public funding of R&D needs to increase substantially; reducing input subsidies (mainly for fertiliser and water) would free up funds while reducing waste and negative environmental impacts.
- Policy interventions are needed to enable and encourage smallholders to adopt new technologies and practices under more uncertain conditions. Measures to consider include targeted climate change adaptation finance, agricultural insurance schemes, and more secure property rights. Landscape-level (vs. farm-level) approaches are needed to maintain ecosystem services and overcome market failures.
- Demand-side measures are also needed to reduce pressure on agricultural systems. On a caloric basis, a quarter of the world's food is now lost or wasted between farm and fork. For example, food waste reduction measures in developed countries could save US$200 billion per year by 2030, and reduce emissions by at least 0.3 Gt of CO_2e. Policy-makers should also work to reduce demand for food crops for biofuels and promote a shift in diets, away from red meat especially.
- Special measures are necessary to prevent further deforestation and degradation of (mainly tropical) forests, especially when promoting increased agricultural productivity. Achieving zero net deforestation could result in emissions reductions of around 3 Gt CO_2e per year in 2030. Payments for ecosystem services, such as under REDD+, can play a key role in this. Private-sector engagement could also play a significant role.
- Restoring just 12% of degraded agricultural land could boost smallholders' incomes by US$35–40 billion per year and feed 200 million people per year within 15 years. It can also increase resilience to weather shocks and reduce greenhouse gas emissions by nearly 2 Gt CO_2e per year. Initiating forest restoration of at least 350 million hectares by 2030, meanwhile, could generate US$170 billion/year in net benefits from watershed protection, improved crop yields, and forest products. This would also sequester about 1–3 Gt CO_2e/year, depending on the areas restored.

1. Introduction

Global demand for agricultural and forestry commodities – food, fuel, fibre, etc. – continues to surge, driven primarily by emerging and developing economies. This can be very good news for countries with abundant land and water. It provides considerable added potential for economic growth and poverty alleviation: 70% of the world's poorest people live in rural areas and depend on agriculture for their livelihoods, mostly in the tropics.[1] At the same time, it can be very worrisome for those who need to purchase their food, especially in South Asia and sub-Saharan Africa, where 40–70% of all household expenditure is on food.[2]

Agricultural and natural resource commodities have risen in value substantially in recent years, and there is also a growing recognition of the importance of the ecosystem services that forests and agricultural land provide, such as local and global weather and water regulation, carbon storage, and biodiversity. Yet around the world, ecosystems are under pressure from over-exploitation of key natural resources such as freshwater and soil nutrients.

Forest degradation and deforestation are particular concerns, especially in the humid tropics. Roughly a quarter of the world's agricultural land is severely degraded,[3] and rapid urbanisation and population growth are also driving people to clear more forest land for timber and charcoal, and then use the land for crops and pasture, or for larger-scale agriculture.[4] Inadequate soil and water management is exacerbated by loss of vegetative cover, and leads to water and air pollution, as well as erosion and landslides. Key ecosystem services such as water cycle regulation are being compromised, and the natural resource base is becoming less productive. At the same time, climate change is already posing significant challenges, increasing both flood and drought risk in many places, and altering hydrological systems and seasonal weather patterns.

To feed a growing & richer population by 2050, 70% more crop calories will be needed than those produced in 2006.

This chapter makes the case for strategic investment and policy interventions to sharply increase agricultural productivity, reduce pressures on the land, and protect and restore forests. For developing countries, especially, the stakes are very high: if they succeed, they can grow their rural economies, lift people out of poverty, and strengthen their position in global markets – while also helping reduce climate risk and protect vital ecosystem services. If they fail, billions of their people may be unable to feed themselves adequately.

We begin by examining the changing context for agriculture and forestry, including population growth, resource scarcity, and the need to both mitigate and adapt to climate change. We then review supply-side strategies to increase agricultural productivity, including new technologies and practices to increase crop yields, the role of input subsidies and other policy measures, sustainable ways to increase livestock productivity, and "landscape approaches" that boost crop yields while restoring and protecting key ecosystem services. Next, we look at demand-side measures to ease pressures on natural resources, including ways to reduce food loss and waste, alternate approaches to biofuels, and the role of dietary changes. We then examine the natural capital of forests, trends in deforestation, forest degradation, afforestation, and reforestation, and ways to scale up and accelerate positive change. Throughout the chapter, we draw lessons from success stories around the world: from Korea, to China, Niger, Brazil, Costa Rica and the United States. We end with a series of recommendations. For further discussion of some of these issues, see also Chapter 7: Innovation (biofuels) and Chapter 3: Cities (urban land use), as well as sections of Chapter 6: Finance and Chapter 8: International Cooperation.

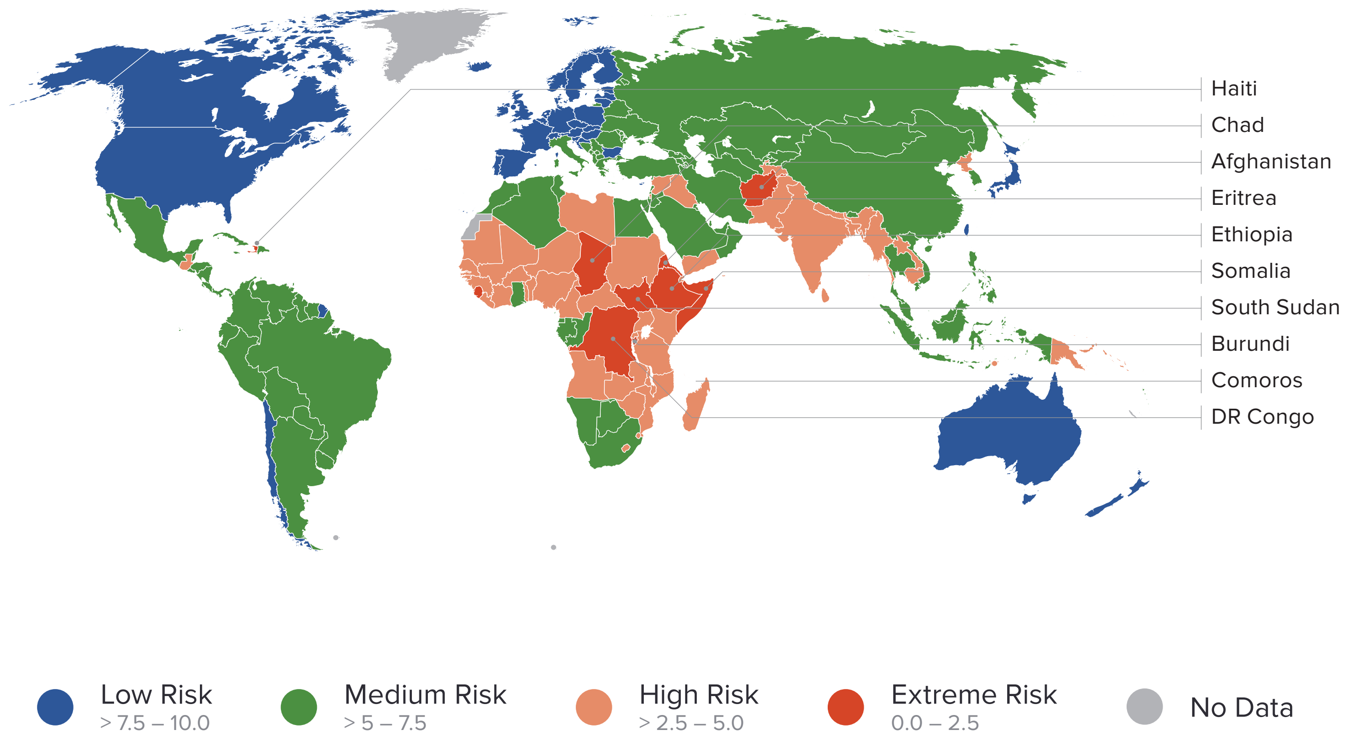
2. The changing context

With the global population expected to grow by 1.2 billion by 2030, and the global middle class set to roughly double by 2030 from 2 billion today, pressures are increasing on food supplies and the underlying natural resource base.[5] Although the share of people living in extreme poverty has been cut in half since 1990, from 43% to 21%,[6] more than 1.2 billion people still lived on less than US$1.25 (2005$) in 2010, and more than 840 million went hungry regularly in 2012.[7] Figure 1 illustrates the breadth of global food insecurity in 2012.

Much of the progress we have made since the period of catastrophic famines in Asia and Africa in the 1970s and earlier[8] is due to extraordinary increases in agricultural productivity, driven by the "Green Revolution", a concerted, multi-decade effort to modernise farming in the developing world. High-yield varieties of rice, wheat and maize were developed and widely distributed, and the use of agricultural inputs (irrigation water, fertilisers) sharply increased. Across Asia, average rice yields nearly doubled, and wheat yields nearly tripled.[9]

Yet far more growth is needed. To feed a growing and richer population by 2050, 70% more crop calories than those produced in 2006 will be needed, primarily due to changes in the developing world, including dietary change.[10] The developing world is where more than 80% of the global demand growth for field crops, fibre and beverage crops, meat, and forest products, including timber, will occur over the next 15 years.[11] Meeting this

Figure 1:
The distribution of global food insecurity in 2012



Source: Maplecroft's Food Security Risk Index 2013.[13] The Food Security Risk Index has been developed for governments, NGOs and businesses to use to identify countries that may be susceptible to famine and social unrest stemming from food shortages and price fluctuations. Maplecroft reaches its results by evaluating the availability, access to and stability of food supplies in 197 countries, as well as the nutritional and health status of populations.

new demand will create huge opportunities for businesses – from small local firms, to multinationals.

Agriculture already plays a key role in many developing countries' economies. The World Bank found that in countries in the $400-1,800 per capita GDP range (2005$), many of them in Asia, agriculture was 20% of GDP on average; in sub-Saharan Africa, it was 34%, and accounted for almost two-thirds of employment and a third of GDP growth in 1993–2005.[12] Agricultural exports can provide crucial revenue to support development in poor countries, and they remain important even for large economies, from Indonesia, to Brazil, to the US.

Agricultural growth could come at a steep price, however. The global agricultural land area (including permanent pastures) grew by about 10% – 477 million hectares (ha) – over the last 50 years,[14] expanding into savannahs, prairies and forests. Tropical forests have been particularly hard-hit, losing carbon storage equivalent to 15% of global greenhouse gas emissions from 1990 to 2010.[15] Vital ecosystem services – water and air purification, flood protection, biodiversity, etc. – have also been compromised. And in some regions, there is little land left that is suitable for agricultural expansion. Water is a particular concern; the United Nations projects that half the global population will be living in areas of high water stress by 2030.[16] Climate change will further exacerbate these challenges (see Box 1).

Agriculture, forestry and other land use are themselves major producers of GHG emissions, accounting for a quarter of total global GHGs in 2010.[17] Emissions from agriculture include methane from livestock, nitrous oxide from fertiliser use, and carbon dioxide (CO_2) from tractors and fertiliser production (see Figure 2). As noted above, agricultural expansion is also a major driver of land use change, in particular through deforestation. It is estimated that deforestation and forest degradation were responsible for 11% of total global GHG emissions net of reforestation; if reforestation and afforestation are excluded, the impact rises to nearly 20% global GHG emissions.[18] Annual net deforestation was 5.2 million ha per year over 2000-2010.[19] Between 2000 and 2010, the world lost an average of 13 million ha of forest (gross) each year to deforestation, or 5.2 million ha net of reforestation and afforestation.[20]

Agriculture, forestry and land use issues differ by geographic region. Farmers and forest-dependent people

Box 1:
The impacts of a changing climate on agriculture and food security[21]

Climate change will have significant adverse effects on crop yields, livestock health and tree growth due to higher temperatures, extended heat waves, flooding, shifting precipitation patterns, and spreading habitats for pests (such as flies and mosquitos) and diseases (such as wheat and coffee rusts) that can follow even small increases in heat and humidity. Without adaptation, yields of the main cereals in developing countries are expected to be 10% lower by 2050 than they would have been without climate change. Water stress on cropping, already substantial in some areas, is likely to increase due to growing water scarcity.

Both world population and average global cereals yields have exhibited fairly constant annual increments in absolute terms since 1980, which translates to a decreasing growth rate in percentage terms. Average annual percentage growth of world population and world cereals yields between 2010 and 2030 are projected to be about 0.7% per year for cereals yields in the absence of climate change, and population at 0.8% per year (U.N. medium variant). Even without climate change, global per capita cereal availability at projected yield growth rates will fall unless agricultural land expansion grows. With growing non-food demands for cereals and climate change, the pressures on land will be much worse.

A range of macroeconomic modelling studies suggest that the primary impact of climate change will be on the poor in tropical countries, mainly through decreased local food supply and higher food prices. The most significant impacts are projected for Africa and South Asia, where poverty is highest, agriculture accounts for a large share of employment and GDP, and adaptation investment per capita is low. But significant parts of other regions will also be affected. Generally, the lower the capacity of people to adapt to climate shocks, the larger the negative impacts. Fears of such impacts can lead to excessive risk aversion, which can keep both people and regions locked into patterns of poverty and resource degradation.

in higher-income countries, for example, typically have access to sophisticated insurance mechanisms, good infrastructure, supportive government institutions, investments, and policies informed by data. They are a small part of highly diversified economies with ample opportunities beside farming or forestry. Adapting to climate change and building resilience will not always be easy, but they have plenty of support and resources. The same is true of a growing number of rural people in the emerging economies of Eastern Europe, Asia and Latin America.

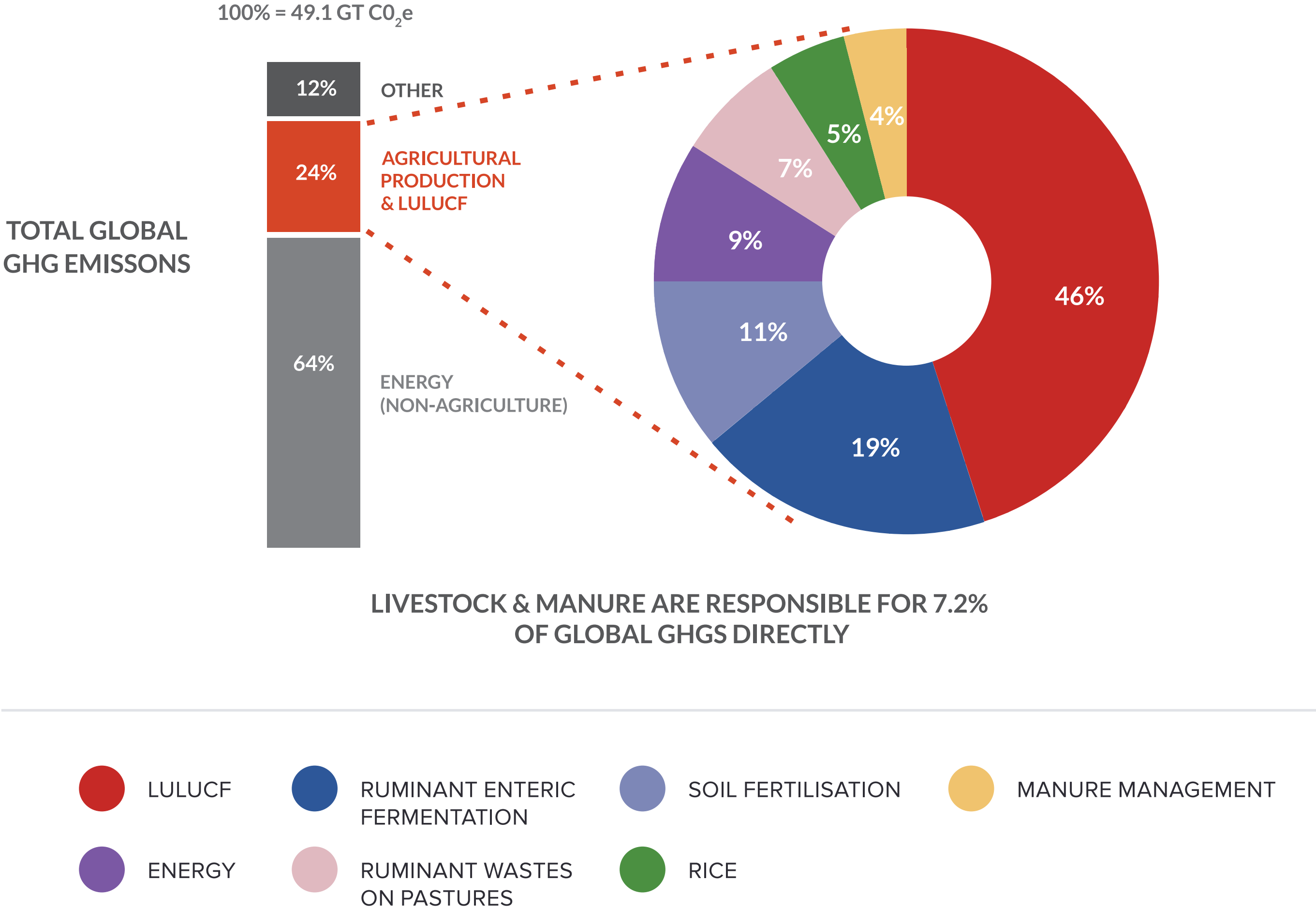
In much of Africa, large parts of South Asia, and significant pockets elsewhere, the majority of the population are smallholder farmers or forest-dependent people living at the economic margin. In sub-Saharan Africa (excepting South Africa), 20% of people live on less than US$1.25 a day and fewer than 10% have access to any form of insurance; in more than half of these countries, formal crop insurance policies are not available at all.[23] Combined with above average climate variability and below-average infrastructure, these factors can make both farmers and governments highly risk-averse, hindering rural development. Short-term food security takes priority over investments that would bring higher and more sustainable growth over the longer term. Climate change exacerbates the problem.[24]

Dealing with climate change in places with concentrations of rural poor will require programmatic approaches at scale that lower the risks for smallholder farmers and forest dwellers who pursue economic opportunities – for example, by engaging with markets instead of focusing only on subsistence food production. Some of these measures can produce "triple wins" of higher productivity, greater resilience, and increased carbon sequestration, as will be discussed later in the chapter. They require tailored institutions and safety nets, however, appropriate for low-income, low-density, and low-infrastructure conditions.

In many cases, it will be necessary to pool risks and financing with entities outside the local farm and forest systems involved, as risks are typically highly covariate over large distances and local resources are meagre. Several African countries, such as Ethiopia and Mali, have done a tremendous amount using their own national resources, but an adequate response will require substantial external finance. Across Africa, the need for agricultural adaptation finance is estimated at US$10 billion or more per year.[25] For context, bilateral aid by OECD members to Africa in 2012 for adaptation in all sectors was US$1.6 billion, and the five largest multilateral funds specialising in adaptation finance have disbursed US$40 million per year for agriculture in Africa over the last 10 years.[26] Funding needs in the Asia and Pacific region for adaptation in agriculture were estimated by the Asian Development Bank at US$3.5 billion in 2009.[27]

There are clearly compelling reasons to invest strategically in the agriculture and forestry sectors, particularly in developing countries. The sections that follow explore a number of opportunities to boost agricultural outputs. Many of these measures would also ease pressures on natural resources, reduce GHG emissions and make farming systems more resilient in a changing climate.

Figure 2:
Global AFOLU greenhouse gas emissions by sub-sector (2010)



Source: World Resources Institute analysis based on UNEP, 2012; FAO, 2012; EIA, 2012; IEA, 2012; and Houghton, 2008, with adjustments.[22]

3. Supply-side measures in agriculture

3.1 Increase crop yields

The Green Revolution has transformed agriculture around the world, but many farms in the developing world are still operating well below their economic potential. If we are to launch a second Green Revolution, however, it will need to address the extra constraints imposed by a degrading land base, water scarcity, and other drought- and heat-related issues. Often the problems will be very location-specific, such as increasing salinity from waterlogging or ocean intrusion, or particular pests or plant or animal diseases. Success can have major impacts on regional development and land use change, as shown in Box 2 for soybean development in the Brazilian Cerrado.

Globally and in specific regions, rapid advances in biological sciences are opening up great possibilities for developing new, more productive and resilient crop varieties. New technologies are making it possible to quickly screen huge volumes of material for desired traits and then to cross-breed them into seeds, revolutionising the business.[29] Breeders have developed methods for mapping and labelling portions of plant DNA associated with useful traits such as drought tolerance or pest resistance. This permits identification before a plant has grown of those seedlings that are most promising for further breeding.

Innovation through large global science partnerships can help break major barriers to further progress in increasing crop yields. An example is "C4 Rice", a multi-disciplinary, multi-centre partnership that hopes to transfer the "super charged" C4 two-cell photosynthesis of crops such as maize to rice, a single-cell C3 photosynthesis crop. If successful, the outcome will be germplasm that crop breeders in individual countries can use to develop adapted varieties that greatly boost yields and reduce water and fertiliser needs.[30]

A key collaboration focused on tropical food crops is the Consultative Group on International Agricultural Research (CGIAR), a US$1 billion-a-year global agricultural research partnership involving 15 research

Box 2:
Technological change in crops leading regional development: soybeans in the Brazilian Cerrado[28]

The Cerrado biome of central Brazil was traditionally considered unfit for large-scale agriculture due to its poor, acidic soils. The Brazilian agricultural innovation system developed soybean varieties resistant to aluminium and to the tropical climate in the 1960s and 1970s. The new varieties could achieve yields two or three times larger than those in southern Brazil.

Cultivation of soybeans in central Brazil soared after 1970, leading to a roughly 40% increase in labour and land productivity in the region from 1970 to 1985. It induced shifts in land use from pasture to crops, and linked the region to international markets at a time when global demand for soybeans was growing rapidly. The new technologies required more skilled labour, requiring intensive use of fertilisers and mechanisation. This accounted for 30% of the increase in educational attainment in the region from 1970 to 1991, through both local knowledge transfer and in-migration.

On the flip side, the first official Brazilian government survey of the state of the Cerrado using satellite imagery found that some 47% of the natural vegetation had been lost by 2008. This inevitably has serious consequences for loss of carbon and biodiversity from a places in the world that has traditionally been considered highly biodiverse and carbon-intense. There is no free lunch.

centres. CGIAR centres were instrumental in the original Green Revolution. They bring together high-level scientific capacity, significant funding, and institutional memory on developing-country agriculture and natural resource management. This enables them to provide farmers with vital science and technology support.

For example, CGIAR's International Rice Research Institute developed a variety of rice (known as "Scuba rice" or, formally, "Sub-1") that can withstand submersion in water, a common situation as floods are increasing in rice-growing regions of South and Southeast Asia. The variety was introduced in India in 2008 after 10 years of development, and 5 million farmers in the region have now adopted Sub-1 varieties.[31] Similar innovations could be invaluable in addressing other major challenges, such as saltwater intrusions in the great river deltas of Southeast Asia.[32]

Improved agricultural practices are also increasing crop yields. For example, scientists have known for many years that paddy rice yields in the tropics can be increased by alternately wetting and drying the crop in key periods during the growing season.[33] A formalisation of these soil, water and nutrient management principles was developed in Madagascar in the early 1980s, called the System of Rice Intensification (SRI). Along with alternate wetting and drying, it includes reducing seeds used per unit area, reducing synthetic fertiliser input, and applying organic manures instead. The practice seems to have worked well in Madagascar, and by 2011, it was also reportedly used in 1 million farms in Vietnam, with average yield increases of 9–15%, and reductions in inorganic fertiliser use of 25% and water of 33%.[34]

SRI is very labour-intensive, however, and requires precise knowledge and timing, as well as reliable water access on demand. It is also likely that SRI is only suited to specific locations, so the opportunities for scaling it may be limited.[35] This and Scuba rice are examples of how the next Green Revolution is likely to require more location-specific approaches than the original Green Revolution. This will place even heavier demands on national agricultural innovation systems for varietal development, capacity-building, and communication with farmers.

The potential economic benefits, however, are substantial. For example, achieving a 10% yield increase (well within historical experience) from a new technology or practice on half of all rice fields could add about US$10 billion/year to farm incomes in current prices and yields by 2030, mostly on small farms and in Asia.[36] Similarly, since rice production now accounts for an estimated 28% of all freshwater use by humans, a one-third savings on farm water use (if it were possible) on 50% of all rice area could free up the equivalent of 7% of total agricultural water use or 4–5% of global freshwater currently used for all purposes.[37]

In 2008, governments only spent US$32 billion globally on agricultural R&D; private-sector funding added another US$18 billion

With some crops, such as maize and wheat, the private sector may play an important role in innovation, as there is a market for hybrid seed, and research on these crops may also have more global (rather than region-specific) applications. However the returns to deploying new technologies on the small farms that predominate in most of Africa and Asia are low, and access to credit is often difficult. Thus there is also a need for public support for scaling-up these commercially viable technologies in some regions or with some farms. For the major cereals, research programmes supported by the CGIAR are critical, especially as traits that will enable adaptation to climate change are added to those being sought.

Public-sector support is also crucial, particularly for rice and various "orphan crops" – some starchy root crops, vegetables, legumes, and other crops of little global market value. Yet in 2008, governments only spent US$32 billion globally – including US$15.6 billion (2005 PPP) in developing and emerging economies. Private-sector funding added another US$18 billion (2005 PPP), primarily in developed countries, according to a global assessment for 2008 done in 2012.[38] Investment levels have increased since the global food crisis of 2008; although there is no comprehensive estimate, trend growth in CGIAR funding and in a few major countries, such as China, public spending in 2014 is likely to be closer to US$20 billion.[39] To put this in context, OECD governments provided US$259 billion in support to farmers in their own countries in 2012.[40] Agricultural R&D accounts for only 3% of public R&D in advanced economies, much less than allocated to sectors such as energy (4.2%), industrial production (6.3%), and defence (24.9%).[41]

In 2012, agricultural subsidies in China rose to US$73 billion, or 9% of farm output; at least US$18 billion were payments based on input use.

The returns on agricultural R&D can be substantial. An independent meta-evaluation of CGIAR-financed food crop research in developing countries from 1971 to 2007, worth US$7 billion in 1990 prices, found it had "significantly demonstrated and empirically attributed" minimum benefit-cost ratios of 2:1, and "plausible extrapolated" benefits of up to 17:1 overall.[42] There is considerable scope to increase funding for agricultural R&D to increase productivity and resilience, whether through multilateral, regional or national institutions.

Large countries can plausibly operate large fully integrated agricultural research systems, as do Brazil, China and India. Smaller countries need to find and nurture opportunities for regional and international collaboration. Innovation will remain central to solving the increasingly complex issues involved. And there is a continuing need for public support to upstream agricultural R&D of relevance to developing countries. CGIAR is a critical institution in this regard, coordinating efforts across more than three dozen donors, targeting priorities, avoiding needless duplication, and maximising synergies.[43]

3.2 Shift input subsidies to delivery of public goods

Many countries subsidise key agricultural inputs – irrigation water, fertiliser, etc. – in an effort to boost productivity, but a growing body of evidence suggests these subsidies can also lead to waste and environmental damage. Policy changes could increase the efficiency of agricultural production and reduce GHG emissions. For example, while synthetic fertilisers are critical to agricultural intensification, they are also subject to overuse, particularly when subsidised, degrading the resource base. In 2010, synthetic fertiliser use also accounted for nearly 1.3 Gt CO_2e of emissions, and this figure is growing.[44]

In China, a life-cycle assessment of fertiliser use in 2013 found that nitrogenous fertiliser-related emissions, including the energy used to produce fertilisers, accounted for 7% of total GHG emissions. For every tonne of N-fertiliser produced and used in China, 13.5 tonnes of CO_2e ends up being emitted (rather than absorbed through crop production), compared with 9.7 tonnes of CO_2e in Europe. The study found that reducing over-application of fertilisers, combined with better water management, could reduce Chinese national GHG emissions by 2% or more, without any loss of food output.[45] Yet in 2012, agricultural subsidies in China rose to US$73 billion, or 9% of agricultural output; at least US$18 billion of these are payments based on input use.[46] India provided roughly US$28 billion in input subsidies to nitrogenous fertilisers and electricity for pumping agricultural water in 2010.[47] Input subsidies are also common in industrialised countries: OECD country governments paid farmers US$32 billion based on input use in 2012.[48]

Phasing out input subsidies would incentivise better, more targeted input use, reducing associated pollution and GHG emissions and saving farmers money, since they pay for inputs even if they are subsidised. Potential GHG emission reductions of 200 million tonnes of CO_2e per year have been estimated from more efficient use of fertilisers in China alone[49] and close to 100 million tonnes of CO_2e per year from more efficient use of water in India.[50] Further benefits could be achieved if funds now spent on these subsidies were redirected to support underfunded public goods such as research and extension; however, such support has shrunk in recent years, even as subsidies for private goods such as fertiliser have expanded.[51]

The situation in sub-Saharan Africa is different, however. There, synthetic fertiliser use in 2013 was estimated at 9-10 kg/ha, compared with an average of 150 kg/ha in Asia.[52] Only about 6% of the crop area in Africa was irrigated in 2011, compared with 48% in Asia.[53] A number of countries in Africa have subsidised fertiliser in an attempt to increase usage, and this can help under some conditions, where use is limited by volatile international fertiliser prices, low commercial development, thin input markets, lack of knowledge, illiquidity, etc., and there are clear exit strategies.[54] However, the same analysis also suggests that the reasons for low usage are often more complex than temporarily high purchase prices or missing financing that might be addressed by subsidies, and that the opportunity cost of subsidies can be large, as other investments might better address the underlying problems.

3.3 Increase livestock productivity

Robust and growing demand for meat and milk, with modest price increases, create significant opportunities for producers who can access the relevant markets, including low-income rural people who raise livestock.[55] Global meat consumption grew at 2.3% per year from 2004 to 2013, and is projected by Organisation for Economic Co-operation and Development (OECD) and the UN Food and Agriculture Organization (FAO) to rise by 1.6% per year from 2014 to 2023, in a context of continued high prices resulting from rapid growth in Asian demand and negative disease, feed and other production cost impacts on the supply of US beef and pork.[56] Even with the rise of large-scale livestock operations in many developing countries, rapidly rising domestic demand can also benefit local small-scale producers, who may work together with larger formal sector producers or processors.[57]

However, the livestock sector is subject to the same "resource crunch" affecting crop production and forests. The supply of grain-fed meat and milk rose rapidly over in the two decades up to 2008, as global livestock prices were rising relative to feed costs, due primarily to rapid growth in Asian demand for meat and milk.[58] Going forward for the next decade or so, livestock prices (and cattle prices in particular) are likely to continue to rise, although there is more uncertainty around future feed costs. [59] Livestock farming is also currently responsible for more than half of direct agricultural emissions (excluding land use change), and over 7% of total global GHGs (see Figure 2). Roughly four-fifths of livestock emissions are associated with ruminants such as cattle, water buffalo, sheep and goats.[60]

There are four significant pathways for achieving economic growth from livestock production. The first three also have the benefit of mitigating GHG emissions. The fourth mitigates livestock emissions only if it is combined with one of the first three.

1. Promoting more efficient beef and dairy production to meet growing demand for beef and milk will increase incomes and use fewer resources per unit of output to produce it.

There is an important and scalable opportunity for increasing the productivity of cattle and dairy operations on large areas of pasture in Latin America, especially Brazil, where pasture productivity is estimated to be currently only at one-third of potential.[61] There are also large variations in the efficiency of pasture use across farms within ecological regions of Brazil – in fact, larger on average than between regions.[62] Treating pasture with lime and fertiliser, introducing improved grass, legumes, and leguminous shrubs, improving health care, and adding shade trees could boost productivity to at least half of potential, enabling a 50% increase in cattle exports.[63] These technologies will have considerable latitude to spread as beef continues to rise in price. However, it will also be critical to ensure that any adjacent common land is not illegally cleared for beef as a result of increased profitability.[64] This pathway would also decrease GHG emissions per unit if pursued in conjunction with the second pathway.

2. There is significant scope for reducing per unit ruminant emissions while improving efficiency of production.

There are already large differences across regions: a kilogram of beef produced in Eastern Europe generates 14 kg of CO_2e GHG emissions on average, compared with 77 kg in South Asia and 29 kg in North America.[65] Within individual regions and farming systems, it has been estimated that if the bottom 75% of producers in terms of GHGs adopted the practices of the top 25%, global GHGs could be lowered by 0.2–1 billion tonnes of CO_2e, depending on the price of carbon.[66] There are several existing options for improving the quality and digestibility of forages and fodder, reducing emissions of enteric methane and improving daily weight gains, so animals can be brought to market sooner. Technologies with the most potential are feed additives, forage management (including new introductions and rotational grazing), increased efficiency in the age structure of herds, and breeding.

Adopting these measures and learning from higher performers is in farmers' own financial interest, but effecting change will require building knowledge among farmers, helping them secure finance for upfront investment costs, and overcoming risk aversion. Forthcoming work by the FAO suggests that at least 150 million tonnes CO_2e of annual livestock emissions can be abated without compensating producers, and that a further 100 million tonnes of reductions could be induced by paying farmers US$20 per tonne of CO_2e.[67]

3. Increased efficiency in producing pork, poultry and eggs would save resources and help shift relative price incentives to favour less GHG-intensive meats.

Pork and poultry are less GHG-intensive than beef and mutton, and lower prices and higher quality could encourage a shift in consumer demand.[68] The "Livestock Revolution" of the 1980s and 1990s mostly transferred industrial-grade pig and poultry production systems and genetics from the US and Europe to developing countries through private-sector investments; the latter were made profitable by rapidly rising local demand and relatively cheap feed grains. This also helped shift meat consumption in developing countries in relative terms, to a larger share of grain-fed poultry and pork instead of grass-fed mutton and beef.[69] There is scope to further reduce supply-chain transaction costs to increase productivity and facilitate market access for pork, poultry, eggs, and other lower-GHG animal protein sources.

Vertical integration in particular allows a measure of branding; confidence in the genetics of the animals, feeds and hygienic practices (typically supplied by the contracting organisation), trust-building through contractual relations, and enforcement. For pork, poultry and eggs, the usual solution is contract farming.[70] Contract farming for poultry and eggs is now pervasive in the US, Latin America and Asia and is being spread to Africa.[71] Spreading this further could lead to better access to markets for smallholders and more efficient, lower-cost production. World meat production in 2013 is estimated at 308 million tonnes, of which 22% is bovine meat and 4% is ovine.[72] If 50% of bovine and ovine meat consumption switched to poultry on a kg by kg basis by 2030, a net emission savings of 0.9 Gt of CO^2e could be achieved.[73]

4. Producers in emerging and developing economies would benefit from being able to sell livestock products to high-value markets through one of the major multinational groups, particularly given the concentration of the global meat industry in recent years.

If these multinational enterprises emphasise reducing the GHG emissions associated with their meat sourcing, as seems likely to happen, countries that wish to benefit from this growth pathway will also have an additional incentive to pursue the first three.

A trend is emerging where developing countries can add value to livestock production by developing the sanitary and environmental credentials needed to attract both orders and investment from major international firms. Only one-tenth of meat production is traded internationally by weight, compared with more than one-third of even more perishable fish.[74] This is largely due to the sanitary (distinct from food safety) issues discussed in Box 3.

Meat trade has nonetheless grown by 40% in the last decade,[75] and pressures are building for changes in both technologies for disease control and regulations. At the same time, the global meat industry is increasingly concentrated: the top 10 meat-centred multinationals had revenues approaching US$200 billion in 2013.[76] Three of these were also members of the Consumer Goods Forum (CGF), an industry association representing roughly 400 of the world's largest retailers, manufacturers, and service providers with combined annual sales of €2.5 trillion, with a proven interest in promoting food safety and environmental sustainability in their supply chains.[77] Being a competitive supplier to this kind of firm will thus require investments in food safety and sustainability, many of which can be addressed via the other three pathways discussed above.

Box 3:
Animal health innovations will influence livestock markets in the coming years

A major market barrier, and one that hampers the scale-up of more efficient production techniques, is the fact that globalisation has led to the rapid transmission of animal disease across borders. For example, an Indian variety of foot-and-mouth disease was associated with more than £8 billion in public- and private-sector losses in the UK in 2001.[78] And of the thousands of diseases known to affect humans, about half are thought to be transmissible between livestock and humans, or "zoonotic". Well-known examples are avian influenza and SARS, but there are many others.
Disease concerns and associated animal health barriers have segmented global meat markets into "disease-free without vaccination" and "with vaccination" categories.[79] The latter countries cannot export livestock or livestock products to the former countries under current regulations, which typically limits exports from developing to developed countries and even within groups of developed and developing countries. Globalisation of markets is creating new pressures to move animals and animal products across borders, with new concerns also emerging about disease transmission. Climate change itself will also help redraw the distribution of diseases as fungi, parasites, and insect vectors expand into new habitats.

How both the technologies and sanitary regulations evolve will determine who benefits from investments in disease surveillance and other animal health measures. The latter are critical to determining who can meet the rising demand for meat products in major markets (for example, the US is precluded from shipping beef to China as of this writing, and until July, so was Brazil).[80]

This is no longer just a matter of interest to traditional meat exporters; Indian beef shipments nearly tripled between 2008 and 2013, and India is now the world's second largest beef exporter, with a one-fifth global market share by weight. India is also the fourth largest exporter of eggs. How vaccines are developed for key diseases will be critical for determining how markets develop. The fact that an animal is vaccinated under current technology significantly lowers its potential market value in international trade.

3.4 Landscape approaches for ensuring sustainable water and land for farming and people

The next Green Revolution will have to address the consequences of the widespread and increasing degradation of productive landscapes for agricultural productivity and resilience, including the loss of key ecosystem services such as clean and abundant fresh water and air. The immediate drivers of land degradation are increasing mono-cropping, pollution, nutrient mining, uncontrolled grazing and wood-cutting on common areas, inappropriate tillage, erosion from rainfall runoff, and misapplication of chemicals.[81]

Agricultural land degradation is bound up with soil structure changes that can affect water retention, increase toxicity from salinisation and pollution, and result in nutrient depletion. These are very hard to measure accurately, but estimates are that about one-quarter of agricultural land globally is now severely degraded, unable to provide the ecosystem services it once did, including growing crops at reasonable levels of productivity for the land in question.[82] In-depth case studies in China, Ethiopia, Mexico, Uganda, Rwanda, Chile, and Indonesia estimated declines in overall agricultural productivity due to degradation in 2003 to be 3–7%, an order of magnitude larger than the estimated cost of remediation.[83]

The technologies discussed earlier in this section, such as specialised crop breeding and improved management practices, can help address land degradation at the farm level, as they directly enhance productivity and resilience. This "double win" can arise from a seed that promises both higher yields and greater drought resistance. But there are also practices that add organic matter to the soil and control water runoff, jointly improving water retention and soil fertility. When these practices involve net additions to carbon sequestration in soils and above ground in trees, they produce "triple wins" that include mitigation as well as increased productivity and resilience. This is the essence of "climate-smart agriculture".[84]

Collective action across a rural landscape can also be crucial. In many cases, the negative impacts of unsustainable practices on one farm can spill over, such as when a farmer cuts down the trees at the top of a slope, affecting the flow of water to farms at the bottom. Conversely, planting trees at the top of the slope could achieve "triple wins" at the landscape level, but not fully pay off for the farmer who planted them. To encourage such actions, there is a need for solid institutions and leadership to ensure that losers are compensated, and that those who need to take action have incentives to do so.

Many "climate-smart" interventions involve trees – planting trees on farmland (for fruit, timber, shade, soil improvement, and other purposes), and/or restoring and protecting forests around agricultural areas. Trees play a crucial role in producing the ecosystem services needed for agricultural productivity and resilience, and a growing body of agroforestry research and practical experience is showing the economic benefits of greater collaboration between the agriculture and forestry sectors. Forest conservation and restoration will be discussed in greater depth in subsequent sections; here we focus on landscape approaches that use trees through agroforestry as part of an overall strategy to improve agricultural productivity and build resilience. Agricultural landscape restoration might also include mosaic restoration of forest at the top of steep slopes to hold soil, retain water, and provide windbreaks; this topic will be dealt with in more detail in the forest section.

Niger offers a prime example of a successful landscape-level intervention combining improved land and water management with agroforestry. Roughly 60% of Niger's population lives on less than US$1.25 (2005$) a day, and most farms there are very small. Since the 1990s, farmers in the Maradi and Zinder regions have interplanted nitrogen-fixing trees on cropland, or allowed roots and stumps to regenerate, increasing tree and shrub cover 10- to 20-fold. The strategy has significantly increased agricultural productivity on 5 million ha of farmland, and helped restore at least 250,000 ha of severely degraded land that had been of little use for agriculture or forestry. Sustainability also increased, as at least one-quarter of producers in the area adopted improved natural resource management techniques.[85] Biodiversity was expanded and soil fertility improved measurably in the entire area.

A growing body of research and practical experience shows the economic benefits of greater collaboration between agriculture and forestry.

Thus, some of the world's poorest people became substantially better off. Recent evaluations have found that farmers in the affected regions of Niger now regularly produce at least 100 kg/ha more grain than previously, other things equal, about 20% of 2010 grain yields in the zone,[86] and even twice as much as before with micro-dosing of fertiliser. Gross real annual income in the region has grown by US$1,000 per household for over a million households, more than doubling real farm incomes and stimulating local non-farm services.[87] Yet all of this required only modest additional government spending or business investment. The main driver was revised legislation on tree ownership; giving farmers more control of the resource provided them with incentives for better care of the trees and sustainable partial harvesting of branches, which allowed the trees to keep growing.

Korea, now a developed country, was deeply impoverished when it emerged from decades of armed struggle and natural resource degradation in the 1950s. Great attention was then put on industrial development and reforestation, originally for firewood (see Box 6 on the latter). Rural economic and social development fell behind urban areas, and in the 1970s the government launched the highly acclaimed New Village Movement *(Saemaul Undong)*, that was to serve elsewhere as a model for rural development through village empowerment in later years.[88] Participation was voluntary, and the main intervention was technical training and assistance with improving participatory village decision-making processes and cooperation in using locally sourced and government development monies, with high success in boosting village incomes (and carbon sequestration through forest restoration) over the years. This was in fact a significant contribution to the development of a productive landscape approach to dealing with degraded soils and degraded forest.[89]

The Loess Plateau projects in China are a particularly impressive example of collective action to stem and reverse land degradation. Deforestation, degradation of grasslands, overgrazing and cultivation of marginal land had led to huge soil erosion problems in China, reducing grain production by an estimated 5.7 million tonnes per year in the late 1980s, and increasing flood and landslide risks.[90] One of the most degraded areas was the Loess Plateau, a region of about 640,000 km^2 covering four of China's poorest interior provinces and parts of Inner Mongolia.[91] At the time, the Loess Plateau was a major source of air-blown dust in Beijing and silt for the Yellow River (almost 1.5 million tonnes per year).[92]

To tackle the challenge, the Chinese Ministry of Water Resources and the World Bank worked together to produce two watershed rehabilitation projects spanning 1994 to 2005, and between them mobilised US$298 million in Bank funds and US$193 million in Chinese government funding. The key elements of the projects were to halt the activities that led to degradation, in particular planting on steep slopes, tree-cutting, and free-range grazing of goats, and to actively encourage regeneration. Land tenure responsibilities and benefits were clarified. Earth-moving equipment was brought in to replace the farmers' hand-dug terraces, which crumbled each year, with more stable terraces three or four times as wide (6–12 metres). Land that was unsuitable for grain production was planted with trees or shrubs instead, or allowed to grow wild again, resulting in large-scale reforestation and grasslands regeneration. To ensure local buy-in and sustainability of the projects, farmer groups and county-level government entities were fully engaged in decision-making and implementation.

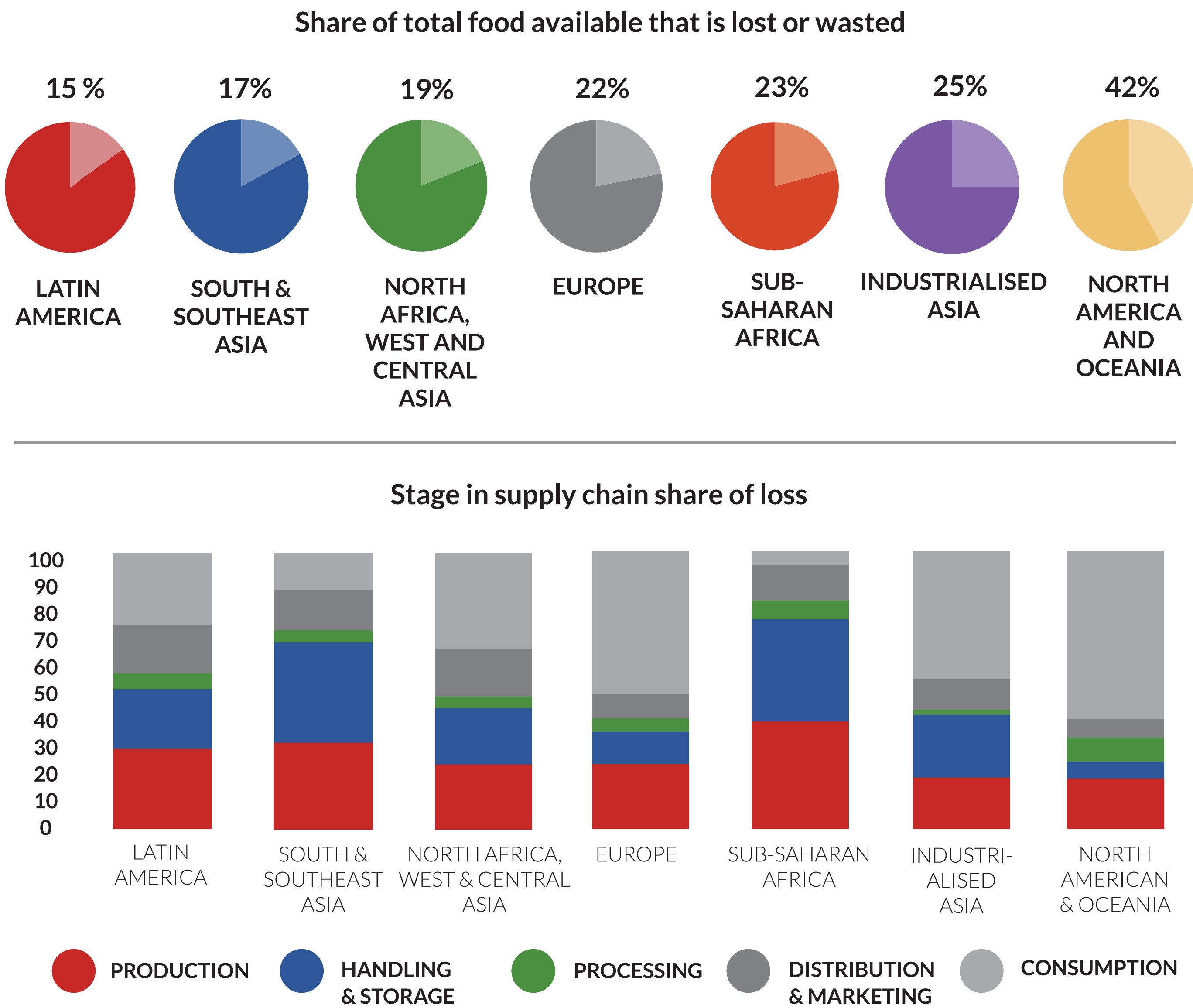
The World Bank estimates that the projects lifted more than 2.5 million people out of poverty and boosted incomes from about US$70 to about US$200 per person per year through agricultural productivity gains and diversification. Per capita grain output rose from 365 kg to 591 kg per year, and the employment rate increased, from 70% to 87%.[93] Water retention was increased, making farms more resilient to drought. Soil erosion was curbed on 920,000 ha, and soil losses were reduced by 60–100 million tonnes per year. Soil carbon storage also increased, mostly due to the restoration of forests and grassland.[94] Moreover, the approaches developed through the project have been applied more broadly across the Loess Plateau – where, as of 2008, more than half the degraded area had been restored – and in the Yangtze and Pearl River Basins.[95]

Scaling-up landscape approaches to agricultural "triple wins" has both technical and resource issues, and benefits greatly from having policy-makers being able to see impressive changes first-hand. An important achievement of the Loess Plateau watershed projects was that the Government of China decided to scale up some elements nationally. Starting in the Loess Plateau itself in 1999 as a flood control measure and then nationwide in 2002 as a restoration tool, the Chinese national US$40 billion "Grain for Green" programme pays farmers for not planting on steep slopes and encourages good practice in water and land management. Twenty million people are reportedly now affected, with the reported payments made during the early years of restoration being the cash equivalent of US$500 plus 1.5 tonnes of physical grain per ha concerned, to compensate for lost production until the tree seedlings grew large enough to provide income from fruit or branches.[96]

Technical estimates suggest that the agroforestry and water harvesting approaches that have done so well in Niger could be scaled up to cover another 300 million ha in sub-Saharan Africa. The World Resources Institute estimates that this scale-up could provide 285 million people an additional 615 kcal per day per person in the zones concerned. It is already starting to occur in the Sahel as news of Niger's success begins to spread.[97]

One challenge is the political support that ensures stakeholder participation and collaboration, and ultimately facilitates funding access. This was vital in the Loess Plateau, where winners and losers needed to be identified and benefits redistributed to overcome resistance to the initiative. Funding for integrated landscape investment will also be essential, including from the private sector, to achieve the scale needed. A recent review supported by the United Nations Environment Programme (UNEP) examined 29 integrated landscape initiatives and 250 financial institutions that support landscape approaches in agriculture.[98] The review identified finance provided by public and private financial actors, from NGOs to investment banks. Almost all cases involved public-private partnerships, and in most cases, the private sector recognised that returns would be positive, but lower than if social and environmental benefits were fully compensated in the marketplace. On the other hand, these partnerships created trust and helped firms

Figure 3:
Food loss and waste by region and stage in the supply chain (% of the lost or wasted calories)



Sources: Lipinski et al., 2013, and WRAP, 2013.[104]

resolve serious local problems such as upstream water pollution by smallholders, which otherwise could affect their operations.

The International Platform for Insetting (IPI) was pioneered by Vittel in France to try to overcome some of the financial and technical knowledge constraints for landscape investment in developing countries. It operates where there is potential to create significant shared value with smallholder farmers through higher-value crops such as coffee, cocoa, fruits, flowers and rubber, or where there is a need for ecosystem services such as clean water. Unlike companies that buy carbon offsets, these companies work directly with farmers to integrate measures to reduce GHGs or provide ecosystem services into their own operations. Projet Pur, an international collective based in France, provides implementation support to companies in the field.[99] The Nestlé example above is an IPI "insetting" activity implemented in conjunction with Projet Pur. IPI is relatively new, but it is already working with five major corporations around the world.

4. Demand-side measures

Increasing food security is not just about increasing food supply; it is also about reducing inefficient or unnecessary demand for food crops and livestock. Three key demand-side strategies can reduce economic costs while benefitting the climate: reducing food loss and waste, reducing biofuel demand for food crops, and shifting toward more healthy diets.

4.1 Reduce food loss and waste

On a caloric basis, an astounding 24% of all food intended for human consumption is lost or wasted between the farm and the fork.[100] In developed regions, more than half of this loss and waste occurs "near the fork"– at market or at the point of consumption. Examples include food that spills or spoils at market, food that expires while still unsold in the store, and cooked food that is not eaten in homes or restaurants. In developing regions, about two-thirds of this loss and waste occurs "near the farm"– during harvest, storage and processing. Examples include fruits bruised during picking, and food degraded by pests, fungus, or disease (Figure 3). This huge level of inefficiency throughout the supply chain carries significant costs. For instance, food waste at home and at restaurants costs the average household in the UK £700 per year.[101] In the US, an estimated $161.6 billion worth of food was wasted at the retail and consumer levels in 2010.[102] Globally, the FAO estimates that food worth about US$750 billion is lost or wasted annually, based on 2009 producer prices.[103]

This inefficiency has significant social and environmental impacts as well. It exacerbates food insecurity and malnutrition, particularly in countries or locales that already find it difficult to adequately feed their populations. And food that is ultimately lost or wasted consumes about a quarter of all water used by agriculture,[105] requires cropland area the size of Mexico,[106] and is responsible for 3.3 billion tonnes CO_2e of global GHG emissions.[107]

But huge inefficiencies signal huge savings opportunities. The UK has reduced its household food waste by 21% between 2007 and 2012 – even as the number of households increased by nearly 4%. This reduction saved roughly £3.3 billion (US$5.3 billion) in 2012 alone, and avoided 4.4 million tonnes CO_2e of emissions.[108]

In the developing world, the priority needs to be to reduce post-harvest losses during storage and handling. Improvements in transport infrastructure, IT and storage technology for larger-scale operations are gradually being adopted, perhaps slowed by the fact that much of the large-scale storage in developing countries since 2008 has been for public long-term security stock purposes that do not attract private capital for improvements. And dealing with grain storage losses in places such as the interior of Africa means getting to the farm level, as 70% of grain storage is done on-farm in small farms.[109]

At the global level, in order to scale up food loss and waste, governments and companies need to start by consistently measuring where and how much food is being lost or wasted within national borders and along food supply chains. What gets measured gets managed. Second, governments, intergovernmental agencies and companies need to increase investment in low-cost, low-emission technologies for storing food in low-income and middle-income countries, and in improved food inventory systems everywhere. For example, farmers in West Africa are beginning to make widespread use of airtight, reusable plastic storage bags to prevent insects from damaging cowpeas. These farmers have seen an average increase in cowpea-related income of 48%, and cowpeas that had been stored in these bags generally fetch a price 5–10% higher than those stored by other methods due to higher quality.[110] Similar approaches are being used for in-village grain storage in the Sahel.

Third, food retailers need to push their suppliers to squeeze waste out of their food supply chains and educate consumers on how to avoid wasting food at home. The UK's leading food retailers are already showing how this can be done. Some may be concerned about lost sales, but recent studies in the UK indicate that consumers who reduce their household food waste are "trading up", spending about half of their savings on higher-value – which often means higher-margin – foods in the store.[111] Finally, more food that now goes to waste can be put to good use if governments in high-income countries support "Good Samaritan" laws and/or tax breaks to facilitate or encourage donations of excess food by restaurants and supermarkets.

Globally, the FAO estimates that food worth about US$750 billion is lost or wasted annually.

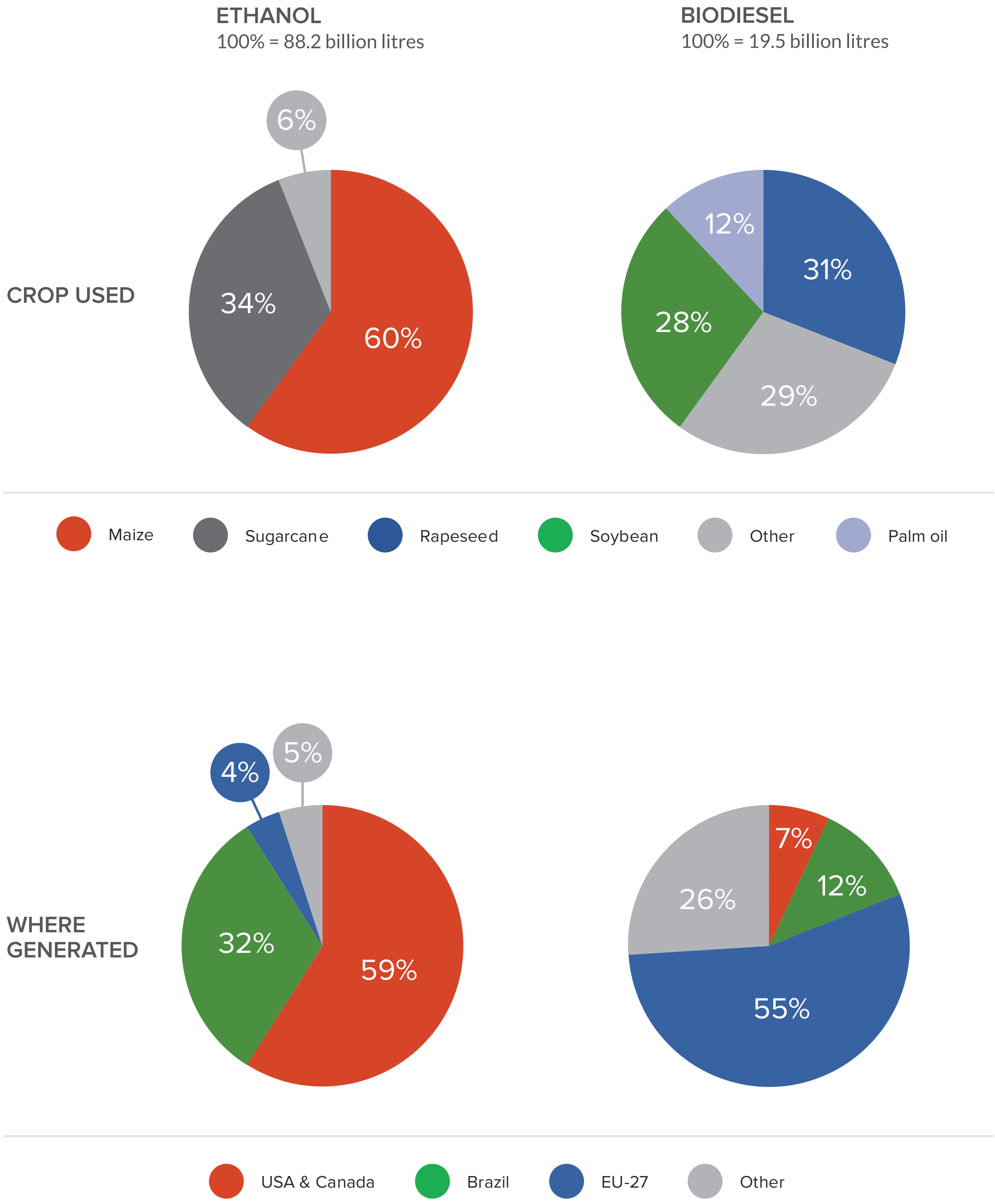
Reducing food loss and waste at scale will generate significant benefits. In developing countries, reducing losses near the farm can increase net farmer incomes, make more food available locally and even nationwide, make the country's agriculture sector more competitive, and help combat poverty – while reducing pressure on the natural resources used in farming. In developed countries, reducing food waste can improve profit margins for food retailers and restaurants, save households money, and reduce waste management costs.

4.2 Reduce biofuel demand for food crops

Another demand-side opportunity concerns biofuels. Liquid biofuels – ethanol and biodiesel – provided 2.7% of the world's transport fuel in 2010, and consumed nearly 5% of world crop production in terms of energy content.[112] Feedstocks for "first-generation" biofuels – which make up almost all the supply – are primarily major food crops, in particular maize, sugarcane, rapeseed (canola), and soybeans (Figure 4).

The widespread use of first-generation biofuels raises serious questions about the opportunity cost of using all that land, water and energy to produce fuel.[113] That

Figure 4:
Shares of feedstocks and places in global liquid biofuels production (2010)



Source: Authors' calculations based on Searchinger et al., 2013.[117]

opportunity cost varies greatly depending on the feedstock used and the policy design. For instance, sugarcane-based biofuels provide far more energy relative to inputs required than maize-based biofuels.[114] An additional challenge to first-generation biofuels is the impact on food prices. There is widespread agreement that biofuels played at least a substantial role, amongst other factors, in the large increase in global crop prices since the mid-2000s.[115] Inflexible mandates increase the price inelasticity of global demand for feedstocks in the face of supply shocks. Flexible mandates, as Brazil has used for sugarcane-based ethanol, are preferable.[116]

Policies that support inefficient biofuels are expensive. Transport biofuel subsidies in 2012 amounted to US$19 billion,[118] and consumers paid tens of billions more for higher-priced food.[119] To limit cost, any policy in support of biofuels should carefully discriminate between feedstocks and focus on sources that do not compete for land and water.[120]

Yet more than 30 nations have established, or are establishing, targets and mandates that call for a greater share of their transportation fuel to consist of biofuels.[121] Many of these targets hover around 10%. If such a target level were global by 2030, then meeting it with first-generation biofuels would require 23% of current crop production in energy terms.[122] The International Energy Agency (IEA) estimates that if the entire global biomass harvested as food, feed, forage and timber in 2000 were converted to bioenergy under current technologies, it would only meet 20% of world energy needs in 2050.[123] Clearly such targets cannot be met with first-generation technologies, and should be based instead on waste materials and third-generation biofuels.

Second-generation biofuels have been under development for many years, and rely on non-food biomass. The feedstocks include cellulose-rich plants and trees, agricultural by-products and food waste. Initially, development focused on using cellulose-rich plants and trees grown on natural resources that would also be suitable either for food production (crops) or carbon sequestration and biodiversity (forests). Attention has turned in recent years to using food waste (especially used cooking oil), paper, scrap wood, maize stover (leaves and stalks left after harvesting) and sugarcane bagasse (the fibre left after processing the stalks) as feedstock in biofuels, aiming to minimise both financial costs and drains on additional natural resource use. However, commercial viability to date has been limited in the absence of subsidies. Like other renewable energy sources, second-generation biofuels using wastes are likely to require transitional support for a number of years to scale and become competitive across a wider set of markets.

A recent report estimated that such waste-based biofuels could technically fuel up to 16% of all European road transport by 2030.[124] This is based on a finding that Europe has 220 million tonnes of truly unused wastes which, if used for biofuels, could displace 37 million tonnes of oil used for fuel, and on a net basis decrease GHGs that would have come from equivalent fossil fuel use by 60%, while adding €15 billion to the rural economy. Uncertainties remain, however, on technologies yet to be scaled up commercially and their need for subsidies.

Transport biofuel subsidies in 2012 amounted to US$19 billion, and consumers paid tens of billions more for higher-priced food.

Third-generation biofuels, based on fast-growing algae and microorganisms, are now under development and in the demonstration phase. With further technological improvement and deployment, these advanced biofuels could potentially have much less impact on land and water use and food prices. While pilots exist, more R&D and demonstration is needed for these technologies to become commercially viable. (See Chapter 7: Innovation for further discussion of advanced biofuels.)

4.3 Shift diets

A third demand-side opportunity concerns diets. Reducing overconsumption of food in general and of livestock products – red meat in particular – can benefit human health, national economies, and the climate. In high-income countries and increasingly in some urban areas elsewhere, overeating has become a chronic health issue. The World Health Organization estimates that 1.4 billion adults globally were overweight in 2008 and, of these, 500 million were obese.[125] Obese people on average incur 25% higher health care costs than a person of normal weight.[126]

Shifting to more nutritionally balanced diets – which includes reducing over-consumption of calories and of red meat – in high-income countries and cities where diet-related diseases are on the rise would achieve multiple benefits. It would improve human health and would reduce health care costs. It also would benefit the climate by reducing excess food consumption and the greenhouse gas emissions associated with this, particularly for beef, which is on average more greenhouse gas-intensive than other sources of protein.[127] Better nutritional education is important, and works.[128]

Box 4: **Produce and protect**[133]

Agricultural growth need not depend upon or trigger deforestation, if agricultural intensification is complemented by forest protection policies. The experience of Brazil provides an important example. Since 1970, crop yields in Brazil have quadrupled and livestock productivity has doubled. Brazil is presently among the three largest global producers of sugarcane, soybeans and maize, and plays a major role in the global value chain for beef. This boom in productivity is the result of many factors, including investment in the national agricultural research agency, advances in soil improvement and crop breeding, expanded agricultural credit, and rural infrastructure.

During the 1990s through 2005, however, this agricultural growth was linked with very high rates of deforestation. Productivity gains alone were not sufficiently relieving pressure to convert forests, particularly the Amazon. Complementary strategies that made clearing the forest frontier economically, legally and/or reputationally "expensive" were needed. And they came in the mid-2000s in the form of technology-enabled transparency on forest clearing activity, backed by law enforcement and agricultural finance conditioned on compliance with anti-deforestation policies.

The impact was significant. The rate of deforestation in the Brazilian Amazon fell by 76% between 2005 and 2012 – although there was an uptick in deforestation in 2013. During the same time period, production (by tonnage) of Brazil's major agricultural commodities increased as well. Soybean production grew by 29%, sugarcane by 70%, and beef by 8%.

5. Forests

Throughout history, humanity has carved agricultural land out of natural forests, and this continues today. At least in theory, the strategies discussed in the last two sections could help ensure food security for a growing population while reducing pressure to turn more forests into cropland. But the latter is not guaranteed; higher financial returns per agricultural hectare could stimulate demand to farm even more land.[129] Likewise, demand for timber, pulp and bioenergy is projected to grow over the next 15 years, putting even more pressure on lands currently supporting natural forests.[130] Projections to 2050 indicate a threefold increase in wood removals by volume compared with 2010.[131]

Yet the value generated by agriculture in former forestlands and by the extraction of forest products also brings costs. Forests are an important form of natural capital, generating economic returns (and climate benefits) for countries, companies and citizens. The ecosystem services that forests provide are especially important to the resilience of agricultural landscapes. For example, clearing of trees upstream and upslope creates significant erosion issues, leaching of nutrients, and water problems downstream and down slope. Thus, protecting remaining natural forests and restoring forest cover – globally and in individual regions – is a key part of feeding the world and building a resilient economy. It will become even more important as we intensify agriculture to boost crop yields and increase food production. In other words, we will need to "produce and protect" at the same time (see Box 4).

Like agriculture, which produces consumer goods (and a few intermediary products) for sale, forests can yield goods for markets, such as timber. As is the case with agriculture, increasing demand for forest products can increase pressures on land resources, although to an extent technological or organisational innovations can help to meet increased demand while minimising GHG emissions. However, for forests, the greatest economic value generated is not from products but from ecosystem services, most of which are not currently traded in markets. Leading forest specialists and economists estimate that conserved and sustainably managed forests generate more than US$6,000 per ha per year in aggregate value, with values varying between forests and coming mainly from non-remunerated ecosystem services.[132] The preponderant importance of non-market ecosystem services, combined with the long time period required to regenerate forests, imply the need for institutions and actions to internalise the net social value of forests for all who impact on them.

5.1 The natural capital of forests

Forests – ecosystems dominated by trees – today span about 4 billion ha and occupy about 31% of Earth's land area excluding Antarctica.[134] They are home to 350 million people around the world, while 60 million indigenous peoples almost wholly depend on them for their livelihoods.[135] And they are critical to everyone for the forest products, watershed protection, carbon storage, and other benefits they provide.

More specifically, forests are the source of several revenue-generating benefits, including:

- *Timber and pulp*. Many forests are actively managed to yield timber and pulpwood. The economic value of industrial roundwood production, wood processing, and pulp and paper production amounted to US$606 billion in 2011.[136] If sustainably managed, forests can continue to provide these products for generations to come.
- *Wood fuel and charcoal*. Forests can provide energy in the form of wood fuel and charcoal, which had a global economic value of US$33 billion in 2011.[137]
- *Non-timber forest products*. Forests provide a range of other products that can be used as food (e.g. wild

fruits and nuts), source material for medicines (e.g. the cancer drug Taxol), dietary supplements (e.g. ginseng), traditional arts and crafts, landscape products (e.g. wood chips and pine needles for mulch and bedding), and more.[138] The estimated economic value of non-timber forest products was around US$88 billion in 2011.[139]

- *Crop yields*. Some on-farm trees can increase agricultural productivity by preventing soil erosion, fixing nitrogen, enhancing soil organic matter, and increasing soil moisture levels. Niger, discussed earlier, is a case in point.[140] Likewise, forests surrounding farmland serve as habitat for bees and other crop pollinators. Forest-based pollinators in Costa Rica increase coffee yields by 20% and reduce misshapen seeds by 27% when the coffee plantation is within 1 km of a forest.[141] In addition, forests upstream of farmland can help ensure clean and regular water flows for downstream agriculture use.[142]
- *Recreation*. People enjoy forests for hiking, camping, hunting, bird-watching, and other forms of recreation. In China, forest-based recreation and tourism in forest parks generates about US$3.3 billion in entry fees alone.[143] In the United States, recreation and tourism in national forests alone contribute $2.5–3 billion per year to national GDP.[144] In some countries such as Costa Rica, forest-related ecotourism has become an important contributor to the national economy and jobs.[145]

At the same time, forests generate several benefits or services that help avoid real economic costs, including:

- Water filtration. Forests are important for maintaining clean, stable drinking water supplies for downstream cities and other users.[146] Rainwater percolates through forest soils before entering groundwater, filtering out impurities. Leaves and forest floor debris prevent sediment from entering streams and lakes. A US study found that drinking water treatment costs decrease as the amount of forest cover in the relevant watershed increases. In fact, the share of forest cover in a US watershed accounts for about 50–55% of the variation in water treatment costs.[147]
- Landslide prevention. Through their roots and forest floor debris, forests on slopes can hold soils in place and thereby prevent landslides during heavy rain events. In Switzerland, the benefits of protected forests are estimated at US$2–3.5 billion per year due to avoided costs of avalanches, landslides, rock falls and flooding.[148]
- *Flood mitigation*. Forests and forested wetlands can affect the timing and magnitude of water runoff and water flows by acting as "sponges". Water is stored in porous soils and debris, and then is slowly released over time. Through this process, forests can lower peak flows during heavy rainfall or flood events.[149] In the Upper Yangtze River Basin in western China, for instance, flood mitigation provided by forests saves an average of US$1 billion annually from avoided storm and flood damage.[150]
- *Coastal protection*. By serving as "speed bumps" for incoming storms, some coastal forests can attenuate the impact of storm surges and thereby avoid costly damage. In Vietnam, the restoration of 18,000 ha of mangrove forests resulted in annual savings of US$7.3 million in sea dyke maintenance and storm surge protection, an estimated cost-avoidance of US$405 per hectare.[151]
- *Air quality improvement*. Forests can improve local and regional air quality. Trees can trap or absorb air pollutants – such as sulphur dioxide, nitrogen dioxide, and small particulate matter – that can trigger asthma or other respiratory problems and that are emitted by power plants, manufacturing facilities, and automobiles.[152]

Box 5:
Why forest carbon really matters to climate change[156]

Forest trees and other vegetation actually remove carbon (in the form of CO_2) from the atmosphere, providing substantial climate benefits. According to one study, stopping all tropical deforestation and forest degradation could reduce carbon emissions by 5.14 gigatonnes (Gt) of CO_2e per year.[157] For comparison, emissions from fossil fuel combustion and industrial processes in 2010 have been estimated at 32 Gt CO_2 (±2.7).[158] Second, allowing all secondary forests and fallow lands from shifting cultivation systems to continue growing would sequester another 3.7 to 11 Gt CO_2e per year out of the atmosphere and store it in regrowing forests. Finally, re-establishing forests on 500 million ha of land that once supported them could theoretically provide an additional global carbon sink of about 3.7 Gt CO_2e per year if the annual accumulation of carbon in trees and soil were a modest 2 tonnes of carbon (or 7.34 t CO_2e) per ha per year.

Thus, implementing these measures could get us a long way towards stabilising the concentration of CO_2 in the atmosphere. However, these figures reflect only the estimated biophysical potential. They do not factor in the opportunity costs of land in a world demanding more food and wood, nor the relative ease or difficulty of implementation.

Nonetheless, more sustainable management of the world's forest resources is a mitigation strategy that can be implemented now, and can thus lead to near-term emission reductions as we wait for emission reduction technologies in other sectors such transportation and energy to develop and evolve.

- *Global climate change mitigation*. Forests play a significant role in the global carbon cycle and thus in regulating the world's climate (Box 5). During the process of photosynthesis, trees absorb carbon dioxide from the atmosphere. Some of this carbon gets stored in branches, trunks and roots, while some ends up in the soil as leaves and other parts of trees decay.[153] The world's forests absorbed an amount of CO_2e equal to about half of the fossil fuel emissions in 2009.[154] On average, forests can store up to 32 times more carbon in live biomass than grasslands or croplands.[155] Forests are thus at the front lines of minimising the economic risks of climate change.

Forests also play a positive role in regional and local climates. Of particular relevance to economic development is the fact that forests pump a lot of water vapour into the atmosphere and thereby can affect regional precipitation.[159] One study found that Amazonian deforestation could lead to 12% less rainfall in the rainy season and 21% less in the dry season by mid-century. Such reductions could have significant consequences for agriculture and hydroelectric power, both inside and outside the Amazon region.[160]

Finally, forests support more than half of the world's biodiversity.[161] While biodiversity has its own intrinsic value, it is also the storehouse of the genetic information for the planet which underpins many of the other benefits described above and is the basis for resilience to future climate change, diseases, and other phenomena that might affect humankind.

Estimates of the value of ecosystem services provided by forests are typically very large, and mostly need to be derived from models and related calculations, as opposed to being observed in a marketplace. A new update of a landmark 1997 study illustrates the magnitudes. It estimated that forests alone in 2011 provided ecosystem services worth US$16.2 trillion in 2011 prices.[162]

5.2 Trends in forest capital

Despite these benefits, market and governance failures mean that governments and companies are not sufficiently managing forests with long-term returns in mind. At the moment, the quantity and quality of this natural capital is declining. Between 2000 and 2010, the world lost on average 13 million ha of forest (gross) each year to deforestation – the clearing of forests and subsequent conversion of the underlying land to some other use.[163] This annual loss is equivalent in area to Greece. During the same decade, millions of additional hectares of forests were degraded – a reduction in biomass and carbon stocks due to fires and human-induced activities such as selective logging.[164]

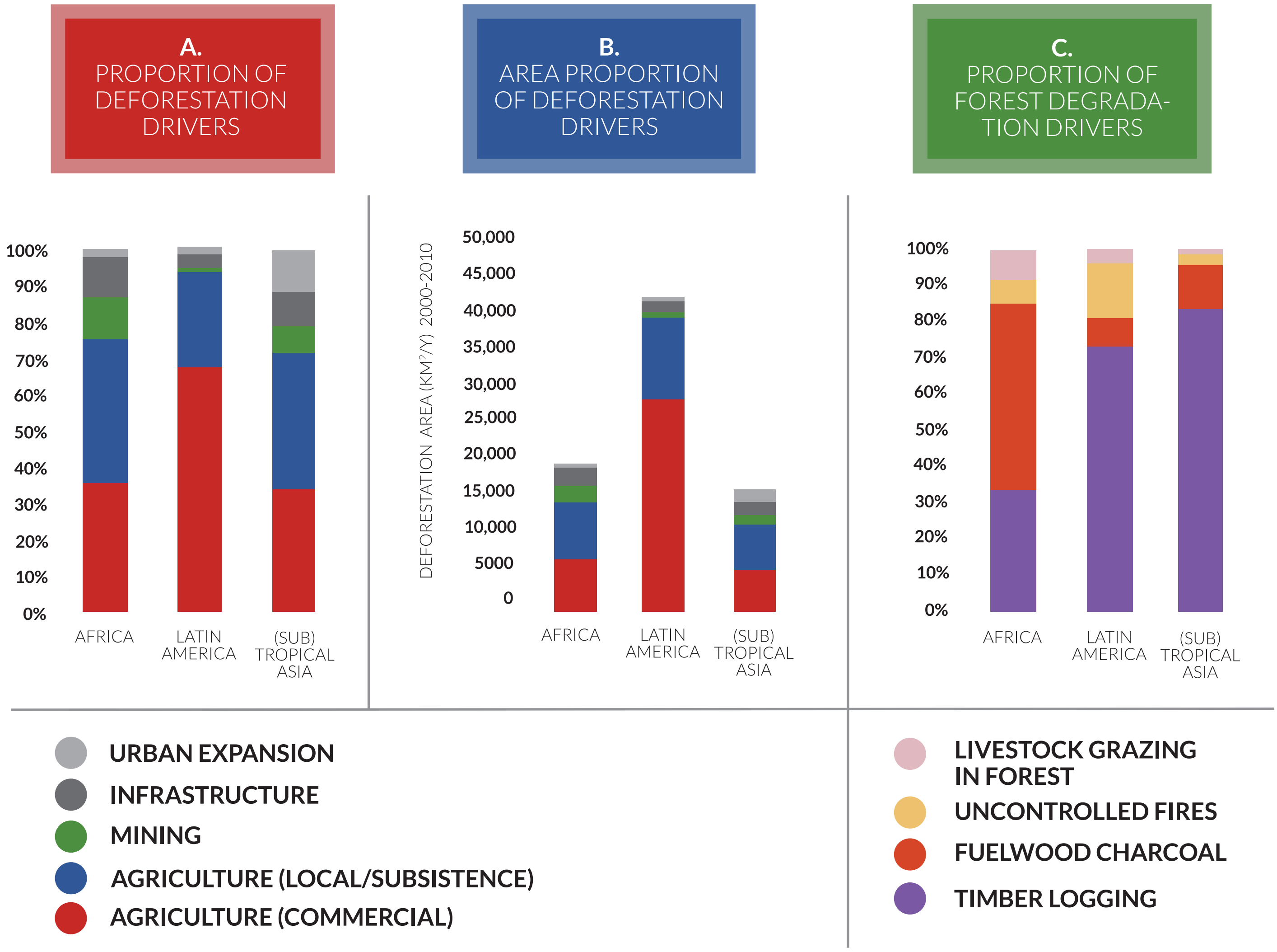
This decline poses considerable economic costs. It reduces the long-term capacity of forests to generate the revenue and avoid the costs described above. It can impact market access and performance for companies trading with concerned countries and consumers. For example, since 2008, a number of leading forest-product consuming countries have banned the import of forest products that have been harvested illegally in the country of origin. Examples include the 2008 amendments to the US Lacey Act, the EU Timber Regulation and Australia's Illegal Timber Prohibition Act.[165] These laws are beginning to pose market risks to companies that do not abide. For example, Gibson Guitar Corp. was fined $300,000 to settle a US government probe into importing illegal wood from Madagascar.[166] Retail flooring company Lumber Liquidators' share price dropped as much as 13% immediately after US officials executed search warrants at its headquarters on suspicion of trading wood illegally logged in Russia.[167]

In terms of climate, continued forest loss and degradation means forgoing some low-cost opportunities to combat climate change and adds to the economic risks of climate change.[168] In fact, as noted earlier in this chapter, land use change – mostly deforestation and forest degradation in the tropics[169] – currently accounts for close to 20% of annual global human-induced greenhouse gas emissions when reforestation and afforestation are excluded, or about 11% of global emissions when they are included.[170]

A suite of interlinked factors is driving the decline in forest capital. Proximate causes include agriculture (clearing for both crops and livestock), timber harvesting, extraction for fuelwood or charcoal, mining and road-building.[171] In the tropics, commercial and subsistence agriculture are the leading drivers of deforestation, while timber and fuelwood extraction are the leading drivers of degradation (Figure 5). Behind this is the increasing demand for forest products from a rising population with rising consumption.

The underlying causes are a number of market and governance failures. For instance, market prices, tax policies, lending conditions, and commodity procurement practices often do not reflect the wider economic value of a forest. In economic terms, these benefits are not "internalised" by the market. These shortcomings are compounded by the fact that decisions about the fate of a forest are often made in the absence of good information, in a non-transparent manner, and without adequate accountability. In some places, corruption and powerful vested interests hold sway, institutions are weak, and the rule of law is not enforced.[172] And in some places, local people who live in and near forests have weak or no property rights regarding forests or the benefits derived from forests.[173] Any form of capital – whether natural,

Figure 5:
Proximate causes of tropical deforestation and forest degradation (2000–2010)



Source : Kissinger et al., 2012.[174]

financial or human – needed to underpin strong economic growth cannot be enhanced and utilised effectively under such market and governance failures.

5.3 Emerging recognition of the value of forest capital

Three general approaches to securing and increasing the value of forests' natural capital are being implemented to various degrees around the world (Box 6):

- *Conserve*: Avoid deforestation and degradation in remaining natural forests.
- *Sustain*: Manage some forests – both natural and plantation forests – to yield timber, pulp, and other goods in a manner that is sustainable socially, environmentally and economically.
- *Restore*: Restore some of the world's degraded and lost forests into natural forests through active restoration and/or passive regeneration methods.

If effectively implemented, the combination of these approaches would enhance forest capital, helping drive economic growth while combatting climate change. And history indicates that forest recovery can go hand in hand with economic development. During the latter half of the 20th century, for instance, South Korea's forest cover nearly doubled while its economy grew more than 25-fold in real terms.[175] Between 1986 and 2005, Costa Rica's forest cover increased nearly 20% while its economy grew 2.5-fold in real terms.[176] Of course, numerous factors were involved with these economic transitions, and cause-effect relationships between factors are complex. Still, these examples show that deforestation is not an inevitable part of economic growth.

5.4 Scaling and accelerating change

Scaling and accelerating the conservation, sustainable management, and restoration of forests will require addressing the governance and market failures that

LAND USE

Figure 6:
South Korea: Same area before 1960 (top) and after 2000 (bottom)

Photo Credit: Korea Forest Service

currently undermine the natural capital of forests. There are many possible strategies for doing so. One is to incorporate the value of forests into national economic accounts, thereby appropriately recognising the contribution of forest capital to a country's growth (see Chapter 5: Economic Policy for a discussion on better accounting approaches and metrics). Another is creating, financing, and sufficiently enforcing protected areas. Yet another is building markets for wood and paper products certified as coming from sustainably managed forests and for agricultural commodities certified as sustainably grown. Although important, we do not expand upon these here. A lot of research has gone into them already.[181]

Rather, based on analysis and expert input, we highlight three of the enabling factors required for any successful management of forest resources for economic and climate benefits:

- Secure tenure;
- Improved land use planning; and
- Better law enforcement.

In addition, we highlight four seeds of transformational change – some recent developments, some needing greater attention – that could result in significant economic and climate benefits:

- Technology-assisted transparency;
- Zero-deforestation supply chain models;
- Payments for watershed services; and
- Reducing Emissions from Deforestation and Forest Degradation plus (REDD+) finance.

As is the case with cities and energy, many of these strategies harness one or more of the three key drivers of change. Improving land use planning processes is a means of raising resource productivity, in this case land use productivity. REDD+ finance and payments for watershed services are a form of increasing infrastructure investment, in this case investment in the natural infrastructure of forests. Innovations in information and communication technologies are enabling never-before-possible transparency about forests, while zero-deforestation supply chains are an innovative new business model with great potential. Underlying these drivers of change is the potential for improvements in tenure and law enforcement – institutional conditions that set the context for how forests are managed.

Secure tenure

Secure tenure – the assurance that the rights, rules and institutions governing the conditions of access and use of the land and its forest resources will be respected by government and society – is an important precondition for motivating people to invest in conservation, sustainable management, or restoration of forests. Individuals, families, or communities are unlikely to invest if they do not have clear rights to, or ownership, of that land, if that land can be taken away from them without due process and fair compensation, or if they do not have rights to any of the benefits of trees on that land.

Box 6:
National examples of conserve, sustain and restore

Conserve: In addition to Brazil (see Box 4), countries such as Mexico, Thailand and Panama have reduced their rates of deforestation during the first decade of this century. [177]

Sustain: Sweden, a leading supplier of timber, has about 80% of its forests certified as sustainably managed by either the Forest Stewardship Council or the Pan-European Forest Certification systems.[178]
Restore: Between 1953 and 2007, South Korea restored its forest cover from 35% to 64% of the country's total area (see photo).[179] South Korean forests now provide a number of important economic benefits to the country, including water benefits (US$23 billion), carbon sequestration and air quality improvement (US$19 billion), erosion control (US$12 billion), forest-based recreation (US$13 billion), and other benefits (US$27 billion). The aggregate annual value of these economic benefits (about US$94 billion) is equivalent to about 9% of the country's 2010 GDP.[180]

Secure tenure has proven particularly effective when it comes to indigenous peoples and local communities with deep historical and cultural connections to the land. Emerging evidence from countries including Brazil, Bolivia, Guatemala, Mexico and Tanzania indicates that forests with clear and enforced property rights for indigenous peoples and local communities living in them are better conserved and more sustainably managed than forests that lack such security in rights. In Bolivia, for example, the deforestation rate in forests owned by indigenous communities is one-11th of the rate in other areas – which includes areas without secure tenure, privately owned forests, and those held by the government. In Guatemala, the deforestation rate in community concessions in the Maya Biosphere Reserve is one-20th of the rate in other parts of the Reserve, where the government owns and manages the forest, but illegal settlement and logging still occur.[182]

Providing legal recognition of indigenous and local community rights to forests and supporting the integrity of these rights would be a low-cost way for a government to avoid deforestation and unnecessary conflict when it comes to natural resource management.[183] Ways that governments can support these rights include mapping community forest boundaries, helping expel illegal loggers, and not granting commercial concessions within community forests.

Secure tenure is an important strategy because it addresses some of the underlying governance failures affecting forests and because of the scale of its potential impact. More than half a billion hectares around the world are legally or officially designated as indigenous and community forests. Getting every hectare of these forests to the level of clarity and enforcement of rights as in the Maya Biosphere Reserve and in the Bolivian Amazon would help sustain the forest capital of about one-eighth of the world's forests. And potential exists in the additional forest areas held by communities under customary rights that are not yet recognised and protected by governments.[184]

Improved land use planning

Good land use planning can help optimise how land is used, encouraging agriculture in highly productive areas and prioritising forests in areas in need of watershed protection, having high forest-dependent local livelihoods, and other factors. Tools for land use planning include forest zoning (e.g. designating protected areas), tax incentives, and more.[185] Good land use planning provides clarity around procedures and land classifications, which can lower transaction costs and provide certainty to businesses and landowners. But in order to generate these impacts and avoid corruption, planning processes need to be transparent and participatory when being developed and enforced once approved.

Between 1986 and 2005, Costa Rica's forest cover increased nearly 20% while its economy grew 2.5-fold in real terms.

One example of improved land use planning is Colombia's expansion of its protected forest areas through the enlargement of the Serranía de Chiribiquete National Natural Park in 2013. This protected area, in a highly biodiverse region within the Amazon rainforest, increased from 1.3 million ha to almost 2.8 million ha, an area as large as Belgium.[186] In addition to zoning, the policies and interventions summarised by the associated "Amazon Vision" initiative (which includes the expansion of Chiribiquete) also promote improved governance of forest resources, alternative low-carbon development activities, and more secure rights and livelihoods for indigenous peoples in the regions concerned, in partnership with the private sector and civil society.[187]

Another example is Costa Rica. The country has conserved and restored forest capital since 1986 through land use planning policies and processes, in conjunction with wider market shifts in the national economy and agricultural subsidy reforms.[188] For instance, the country prohibits conversion of mature forests to other land uses. Roughly 25% of the country is zoned as protected forest, while some surrounding areas are sustainable management zones. And the nation has implemented a payment for ecosystem services (PES) system designed to encourage land managers to conserve, sustainably manage, and restore forest landscapes (Box 7).[189]

Better law enforcement

Economists have long argued that the rule of law is an important foundation for well-functioning markets and the efficient use of capital.[190] This is no less true for natural capital. Having clear and enforced laws increases the likelihood that private-sector actors will be able to compete on a level playing field, that decisions of public-sector actors are followed, and that natural resources will be more sustainably managed.[191]

Better law enforcement is paying dividends in sustaining forest capital. For instance, a major cause of the decline in deforestation in the Brazilian Amazon from 2005 to 2012 was that the government ramped up its enforcement of the Forest Code that set limits on forest clearing. The use of remote sensing to detect infractions in near-real-time, more agents in the field to follow up on those detections, and visible applications of fines and other penalties combined to boost law enforcement at the Amazon forest frontier.[192]

Law enforcement is an important strategy because it addresses some of the underlying governance failures and because of its potential scale of impact. Well-executed law enforcement can affect an entire country's forests.

Technology-assisted transparency

It has long been recognised that transparency regarding the physical state of forests and decision-making about forests is a critical foundation for any effort to conserve, sustain and/or restore the natural capital of forests. Recent advances in technology have the potential to amplify the power of transparency. The convergence of low-cost satellite imagery, cloud computing, high-speed internet connectivity, smartphones and social media is ushering in a new world of "radical transparency" where what is happening in a far-away forest can now be known close to home. Exemplifying this convergence, the Global Forest Watch system now makes it possible for anyone freely to identify changes in forest cover anywhere on the planet at relatively frequent time intervals.[193]

This level of transparency is vital for the successful implementation of other strategies described in this chapter. For instance, it enables monitoring and verification in pay-for-performance PES finance. It enables commodity buyers and suppliers to demonstrate adherence to supply chain commitments. And it provides the information needed for better land use planning and effective law enforcement.

Technology-enabled transparency is an important strategy in part because its scale of impact is substantial. All of the world's forests now have a level of transparency that they have never had before. It is also important because it helps tackle the governance failures that prevent the full realisation of forest's natural capital. Transparency can trigger accountability, deter corruption, and empower better-informed decision-making.

Zero-deforestation supply chain models

Increased transparency is leading to increased corporate supply chain pressure to curtail deforestation. Because many customers and employees of companies care about forest conservation, being associated with deforestation can negatively affect a company's brand value, sales, and employee morale. And a company's brand image can constitute a large share of its corporate value.[194] Recognising this connection, some companies have taken steps to leverage their supply chain power to disassociate their business activities from deforestation-related commodities.

> *In Bolivia, the deforestation rate in forests owned by indigenous communities is one-11th the rate in other areas.*

Starting in mid-2006, for example, members of the Brazilian Vegetable Oils Industry Association and the National Grain Exporters Association committed to a moratorium on soybeans linked to deforestation in the Amazon.[195] The moratorium has been quite effective; soy-linked Amazon deforestation has dropped to minimal levels.[196] More recently, members of the Consumer Goods Forum (CGF) such as Unilever and Nestlé have been making commitments to achieve deforestation-free commodity supply chains by 2020 and to curtail procurement from suppliers who do not comply. Such pledges offer a hopeful glimpse of where supply-chain behaviour is moving, and their impact is already trickling upstream to commodity producers and traders. For instance, as of mid-2014, more than 50% of globally traded palm oil is covered by "zero deforestation" commitments.[197]

The zero-deforestation supply chain model is an important strategy because it addresses both market and governance failures affecting forests. To the degree that buyers follow through on their commitments, the financial flows of commodity purchases will be aligned with sustaining forest capital. And the procurement practices will necessitate heightened transparency and accountability. This supply chain model is also important because it has the potential for impact at a large scale. The CGF consists of 400 of the world's leading consumer goods manufacturers and retailers from 70 countries with combined annual sales of €2.5 trillion.[198] Its members reach deep into the global supply chains that most affect the planet's forests.

Building on the CGF's work, the Tropical Forest Alliance 2020 (TFA 2020) is bringing together governments, the private sector and civil society to support zero-deforestation.[199] TFA 2020 members are committed to reducing the deforestation in tropical forests that is driven by production of four major global commodities: palm oil, soy, beef and paper and pulp). It includes many of the major global companies that trade these products, manufacture consumer goods containing them, and sell them. This includes companies such as Unilever, Coca-Cola, Pepsi Co, Nestlé, Danone, Kellogg, Colgate, Procter & Gamble, L'Oréal, Mars, Walmart, Cargill, Wilmar International, Golden Agri-Resources, Tesco, Casino and Carrefour. The participating companies have undertaken to remove products from deforested areas from their supply chains in some cases by 2015, and in others by 2020. In the case of palm oil, companies participating in the initiative have 15% of the total consumer market by volume, and well over 50% of the global trade in the commodity. TFA 2020 also works with the governments of the producer countries (such as Indonesia, Colombia, Nigeria and Ghana), and with international donors, including the United States and several European governments, to ensure that local producers can meet the new sustainability standards and to help support anti-deforestation policy. The CGF recently called for a global climate agreement that includes large-scale financial incentives for reduced emissions through REDD+.[200]

Together with the CGF, a number of banks have also engaged in a Banking Environment Initiative to support consumer companies in their efforts to reduce deforestation through a Soft Commodities Compact.[201] The Compact commits banks to work with consumer goods companies and their supply chains to develop appropriate financing solutions that support the growth of markets producing timber products, palm oil, soy and beef without contributing to deforestation. Eight banks had adopted the Compact as of mid-2014.

Payments for watershed services

Payments for ecosystem services (Box 7) monetise some of the economic benefits that forests provide beyond those traditionally traded in private markets (e.g. timber). One form of payment gaining traction relates to investing in forests as a low-cost means of securing stable, clean freshwater supplies. Leaders of New York City, for example, opted in the 1990s to conserve and restore forests in upstream watersheds that supplied the city's drinking water instead of investing in building an expensive new water filtration system. In so doing, the city saved $6.5–8.5 billion while securing long-term, clean drinking water supplies.[202] Others are following suit, including cities such as Quito, Ecuador; São Paulo, Brazil; and Bogota, Colombia. Investments in watershed protection upstream of Bogota are projected to save the city US$35 million over the course of 10 years.[203] In essence, these payments for watershed services recognise forests as a form of natural infrastructure that can be lower cost than the traditional concrete-and-steel "grey infrastructure" of water filtration, water storage, and related technologies.

Transparency can trigger accountability, deter corruption, and empower better-informed decision-making on forests.

Payments for watershed services are an important strategy because they monetise one of the traditionally non-marketed benefits that forests provide and thereby better reflect the economic value of forest capital. Their scale of impact, however, will likely not be global. Not every city relies on freshwater that is filtered and moderated by upstream forests. But such payments are an investment that some cities and businesses can make that provides both economic and climate benefits, complementing the strategies described in Chapter 2: Cities. And the next 15 years are an opportune time. Analysis for the Commission has estimated water infrastructure investment at US$23 trillion in 2010 prices, covering the period 2015–2030.[204] Investing in the natural infrastructure of upstream forests can be a viable alternative that could significantly reduce these projected costs.[205]

REDD+ finance

Curbing forest loss in low- and middle-income countries will require a concerted effort along three tracks. First, governments must implement sustainable land use reforms that are in the long-term interest of its economy and its people. Second, the private sector, especially global commodity sellers and buyers, must implement zero-deforestation policies and create demand for sustainable supply. Third, the international community must support both transitions through REDD+ payments – i.e. payments for verified reductions in forest emissions.

Some level of conserving, sustaining and restoring forests will be in the self-interest of governments, communities and companies in most cases, at least in the medium to long term. But this is unlikely to be sufficient to motivate the economically efficient level of investment in forest capital on its own, for two reasons. First, political economies in low- and middle-income countries often favour resources extraction in the short run. Second, a critical portion of the benefits provided by forests are important global public goods in nature, including carbon sequestration. International financing and support, such as through REDD+, will be required to close the near-term gap and shift the political equation.

REDD+ can help defray opportunity costs when shifting away from business-as-usual forest practices. If designed well, REDD+ programmes can help farmers and forest-dependent people adopt new practices that conserve, sustain and/or restore forests. In most cases, forest loss is driven both by market failures – primarily the lack of valuation of the global carbon externality – and governance failures.

When REDD+ was first introduced, most attention was given to the market failure. REDD+ payments were seen as a necessary financial tool to internalise the global carbon externality to match the opportunity cost of private landowners behaving rationally in functioning markets. In other words, REDD would "outcompete" profitable production that damaged forests and cause a shift away from business-as-usual forest practices.

If designed well, REDD+ programmes can help farmers and forest-dependent people adopt new practices that conserve, sustain, and/or restore forests.

If designed well, REDD+ programmes can indeed help farmers and forest-dependent people adopt new practices that conserve, sustain, and/or restore forests. In most cases, however, REDD+ payments will not need to fully compensate the private opportunity costs of individuals
or companies that wish to fell trees for timber or agricultural land.

Rather, the most important function of REDD+ payments is arguably to deal with the governance failures. REDD+ should be seen as a transitional tool to strengthen reforms intended to implement sustainable land use policies and ramp up law enforcement. It is cheaper to clamp down on illegal logging or redirect agricultural expansion to degraded lands than to pay off those causing deforestation. Seen this way, even relatively small REDD+ payments can cover the "political opportunity costs" and help strengthen the hand of reformers within public authorities to overcome vested political and economic interests to promote good governance and the rule of law. This, in turn, can increase the legal, market and reputational "cost" to those who deforest, and create a level playing field for sustainable producers. REDD+ finance can thereby help facilitate the politically and sometimes financially costly transition toward public policies and private practices that build forest capital.

Box 7:
Payments for ecosystem services[206]

More than 300 payments for ecosystem services (PES) programmes have been established worldwide to support biodiversity, watershed services, carbon sequestration and landscape beauty. PES are arrangements whereby users or beneficiaries pay a provider, such as a farmer, for the ecosystem services from which they would like to benefit. Some are driven at the international level (e.g. REDD+), others at the national level, and others at the local level (e.g. payments for watershed services). The payments can be made by governments, development banks, or by private actors (e.g. beverage companies that pay upstream landowners to manage the land in ways that maintain downstream water quality and flow).

PES are estimated to channel more than US$6.5 billion annually through national programmes in China, Costa Rica, Mexico, the UK and the US. However, in order to be effective, PES schemes require clearly defined property rights; clearly defined goals and objectives; monitoring and reporting; good enforcement; and approaches to ensure that the ecosystem benefits go above and beyond what would have occurred without PES, that they are long-lasting, and that they don't simply shift environmental damage to another location.

Most REDD+ financing thus far has focused on technical assistance, getting countries "ready" for larger-scale action. Areas supported include assessments of drivers of deforestation, economic impact studies, drafting national strategies and consulting key stakeholders, setting emission reference levels, developing forest and emissions monitoring, and designing payment and benefit distribution systems.

Such capacity-building has been important and will continue to be needed in some countries that lack the capacity to manage conditional cash transfer programs at an operational scale. Going forward, however, REDD+ financing will need to increasingly shift to pay-for-performance, wherein REDD+ payments are made to governments or other relevant stakeholders once they demonstrate verified emissions reductions through avoided deforestation.[207] Payments, in other words, are tied to and timed with delivery of quantifiable results. This shift is important for creating a financial push to rectify governance and market barriers, to implement critical policy reform, to start realising emissions reductions in the near term, and to start getting funds flowing to the people living in and around forests whose land management practices need to change.

Making financing conditional upon performance has a track record from other sectors, and is gradually being seen as good practice in development assistance. It has been used in education, health, energy, and poverty alleviation.[208] Brazil's highly acclaimed multi-billion-real "Bolsa Familia" programme, for instance, provides financial assistance to low-income families if their children are enrolled in school, maintain good attendance levels, receive vaccinations, etc.[209] The "Bolsa Floresta" program emulates Bolsa Familia for communities preserving forests.[210] Mexico, Costa Rica and other countries have implemented successful payments for ecosystem services schemes.[211] Brazil has applied the concept to both positive and negative incentives. It blocked the equivalent of US$1.4 billion in agricultural credit on the grounds of illegal forest clearing from 2008 to 2011 – a step that played a role in curtailing deforestation rates and saved an estimated 2,700 km^2 of forest.[212]

Another example with potentially significant impacts is Indonesia, which has begun implementing land use policy reforms and law enforcement efforts following a major results-based REDD+ agreement with Norway. The forest conservation measures resemble those that led to success in the Brazilian Amazon, and represent a major policy shift.[213] For recipient countries such as Indonesia, key benefits of such agreements include reinforcement of high-level political commitment, internal discipline, and the multiple benefits of increased confidence in the rule of law resulting from a transparent, results-based agreement.

The Forest Carbon Partnership Facility, managed by the World Bank, has set up a carbon fund to pilot REDD+ payments. So far, eight countries have been included in the pipeline, with six more to be considered in the coming months.[214] Donors are increasingly applying a similar approach bilaterally. Germany signed its first contract with the state of Acre in 2013 under its promising new REDD Early Movers programme, which emphasises paying for emissions reductions through existing national mechanisms for sustainable development.[215]

For REDD+ financiers, benefits of the pay-for-performance approach include greater transparency, more accountability, and increased confidence that their investments are achieving more immediate impact. For the receiving country, key benefits include reinforcement of high-level political commitment; internal discipline; increased transparency of forest loss and what drives it; mobilisation of new internal constituencies, such as indigenous peoples and local communities advocating reforms, and the multiple benefits of increased confidence in the rule of law. This approach can also offer a welcome source of revenue to local communities and local governments.

A number of international financing streams are available to support REDD+. One assessment estimated that donors from 15 countries and the European Commission had pledged about US$4 billion for 2010–2012 (about US$1.3-2 billion per year); US$2.5 billion of this has been pledged for future payments pending performance.[216] Other studies indicate total pledge figures in the US$3 billion range.[217] But to sufficiently secure the world's forest capital and meet the challenge of climate change, much more REDD+ funding will be required, for capacity-building and increasingly for payments for performance.

The Stern Review, for instance, estimated that the opportunity costs of forest conservation in eight countries responsible for 70% of land use-based emissions in the early 2000s were US$5 billion per year.[218] The Eliasch Review estimated the cost of achieving a 50% reduction in global deforestation by 2020 via carbon markets to be US$11–19 billion per year.[219] This estimate is likely to be too high, since it assumed paying the global market price and the need to cover full opportunity costs. Yet these figures serve to illustrate the discrepancy between need – however estimated – and current availability of funding.

The international community has agreed on the rules for REDD+, including results-based REDD+ payments through the Warsaw Framework.[220] The key remaining question is how to generate the demand for emission reductions to mobilise sufficient finance. Options include carbon markets, a results-based REDD+ window in the Green Climate Fund (assuming it is sufficiently capitalised),[221] or countries deciding to count emission reductions from REDD+ as part of their "nationally defined mitigation contributions" to the climate agreement (or as an additional international mitigation commitment). With a clear signal for the post-2020 period agreed as part of the Paris agreement in 2015, donors could potentially cover the scaling-up of results-based finance for the remainder of this decade. But clear policy is urgently needed for the next 15 years.

6. Recommendations

Several recommendations emerge from the Commission's work. We present them here in three categories, matching the structure of the discussion above:

Enhancing agricultural productivity and resilience in developing countries

- Governments and their development partners should commit to and start restoring 150 million ha of degraded agricultural land through scaled-up investment and adoption of proven landscape-level approaches, including improved soil and water management.

The recommended amount is equivalent to restoring 12% of degraded agricultural land by 2030.[222] This will require working with farmers, farm groups and the private sector. Where infrastructure and cross-farm externalities are big issues (e.g. China's Loess Plateau), launching 20 new intensive projects per year, spanning 1 million ha globally, for the next 15 years could be achieved with US$1 billion per year in new investment. Where farmers can directly recover benefits from their own actions (e.g. the Maradi and Zinder regions of Niger), with supportive policies and extension services, farmer-managed natural regeneration could restore another 9 million ha per year, or 135 million ha cumulatively – a significant share of which would be landscapes incorporating agroforestry.[223] By year 15, the combined 150 million ha of restored agricultural lands could provide US$30–40 billion/year in extra smallholder income, additional food for close to 200 million more people, more resilient landscapes, and an additional 2 Gt per year in sequestered CO_2e.

- **Multilateral and bilateral funders, as well as foundations, should sharply increase finance for climate change adaptation, prioritising the poorest farmers in countries that are exposed to significant climate hazards and lack credible access to infrastructure, alternative employment, and risk insurance mechanisms.**

Specific instruments to support include infrastructure, institutions and programmes that help smallholders to invest more fully in their own market-oriented agricultural activities in the presence of rising climate risks. An example is the African Risk Capacity fund (ARC) recently launched by the African Union at a US$200 million level, covering drought insurance in Kenya, Mozambique, Niger, Senegal and Mauritania – an innovative pilot in risk pooling across regions of Africa. Similar interventions may be useful in remote rural areas in other parts of the world, where adaptive capacity is also low.

- **Bilateral donors, foundations and national governments in developing countries should collectively double the financing of crop, livestock and agro-forestry R&D in developing countries from US$15 billion in 2008 to US$30 billion in 2030.**

The additional funding should target higher-yield and climate-resilient agriculture opportunities, and assess added value for carbon sequestration and biodiversity in the process, as in "climate-smart" agriculture. This includes (but is not limited to) stakeholder-coordinated funding through the Consultative Group on International Agricultural Research (CGIAR), which currently amounts to US$1 billion per year.

- **Governments should phase out direct agricultural input subsidies, and redirect the savings to support the efforts described above and to provide more direct support to low-income farmers.**

Input subsidies – including on the order of US$46 billion in input subsidies in China and India and US$32 billion in input-based payments to farmers in OECD countries, among many others – reduce efficiency where inputs are overused, and add to greenhouse gas emissions, particularly when directed to nitrogenous fertiliser and electricity subsidies for pumping irrigation water. Input subsidies may still be appropriate, however, as temporary solutions to specific market failures or to help farmers in the poorest countries deal with global shocks.

Managing demand for agricultural products

- **Nations and companies should commit to reducing the rate of post-harvest food loss and waste by 50% by 2030 relative to present levels.**

In so doing, they should commit to measure, report, and take action on food loss and waste. Savings from reducing post-harvest food losses in developing countries will be vital to their being able to meet projected future food needs. A 50% reduction in global consumer food waste alone by the developed countries and middle class in developing countries could save up to US$200 billion in food expenditures and 0.3 Gt of CO_2e per year by 2030.[224]

- **Governments that subsidise or mandate the use of biofuels should phase out these interventions to the extent that they involve food crops.**

If biofuels are considered important to meeting climate and/or energy policy goals, policies should focus on supporting the development of second- or third-generation biofuels using feedstocks that do not compete in major ways for productive land and fresh water. If the purpose of the policies is to boost rural incomes, the funds can be applied to other measures that do not put as much pressure on land and freshwater resources.

Forests

- **Governments, companies and trade associations should commit to eliminate deforestation from the production of agricultural commodities by 2020 and halt the loss of natural forests globally by 2030.**

This target should be achieved in a manner that contributes to improved livelihoods of forest-dependent people. It builds upon progress already being made by some forest-rich countries and momentum started by the Consumer Goods Forum and the Tropical Forest Alliance 2020. Achieving it will require leveraging many promising seeds of change. For instance, advances in agricultural productivity (both on the supply and demand side) will be needed to satisfy food needs on existing agricultural land. Likewise, improved land use planning, REDD+ finance, technology-enabled transparency, zero-deforestation supply chain models, secure tenure, and better law enforcement all have a role to play.

- **Developed countries should aim to provide at least US$5 billion per year in REDD+ financing (focused increasingly on payments for verified emission reductions).**

This amount is at least a doubling of current annual financing of REDD+ and is beyond whatever funding is provided by carbon markets.[225] There needs to be a shift from the current focus on capacity-building to incentive payments for verified emission reductions, recognising that some countries may still require financing for readiness and preparatory activities. Financing for REDD+ is an essential part of international cooperation and burden-sharing on climate, particularly since forests are providing a global public good by absorbing and storing carbon. It helps governments that are determined to protect national forest capital, but that also worry about the livelihoods of people living in and near forests and the interests of formal commercial enterprises.

- **Governments should commit to and start the restoration of at least 350 million ha of lost and degraded forest landscapes by 2030.**

This target complements the restoration of 150 million ha of degraded agricultural land discussed above. It is needed to catapult restoration onto the global policy agenda, raise awareness of restoration's benefits, trigger active identification of suitable areas for restoration, create enabling conditions, and mobilise the human and financial resources needed for restoration at scale. This target includes and builds upon the Bonn Challenge, an existing voluntary goal of getting 150 million ha of degraded forest landscapes into the process of restoration by 2020. Restoring 350 million ha by 2030 is consistent with Aichi Target 15, which calls for restoring 15% of degraded ecosystems,[226] and could generate net benefits on the general order of US$170 billion per year.[227]

Endnotes

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5 We assume the population growth rate to 2040 to be 0.86% per year, following the UN's medium-variant estimate to 2050. Similarly, the urban population is projected to grow about 1.6% per year over this period, and this can be used as a proxy for growth of the middle class to a lower bound of 3 billion. An upper bound is derived from an OECD estimate of 4.9 billion middle class people in 2030. The central tendency of 4 billion seems reasonable, recognising the uncertainties in predicting global household income distribution patterns 15 years in advance.
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66 Gerber et al., 2013. Tackling Climate Change through Livestock. The low end assumes that there is little or no market value to reducing emissions, but there are efficiency savings from the technologies in question.

67 Personal communication from Dr. Pierre Gerber.

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See: Wohlgenant, M.K., 1985. Estimating Cross Elasticities of Demand for Beef. Western Journal of Agricultural Economics, 10(2): 322–329. Available at: http://www.jstor.org/stable/40987719. If anything, the measured effects in this classic paper have likely been amplified by the increased consumer acceptance of chicken and leaner pork for health reasons in recent years.

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Available at: http://www.globalmeatnews.com/Industry-Markets/BSE-ban-on-Brazilian-beef-lifted-by-china-Australian-concerns.

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Grain yields in the Maradi and Zinder regions in 2010 can be found at:

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Available at: http://www.wri.org/resources/maps/global-map-forest-landscape-restoration-opportunities. They estimate that there are 2.314 billion ha of lost and degraded forest landscapes around the world (relative to land that could support forests in the absence of human interference; precise data and interpretation confirmed by map author Lars Laestadius, 14 August 2014).

The Aichi Target #15 states: "By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification." 15% of 2.314 billion ha is 347 million ha. See http://www.cbd.int/sp/targets/. [Accessed 22 July 2014.]

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Chapter 4

ENERGY

Main points

- Fast-rising energy demand will require some US$45 trillion in new infrastructure investment by 2030. This is an opportunity to build more efficient, less polluting, more flexible energy systems that are also less vulnerable to rising and volatile fossil fuel prices.
- The choices made in next 15 years are also critical for the climate, as energy production and use already account for two-thirds of global GHG emissions. A large-scale shift to low-carbon energy supplies is crucial for avoiding levels of dangerous climate change.
- Coal now accounts for over 40% of global electricity production, but there are compelling reasons to reduce that share. Coal accounts for 73% of power sector GHG emissions, and its use in power generation and industry can also result in severe air pollution. Moreover, fast-growing economies such as China and India are having to import coal as domestic supplies cannot keep up with growing demand. These factors make it sensible to shift the "burden of proof", so that coal is no longer the default choice for new power plants, but the last resort if no better options can be found.
- Key renewable energy sources have fast gone from prohibitively expensive to realistic options for future energy supply, and for the generation of electricity in particular. The cost of wind power is one-third or one-quarter what it was 25 years ago; solar power costs have fallen by half just since 2010. Thus, the cost gap between renewables and fossil fuels is narrowing, and in some markets, renewables are already cost-competitive – even more so if their multiple benefits are considered.
- Energy efficiency offers large potential to meet future energy needs without resorting to more marginal and harmful sources of energy. In developed countries, it is already the biggest source of "new" energy supply, but large untapped potential remains. Developing countries have even more to gain by managing demand. India's energy requirements in 2030, for example, could be as much as 40% greater in a scenario of low energy efficiency than in one with high energy efficiency.
- Natural gas has become a key energy source in many markets, displacing coal and reducing GHG and air pollution impacts. For gas to be a potential "bridge" to lower-carbon energy systems, there must be strong policies to limit fugitive methane emissions, put a price on carbon emissions, and continue to drive a shift towards lower-carbon technologies.

1. Introduction

Energy is vital to modern economies: for industry, transport, infrastructure, information technology, building heat and cooling, agriculture, household uses and more. Any nation that wants to grow its economy and improve living standards must secure a robust energy supply. As incomes rise, so does energy use: high-income countries consume more than 14 times as much energy per capita as Least Developed Countries, and seven times as much as lower-middle-income countries.[1] As more countries rise out of poverty and develop their economies, energy demand will rise with them, putting pressure on local supplies as well as global energy systems.

Energy is costlier, prices are more volatile, and for several fast-growing countries, supplies are now also less secure. There is a need to reconsider which energy options are lowest-cost and "safe bets"; the advantages of coal in particular have been eroded as large, fast-growing economies find their domestic supplies cannot keep up with demand, some regions have seen low-cost gas emerge as an alternative, and many grapple with air pollution and other social costs. Reducing coal use is also crucial to reducing climate risk.

Responding to these new challenges will require a multi-faceted approach. One key task is to increase resource efficiency and productivity – to make the most of our energy supplies. Some countries have already made significant gains in this regard, but there is much untapped potential. Innovation also is expanding our energy options: from the revolution in unconventional gas and oil, to the rapid growth of renewable energy resources, most notably wind and solar power. In many countries, falling costs are already enabling renewables to become a mainstay of new energy supply. Maintaining the speed of innovation will further expand these opportunities.

A massive wave of energy infrastructure investment is coming: to keep up with development needs, spending may need to increase by 40–50%.

Policy-makers face crucial choices in the next few years. A massive wave of energy infrastructure investment is coming: to keep up with development needs, around US$45 trillion may need to be invested in the next 15 years.[2] This gives countries a chance to build robust, flexible energy systems that will serve them well for decades to come, but it also represents a critical window to avoid locking-in technologies that expose them to future market volatility, air pollution, and other environmental and social stresses. Investing in energy efficiency and low-carbon technologies may increase upfront costs, but it will also bring multiple benefits.

This chapter explores key issues for energy systems in countries at different stages of development. We start by noting major energy trends around the world, then take stock of "seeds of change" that may offer opportunities for countries to strengthen and diversify their energy systems and improve productivity. We also assess some of the barriers to change, which can be considerable, and discuss ways to overcome them, which may require new decision-making frameworks, business models and financing arrangements. Like major changes in the past, transforming energy systems will require deliberate effort. We end the chapter by identifying concrete steps that can be taken in the next 5–10 years.

Energy is a broad topic, and our analysis is not comprehensive. While we discuss other sectors, we give priority to electricity production, which is crucial to economic growth, is increasing rapidly, and offers significant near-term opportunities for improvement. Most models for mitigating climate change also agree that the electricity production has the largest potential for rapid reductions in energy-related CO_2 emissions, while decarbonising other sectors will be slower.[3]

Key energy-related issues are also covered in other chapters. Chapter 2: Cities examines how more compact urban forms can reduce energy use, especially for transport; Chapter 3: Land Use and Chapter 7: Innovation both discuss biofuels, and Innovation examines how policy can support and accelerate technological advances that could fundamentally change energy consumption and supply patterns. Chapter 5: Economics of Change addresses the role of carbon pricing and the need to reform fossil fuel subsidies, and Chapter 6: Finance looks at stranded-asset risks and at ways to reduce financing costs for low-carbon energy.

2. A changing energy landscape

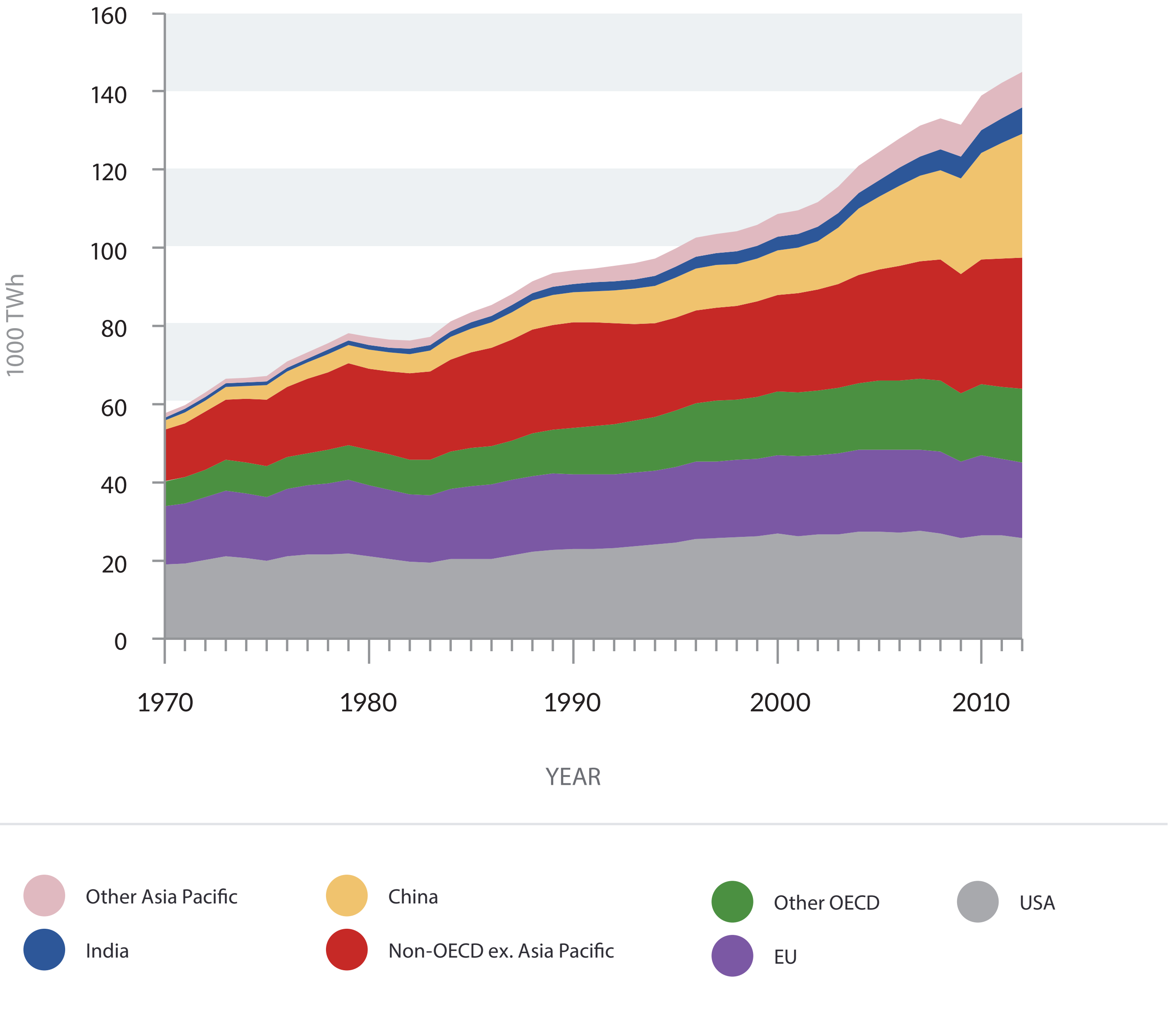
We are in a period of unprecedented expansion of energy demand. Energy use has grown by more than 50% since 1990,[4] fuelling a global economy that has more than doubled in size.[5] As much as a quarter of current world energy demand was created in just the last decade.

In the 1980s and 1990s, energy demand growth was roughly evenly split between Organisation for Economic Cooperation and Development (OECD) and non-OECD countries, but since 2000, against most predictions, all of the net growth has occurred in non-OECD countries, with China alone accounting for more than half of the increase.[6]

Past projections often failed to anticipate these dramatic shifts, which nonetheless have affected the energy prospects of nearly all countries. The future is now even more uncertain, as projections show anything from a 20% to 35% expansion of global energy demand over the

Figure 1

Global primary energy consumption by region 1970–2012



Note: A terawatt-hour (TWh) is a trillion watt-hours, or the annual power consumption of about 100,000 average US homes. Primary energy refers to energy inputs not yet subject to conversion or waste.

Source: BP Statistical Review of World Energy 2013.[8]

next 15 years.[7] The exact nature of the change that this will bring cannot be known with any certainty. Given the economic importance of energy, however, countries need to ensure that their energy systems are robust and able to adapt to a range of possible future scenarios.

Fossil fuels now provide 87% of our primary energy supply: oil (33%) is used mostly in transport and petrochemicals production, while coal (30%) is a mainstay of electricity production and some industries; natural gas (24%) is gaining ground across sectors, from electricity and heat production to manufacturing.[9] These global shares have changed only slowly, but conceal disparate trends. Coal use has grown by nearly 70% since 1990, but almost entirely in a handful of countries (China alone accounted for 90% of the increase). In the rest of the world, coal provides just 16% of energy, and the large majority of new supply outside transportation has involved natural gas.

Electricity demand grows fast as countries develop, with increased reliance on electricity to meet a range of needs. Electricity's share of energy use has nearly doubled in 40 years and looks set to increase further.[10] Close to 40% of all energy is now used to produce electricity; 63% of coal is consumed for this purpose, and 41% of power comes from coal-fired plants.[11] Twenty countries rely on coal for more than half their electricity production, but 30 others get more than half their power from natural gas, 34 from hydropower, and a handful from nuclear power.[12] In recent years, renewable energy sources, particularly solar and wind power, have been growing rapidly, and non-hydropower renewables supplied 4.7% of electricity in 2012, more than double their share in 2006.[13]

Global energy markets have also undergone major changes that affect all countries. Prices are much higher overall: oil and natural gas prices are three to four times higher in real terms, and coal prices are twice as high, as 25 years ago. Even in the shale-gas-rich United States, gas prices are almost twice what they were in 1990.[14] Although global gross national product (GDP) is twice as high, the share we spend on energy has risen from 8% in 1990 to 10% today, and while total energy use has increased by one-third, more than 80% of the increase in expenditure since 2000 has been due to increasing prices.[15] Fossil fuel prices also are more volatile, with larger, more frequent and more unpredictable fluctuations, which can depress investment and cause other economic damage. It is unclear whether this pattern will continue: as with energy demand, past forecasts of energy prices have proven to be poor guides to the future. Given the recent record, however, it seems unwise for any country to bank on a future of low, stable fossil fuel prices.

Adding to the uncertainty is a steep rise in energy trade. Not only is 62% of oil internationally traded,[16] but increasingly, so are coal and natural gas, which have historically been produced and consumed domestically. Combined with high prices, this puts pressures on the balance of payments in several countries. Given that oil and gas reserves, especially, are highly concentrated – in each case, just five countries hold more than 60% of proven reserves[17] – importers worry about energy security. Up to now, coal's local availability has been a big part of its appeal, but increasingly, major coal users (India in particular, and to some degree also China) are having to rely on imports to cover much of their demand growth.

Finally, the environmental impacts of fossil fuel use have become hard to ignore. Many countries are struggling with severe air pollution, especially in urban and industrial areas; China is the most visible example, with public outrage about air quality leading the government to launch a "war on pollution" in early 2014.[18] Concerns about climate change have also escalated. Energy use already accounts for two-thirds of global greenhouse gas (GHG) emissions,[19] and those emissions continue to rise. The future of the climate therefore depends, to a great extent, on whether we can reverse this trend and meet the world's energy needs with low-carbon systems (see Box 1).

The evidence suggests that, without a deliberate change of direction, fossil fuel use will continue to grow, and so will its economic, security and environmental impacts. There is no imminent "peak" that will slow this trend; the world is not "running out" of fossil fuels. The cost of developing and extracting new resources is increasing: global investment in fossil fuel supply chains rose from US$400 billion in 2000 to US$950 billion in 2013, and 80% of upstream oil and gas spending through the 2030s is expected to be used to compensate for declining production at existing fields.[26] Conditions are also shifting in other, fundamental ways:

China's energy use has nearly tripled since 2000, mostly fuelled by coal.[27] This phenomenal increase has been accompanied by strong economic growth, but also resulted in a highly energy-intensive economy with significant distortions, high levels of air pollution, and an emerging need to import energy. Changing direction will be a Herculean task, closely connected with efforts

Box 1

Carbon budgets and emissions from energy use

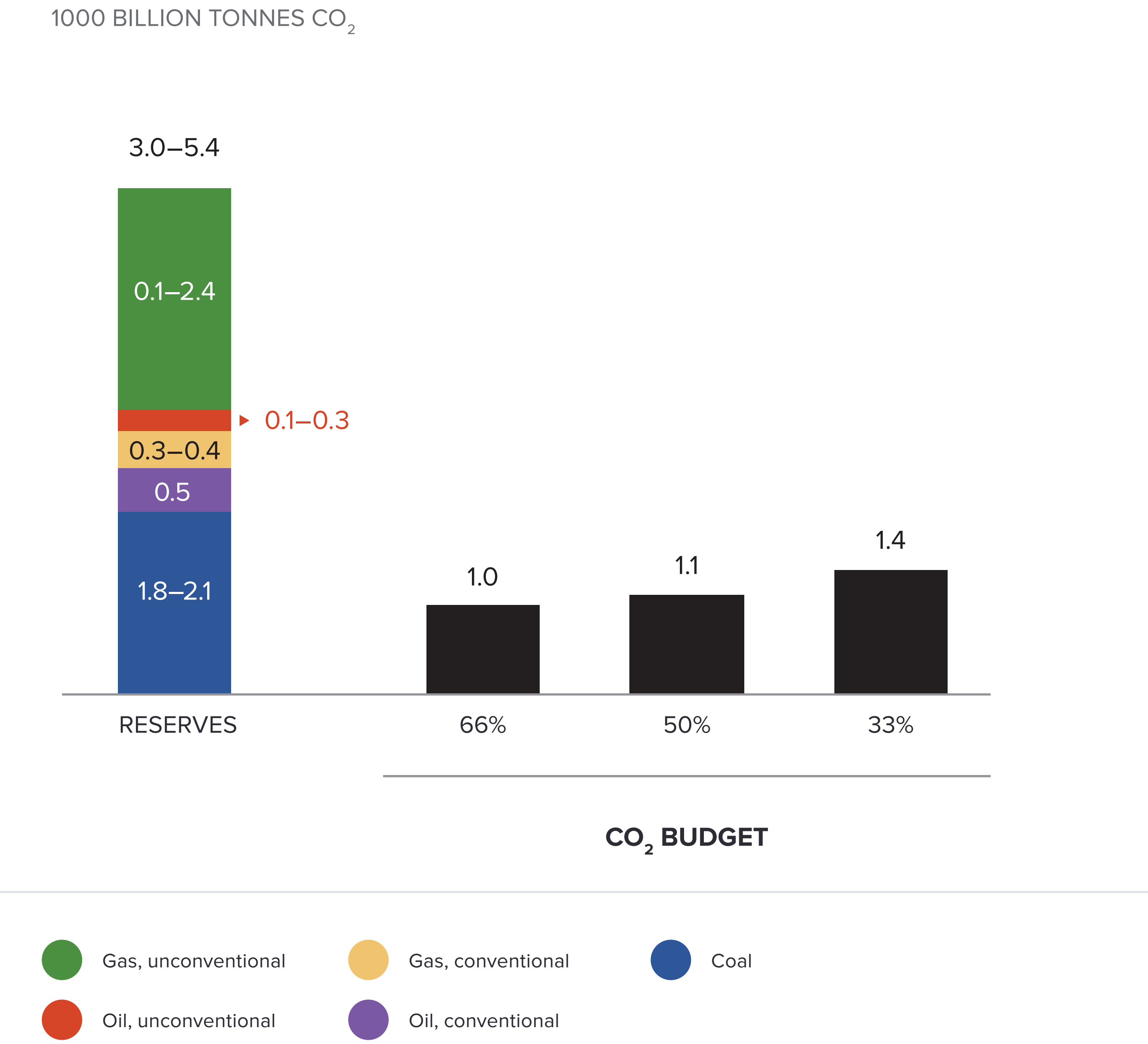
Climate impacts depend on the total emissions accumulating in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) has estimated that for a 50% chance of limiting global warming to 2°C, cumulative GHG emissions up to 2100 cannot exceed 4.4 trillion tonnes of CO_2 equivalents (CO_2e).[20] After discounting past emissions, and accounting for non-CO_2 greenhouse gases, just over 1.1 trillion tonnes remain for CO_2 emissions from human activities, including energy use. This thus sets a "carbon budget" for GHG emissions.

Yet proven fossil fuel reserves (i.e. resources that can be economically recovered) would release far greater volumes if burnt. Coal reserves alone would exceed it by a factor of almost two. Though estimates are uncertain, fully exploiting coal, oil and gas reserves could mean an overshoot up to a factor of five (see figure). There are also vast resources beyond these reserves (estimated up to 50 times the CO_2 budget), though it is unknown what share of these might become economically viable to extract in the future.

Containing climate change to safe levels will require reducing GHG emissions by up to 90% between 2040 and 2070, the IPCC has said.[21] Yet energy emissions are rising rapidly. Growth in energy supply sector GHGs accelerated from 1.7% per year in 1991-2000 to 3.1% per year in 2001–2010.[22] Energy CO_2 emissions are more than 40% higher now than when the Kyoto Protocol was signed in 1997.[23] Several studies have found, however, that it would be technically feasible to meet energy needs while sharply curbing emissions, and that the cost, while substantial, is manageable on a global scale.[24]

Figure 2

Implied CO_2 emissions of fossil fuel reserves vs. remaining CO_2 budgets for a 2˚C pathway



Note: The figure shows the implied CO_2 emissions of conventional and likely unconventional fossil fuel reserves vs. the remaining CO_2 budget for given probabilities of staying below 2˚C above pre-industrial levels. Budgets are adjusted for likely non-CO_2 emissions. Resource estimates are much greater, particularly for coal (30,000-40,000 Gt for coal, 2,000-5,000 Gt for gas, and 1,000-1.500 Gt for oil). Estimates for unconventional gas are highly uncertain, with little agreement on what resources are appropriately classified as reserves.

Sources: For carbon budgets: IPCC, 2013; fossil fuel reserves shown are ranges for mid-point estimates of a range of different sources, including BGR, 2013; BP, 2014; IEA, 2013; World Energy Council, 2013; and GEA, 2012.[25]

to achieve a more service-based economy. Chinese policy is already responding, with measures including industry restructuring, new infrastructure for urban heating, major international gas deals, and promoting alternatives to coal in power generation. Some analyses suggest coal use could peak or level off in the early 2020s as a result.[28]

India's energy use has nearly doubled since 2000 (though just to one-fifth of China's use).[29] Yet much of the population still lacks access to modern energy, and there are long-standing difficulties investing domestically in new supplies, not least because prices are kept too low to make new investments viable. In recent years, the country has sourced nearly half its new coal use from abroad, and the electricity system, once almost entirely fuelled by domestic resources, increasingly depends on imports to meet new demand.[30] This new dependence raises both geopolitical and balance-of-payments concerns. India also cannot ignore where future energy growth will take it in terms of air pollution, as many Indian cities already have worse air quality than Chinese cities, even prior to a heavy industrial expansion.[31]

The United States, always rich in energy resources, has made a concerted effort to increase domestic energy production. It may become the world's top oil producer by 2015, and be close to energy self-sufficiency in the next two decades.[32] A surge in low-cost gas supply has reduced energy prices and reduced demand for coal, which until recently provided half of US electricity.[33] Stricter environmental standards are also making coal less viable; new wind power and even solar photovoltaic (PV) electricity can be less costly than new coal-fired plants. Overall, coal-fired power has accounted for just 5% of new generation since 2000, closures of plants have accelerated, and proposed regulations would require that any new coal be fitted by carbon capture and storage (CCS). Energy efficiency has also improved, and in some states may in fact stall demand growth in the next decade.[34]

Wind power has grown rapidly in Mexico, which has some of the lowest costs in the world, about $60 per MWh.

The European Union (EU) is recasting its energy systems, with strong policies in place to cut CO_2 emissions, increase renewable energy, and improve energy efficiency. Climate objectives are a major driving force behind this transformation, but energy security is also a strong motivation. The EU has been pioneering new approaches to energy supply, and in particular has driven the adoption of renewable energy for electricity generation. There have been remarkable successes, not least in helping spur innovation that has reduced the cost of low-carbon energy – but those investments have also been politically controversial. Meanwhile, the flagship climate policy of carbon pricing through emissions trading has failed to generate a sustained price signal to give investors certainty. Policy now needs realignment, including to ensure the reliability of the electricity system.

The Middle East is facing constraints from inefficient energy use. Primary energy use is growing at more than twice the global rate,[35] driven by rapidly growing populations and policies that keep energy prices very low. Yet it is far from clear that cheap energy is helping the economy. While around the world, energy productivity (the amount of economic value created per unit energy used) is rising, here it is falling. The cost in terms of forgone export revenues is high and rising, as domestic demand eats into the surplus available for export. National oil companies in some countries are constrained in their ability to finance investment in new fields.

Latin America and the Caribbean have seen energy demand increase by one-third in just a decade amid growing industrialisation and regional commerce.[36] It has a high share of renewable energy (25%), with extensive use of hydropower in several countries and potential for further growth, although social and environmental impacts are a concern. Natural gas use has risen twice as fast as energy demand overall, but with only 4% of global reserves, the region imports most of its supply.[37] Wind power has grown rapidly in Mexico, which has some of the lowest costs in the world, about US$60 per megawatt-hour (MWh), as well as in Brazil, Uruguay and some Central American countries. The region also has great solar potential and is increasingly exploiting it.

Most countries in **sub-Saharan Africa and South Asia** are still struggling to scale-up their energy systems to fuel economic growth and provide modern energy services to all. Power supplies are often unreliable, and large shares of the poor urban and rural populations lack basic energy access.[38] Average per-capita energy consumption in sub-Saharan Africa is one-seventh of that in high-income OECD countries, and in South Asia, it is one-ninth.[39] Aiming to close these gaps, countries in both regions – individually and through regional networks – are making massive new investments in energy infrastructure – including grid expansion, large-scale coal power and hydropower, and increasingly, wind and solar.[40]

These examples make it clear that there is no single way forward, but "business as usual" is unlikely to persist. In the following sections, we delve deeper into the new strategies that countries are pursuing, as well as into the factors that may inhibit change.

3. Seeds of change

Global energy systems are evolving on many levels. Here we focus on a few areas with significant potential for achieving climate and economic goals together, and where decisions in the next five to ten years are crucial:

- A changing outlook for coal power;
- Air pollution as a driver of energy system transformation;
- The emergence of renewable technologies as large-scale, cost-competitive energy sources;
- A growing focus on off-grid approaches to expanding energy access;

- A surge in natural gas use, often replacing coal, and
- Advances in energy efficiency, with significant untapped potential. [41]

We call these "seeds of change", and if they can be successfully grown to large-scale change, they could provide a foundation for a more productive, low-carbon future energy system.

3.1 A changing outlook for coal power

The rise of new opportunities is occurring at a time of increased challenges to established solutions to expand energy supplies, as noted above. Coal in particular has been abundant and affordable for many generations, and in several fast-growing economies, it remains the default option for rapid expansion of the electricity supply, as well as the key source of energy for heavy industry. Coal power has proven scalable, reliable and controllable, and institutions, grid arrangements, and financing systems are set up to support it. Moreover, coal-rich countries have been able to rely on locally available (and thus secure) supplies at times at costs as low as US$20/tonne (t) and, until the last decade, often with a backstop price of no more than US$50/t. Even at higher prices than these, coal can be the cheapest option (in pure financial terms) for new electricity production.

But as noted above, conditions are changing, driven by fast-rising demand and a sharp increase in coal trade. . Since 2007 China has gone from a net coal exporter to the world's top coal importer, buying almost one-quarter of the global trade.[42] Work for the Global Commission indicates that the domestic supply-demand outlook is highly uncertain. Continuation of past trends would lead to a drastically changed energy security situation: in a scenario of continued energy-intensive growth and reliance on coal, China might need to import more than half of its additional coal requirements over the next 10–15 years.[43] Such a scenario may be unlikely, as China has other strong reasons to curb coal use, not least concern with air pollution and ambition to diversify the economy. Energy security adds to the reasons to seek different, less coal-intensive patterns of both energy supply and economic activity.

India has followed a similar trajectory: from near self-sufficiency a decade ago it is now meeting half of growth in coal requirements through imports. It is now the third-largest importer, after China and Japan.[44] Unless it can manage demand growth through improved efficiency and find new sources of electric power, some scenarios suggest it may have to import even larger shares of its coal.[45]

The rise in coal trade has also brought higher import prices, with scenarios in the range of US$85–140/t for the next two decades. Prices are now lower than five years ago, but twice the levels that prevailed historically.[47]

The market has also become more volatile, and future prospects depend greatly on China's and India's import needs. Even at higher prices, vv, if other benefits of moving to other sources of electricity are not accounted for, especially in parts of Asia. Yet the cost gap to some alternatives is now smaller than ever – not least as renewable energy costs are in rapid decline. In many parts of the world, options such as hydropower, natural gas and wind are at or near levels where other concerns – air pollution, energy security, and climate – can tip the balance.

Coal mining and coal-fired power generation also can put pressure on water resources. Thermal power plants consume up to several thousand litres of water per MWh produced, but coal plants typically use more than gas plants, in some cases more than 10 times as much. Mining the coal can add hundreds of litres per MWh – on par with unconventional gas production, and an order of magnitude more than conventional natural gas extraction. Growing coal use can thus cause water stresses and compete with other water uses in regions with water shortages, which include many of today's rapidly growing economies.[48] This has already been identified as a challenge to electricity supply growth in South Africa, and water shortages affect 70% of mines in China.[49]

Coal-fired electricity will still be the cheapest near-term option in some countries – yet the cost gap to alternatives is smaller than ever.

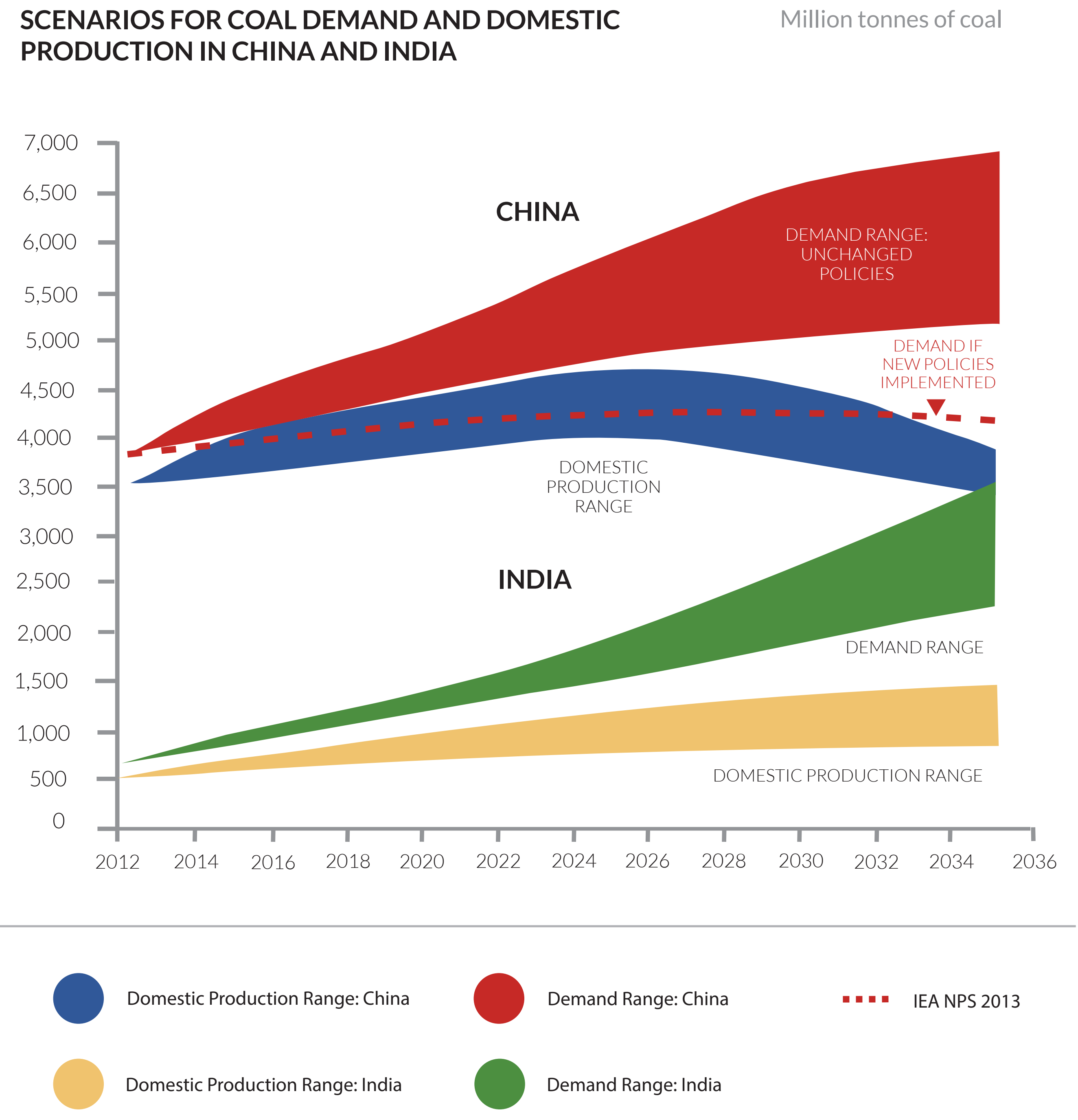
From a climate perspective, meanwhile, major reductions in coal use are an essential feature of climate mitigation scenarios that limit global warming to safe levels.[50] At current production rates, proven coal reserves could last 100 years, and produce 1.6–2 trillion tonnes of CO_2 emissions.[51] Coal is the most carbon-intensive of fossil fuels. In the power sector, coal accounts for 73% of emissions but only 41% of generated electricity.[52] Once built, coal-fired power plants typically operate for decades, "locking in" their high emissions. Work for the Commission shows that about US$750 billion was invested in new coal power plants in 2000–2010 alone, and those plants will emit around 100 gigatonnes of carbon dioxide ($GtCO_2$) if operated for 40 years. Those built in 2010-2020 will add a similar cumulative amount.[53] Any effort to reduce the energy sector's climate impact therefore must include strategies to encourage energy supply options that can displace new coal infrastructure investments.

Shifting to a lower-risk trajectory

On the current course coal could account for 35–45% of global net growth in electricity generation over the next

Figure 3

Ranges for domestic coal production and coal demand scenarios in India and China, 2012–2030, absent change in policies



Note: Main ranges for demand scenarios do not assume policy changes to encourage steps towards lower coal use (China) or are based on a range of different energy efficiency developments for a given rate of economic growth (India). The broken line for China (IEA 2013, New Policies Scenario) illustrates a possible demand trajectory based on Chinese policies to curb coal demand growth. The figure includes all types of coal, not adjusted for calorific content.

Sources: China demand (non-broken lines) based on the range spanned by US Energy Information Administration, 2013; IEA, 2013, Current Policies scenario; Feng, 2012; and Wood MacKenzie, 2013. India demand scenarios are based on the trajectories in the India Energy Security Scenarios (IESS) in Planning Commission, 2013. China production is based on an analysis of depletion trajectories of the ultimately recoverable domestic coal resource. India production numbers span the range considered in the Planning Commission's IESS for future feasible extraction of domestic coal.[46]

two decades, resulting in a 50-60% increase on current levels of coal consumption. Nearly all of the increase is projected in fast-growing regions of Asia, where coal could account for 50–70% of new power supply unless policies are changed.[54] In some countries that momentum is already shifting, however, and implementing policies already proposed (particularly in China) could significantly dent this growth – potentially to just half these levels – while effecting a 15% reduction in the OECD.[55] However, given the long lifetimes of the infrastructure involved, coal could still have a 35% share of global generation in the early 2030s (as noted, it is currently 41%).

These developments contrast with those required to limit global warming to 2°C. Many such scenarios see unabated coal-fired emissions falling to one-tenth of current levels by 2050, with significant near-term reductions. For example, the IEA 450 scenario sees coal-fired power generation falling to 60% of 2011 levels by 2030, even with the development of CCS, and total reductions in coal emissions of 11 Gt.[56] However, analysis carried out for the Commission suggests that as much as half of this reduction could be achieved at zero or very low net cost, once the changing cost of alternatives and reduced health damages and other co-benefits are taken into account.[57]

A key step in shifting policies and investment choices away from coal is to ensure that the full implications of coal use are consistently accounted for. All of the factors discussed above have serious economic and health costs, often high enough to shift the cost-benefit balance in favour of alternatives. Given the known risks associated with coal, it is time to shift the "burden of proof", so coal is no longer assumed to be an economically sound choice by default. Instead, governments should require that new coal construction be preceded by a full assessment showing that other options are infeasible, and the benefits of coal outweigh the full costs. Simply taking a full set of domestic policy concerns into account could lead to a much lower reliance on coal than many national decision-makers now take for granted. Such approaches are already being considered. For example, the European Bank for Reconstruction and Development (EBRD) is already developing a policy which would only fund coal-fired power generation in exceptional circumstances, and a simple quantitative methodology for assessing projects along dimensions of affordability, security and sustainability.[58]

Nevertheless, new coal-fired capacity will continue to be built for some time, undermining efforts to keep climate risk at acceptable levels. From a climate perspective, there is therefore a strong case for developing CCS, and ensuring that new coal power plants either include CCS or can be easily retrofitted in the future.[59] Even with CCS at a large scale, coal use will have to be curbed. However, CCS is the only option that enables the continued use of coal while avoiding CO_2 emissions. Significant progress has been made to develop CCS technology, but it still has a long way to go before it can be counted on as solution. Near-term action is thus needed to make CCS a significant contributor to climate risk mitigation (see Box 2).

3.2 Air pollution as a driver of energy system transformation

The air pollution arising from energy use has multiple and severe impacts, and the increasingly urgent need to reduce it is driving everything from clean cookstove initiatives, to tighter vehicle emission standards, to shifts in power production and industry.[71]

At current production rates, proven coal reserves could last 100 years, and produce 1.6–2 trillion tonnes of CO_2 emissions.

Pollution from energy use accounts for as much as 5% of the global burden of disease.[72] Air pollution is also linked to an estimated 7 million premature deaths each year, including 4.3 million due to indoor air pollution, mostly from cooking and heating with solid fuels.[73] Crop yields also are affected, with ground-level ozone reducing the yield of four major staple crops by 3–16% globally, particularly in South and East Asia.[74]

Valuing these impacts in monetary terms is not straightforward, but existing estimates suggest very high costs, often exceeding the cost of shifting to other energy sources that would also significantly reduce CO_2 emissions. Recent climate mitigation scenarios have estimated global average health co-benefits at US$50 to more than US$200 per tonne of CO_2 avoided, relative to baseline development.[75] Translated into energy costs, these numbers have a dramatic impact on the relative attractiveness of lower-carbon technologies. For example, coal-fired power enjoys a financial advantage in large parts of Southeast Asia, at costs of US$60–70 per MWh. But accounting for air pollution even at the bottom of the range of avoided damages (US$48/t$CO_2$) adds a cost of US$40/MWh, enough to bridge or exceed the cost gap to alternative sources of electric power.[76] Even with pollution controls, coal plants in the top 20 CO_2-emitting countries cause global average damages valued as high as US$49/MWh of electricity, although with wide variation (higher as well as lower) between countries.[77] Impacts rise even further if the upstream impact of coal mining, transport and processing are included; one estimate for 2005 put the total life-cycle "true" cost of coal in the United States as high as US$150/MWh,[78] although emissions have since fallen. For comparison, the cost of electricity production

Box 2
What would it take to develop carbon capture and storage at scale?

CCS offers the potential to capture CO_2 emissions from power plants and large industrial facilities and prevent their release to the atmosphere. It thus provides the option to reduce CO_2 emissions while continuing to use some fossil fuels.

From a climate mitigation perspective, CCS could be highly valuable. Many scenarios to limit global warming to 2°C rely on some level of CCS deployment. Although no assessments suggest that CCS could capture all or most of current CO_2 emissions or allow a continuation of current trends in fossil fuel use, the cost of achieving a low-carbon energy system could be significantly higher without the availability of CCS.[60] In several industrial sectors there are currently no other options for deep emissions cuts.

The development of CCS can build on significant technology progress, and most component technologies are in place, as CCS is already a proven technology in the upstream petroleum sector, and some trials and demonstration projects are under way in other sectors. In the power sector, however, CCS is only starting to be demonstrated: there have been several successful small-scale pilot projects, but the first two full-scale demonstration projects for coal-fired power plants are scheduled to start only in 2014.[61]

Overall, however, CCS development and deployment are not where they need to be to significantly reduce climate risk. For example, for CCS to fulfill its role in climate mitigation,[62] the IEA's 2013 CCS technology roadmap envisages 30 large-scale projects by 2020, capturing and storing 50 million tonnes (Mt) of CO_2 per year.[63] At present, 12 projects are operating, capturing about 25 Mt per year, but only four carry out monitoring consistent with long-term storage. Nine additional confirmed projects under construction would increase the total to about 40 Mt per year captured in 2020, though many projects would use the CO_2 for enhanced oil recovery (EOR),[64] which to date has usually not involved monitoring to ensure long-term storage.[65]

The picture for investment is more challenging still; in the IEA's 2°C Scenario (2DS), the annual investment rate in CCS-equipped facilities would reach almost US$30 billion/year in 2020, with cumulative investment reaching more than US$100 billion,[66] while actual investment in 2007–2012 averaged only US$2 billion per year.[67] Full-scale deployment and construction of supporting infrastructure after 2020 would require further rapid escalation, with more than 2,000 Mt per year captured and stored in 2030, and more than 7,000 Mt per year by 2050. By 2050, a cumulative US$3.6 trillion would need to be invested.[68] While there are many other ways to reduce emissions to levels compatible with the 2°C target, it is clear that efforts must be stepped up if CCS is to play a major role.

Future CCS use also would need support through long-term mechanisms to create demand, underpin investment in infrastructure, and enable the development of new business models for the scaling of the technology. Unlike many other mitigation options, such as renewable energy or energy efficiency, CCS lacks intrinsic value beyond greenhouse gas mitigation, except for niche applications such as Enhanced Oil Recovery (EOR). Although some other commercial uses of CO_2 are under development,[69] they face the challenges of CO_2's low value, low energy content, and the sheer volume that would need to be absorbed to make a real climate impact. EOR and other forms of CO_2 use may nevertheless help improve the economics of demonstration projects and initial scale-up.

Long-term demand therefore would likely need to be driven by stable climate policy. This could take the form of a subsidy such as a feed-in tariff or quota, but ultimately, a long-term carbon price would be more cost-effective. The cost and level of support required cannot be judged with certainty prior to demonstration at scale. In the power sector, estimates have ranged around US$25-100 per tonne CO_2 using current technologies.[70] In addition, there is a need to resolve legal uncertainties and to make the technology acceptable to the public, as concerns (including the risk of CO_2 leakage) have held back some past projects.

The next steps required are clear; if governments want to make the option of CCS available, a rapid scaling of CCS demonstration is the first place to start, but early long-term commitment to climate mitigation also will be a prerequisite.

from new coal plants in the US is around US$100/MWh.[79] Actual impacts may go further still. For example, it is likely that heavy pollution affects cities' attractiveness to talent, and thus their capacity to be longer-term engines of economic growth (see Chapter 2: Cities).

There is significant variation and uncertainty in monetised estimates of the cost of coal-fired power. Still, the overall evidence is clear that continuing to make energy decisions without accounting for these factors leads to pathways with significant health damages, in many cases entailing costs that exceed the cost of switching to lower-polluting alternatives. Rational economic policy would include such costs when comparing energy options.

Many countries have raised air quality standards and tightened regulations as their populations demanded it. In Europe and the United States, air pollution has been reduced significantly, and improvements continue. For example, the damage caused by electricity generation in the EU is half what it was in 1990.[80] As noted above, tighter air pollution controls have also led older coal-fired plants to close and discouraged new construction. In the United States, only 5% of new capacity since 2000 has come from new coal plants.[81]

Now it's China's turn to wage these battles. Many Chinese cities, especially in the north, have severe air pollution, with annual particulate-matter (PM_{10})[82] levels five to seven times the World Health Organization (WHO) guideline level, and average annual sulphur dioxide (SO_2) levels that are triple the WHO 24-hour guideline level.[83] Notably, even requiring coal power plants to install flue-gas desulphurisation systems only slightly reduced SO_2 emissions, because rising coal use in industry mostly offset the benefits.[84]

Mortality from air pollution in China is now valued at 10% of GDP.[85] The pollution has caused severe health effects and growing public concern, pushing the issue to the top of China's political agenda – most notably through the Chinese government's new "war on pollution".

The task at hand is enormous. China's air pollution problem is due to multiple factors: high population density, geographically concentrated energy consumption, a highly energy-intensive economy, and heavy reliance on coal across sectors. Modelling carried out for the Commission indicates that solving the problem will require not only "end-of-pipe" technologies to control pollution, but a far-reaching and accelerated transition for the entire energy system. Coal use in particular must substantially decline, with major implications both for power production and for industry.[86]

China thus must find a more even balance of energy sources, but it also needs to restructure overall economic activity towards less energy-intensive activities. Notably, the new air quality targets are driven not only by concerns about air pollution, but also by dwindling profit margins, runaway energy demands in China's heavy manufacturing sector, and by concerns about energy security, given the growing need for coal imports unless the current trajectory of coal increase is broken. Political leaders also increasingly recognise the multiple potential benefits of a cleaner development pathway, with more innovation , and more value-added services and differentiated manufacturing. All these factors together are creating strong pressures for change.[87]

These dilemmas in China have direct implications for other countries. India, in particular, also has unusually high levels of coal dependence, high population density, and rapidly growing energy demand, as well as severe air pollution in many cities. Investments in the next few years could exacerbate and lock-in all these problems. Energy use needs to increase, but the near-term cost advantage of polluting options needs to be balanced against the risk that expensive corrective action will be needed in the future to reduce pollution. Judging by China's case, such corrections may well be necessary well within the lifetime of energy infrastructure that is now being built, which in turn affects its relative economics vis-à-vis lower-polluting alternatives. On the brighter side, as we discuss next, many renewable energy options are now much more economically viable than they were when China and other countries built out their power infrastructure.

3.3 A new era for renewable energy sources

Renewable energy sources have emerged with stunning and unexpected speed as large-scale, and increasingly economically viable, alternatives to fossil fuels.[91] These technologies have existed for decades, but until recently, only hydropower was used at large scale.[92] That is changing rapidly: while in 1996–2001, just 7% of the increase in electricity production came from renewable sources. In 2006–2011, 27% did, even as total power production grew almost twice as fast.[93] Much of this growth involved hydropower, the main electricity source in more than 20 countries. Yet new renewables, in particular solar and wind power, have also emerged as large-scale options.

This has created a sea-change in expectations. While a decade ago, most analysts expected wind and solar power to remain marginal for decades to come, they now are seen as key contributors to future global electricity needs. For illustration, the IEA's central scenario (New Policies) envisions solar and wind combined adding more electricity production than either coal or gas until 2035.[94] All energy projections are very uncertain, and in the past those for the role of renewables have rapidly been outdated as policies and technologies changed at a fast pace.[95] Yet it is clear that, for countries seeking cleaner, more secure energy systems, the new viability of renewable energy has opened up an enormous opportunity to diversify and expand domestic energy production.

A fast-changing cost profile

The key reason that renewable energy can now play a major role is that costs have fallen very fast. In 1990, wind power was 3–4 times more expensive than fossil fuel electricity, making it infeasible at scale.[96] Since then costs have dropped by half or more while performance has increased dramatically. Improvements have been driven in part by the willingness in some countries to build out wind while costs were still high. In places as diverse as Australia, Brazil, Mexico, South Africa, Turkey, and several US states, the cost of electricity production from onshore wind power now is on par with or lower than fossil fuel alternatives. In Brazil, wind power has been the cheapest source of new power in recent auctions for new electricity contracts. South Africa similarly has seen wind power procured at costs as much as 30% below those of new

Box 3

Air pollution control in the Beijing-Tianjin-Hebei region of China[88]

In In the Beijing-Tianjin-Hebei region (also called JingJinJi) has been targeted by the central government for stringent air pollution reductions, including a 25% cut in ambient PM2.5 concentrations by 2017 on 2012 levels. The region's air pollution is in large part linked to extensive coal use, including for power generation, heating, and heavy industry; Hebei province alone produced one-eighth of the world's steel in 2012.

In response, Beijing, Tianjin and Hebei have jointly agreed to reduce coal consumption by 62 million tonnes from 2012 levels. Key measures include eliminating coal-fired power generation and renovating the residential heating infrastructure in Beijing, as well as drastic industrial restructuring in Hebei province, where a quarter of iron and steel and half of cement production capacity is to be phased out by 2017.

While air quality is undoubtedly a major problem, threatening not just health but also economic development, the air quality programme also seeks to reap multiple potential benefits from a cleaner development pathway. These include addressing the dwindling profit margins and runaway energy demands in the region's oversized heavy industry, through innovation and restructuring towards more value-added production.

The planned actions will entail massive investment, the sacrifice of considerable sunk costs, and difficult political trade-offs. Industrial restructuring will pose formidable economic and social dilemmas, especially for areas such as Hebei province, with its high development pressure and limited financial resources.[89]

Although impressive, there are indications that the planned measures will shift energy use and pollution loads to other parts of China, rather than reducing them altogether; for example plans to scale up coal-to-gas production and coal-fired generation capacity in western areas.[90] Not only would this reduce the potential for multiple benefits but also add a considerable pollution burden to other regions and do nothing to stem the increase of China's total carbon emissions. Furthermore, although ambitious, the planned measures would still be insufficient to meet basic air quality standards.

coal-fired power.[97] Wind power remains more expensive in places where wind resource is poor, fossil fuels are cheap, or where financing or other costs are high, and in offshore installations. As discussed below, larger volumes of wind power also need to account for costs of grid integration. However, in large parts of the world, it is now a fully economically viable source of incremental power supply.

Solar PV power remains costlier, but is now half the cost it was just in 2010,[98] as module prices have fallen 80% since 2008.[99] The world's largest, unsubsidised solar PV plant was contracted in 2013 in Chile: 70 MW in the Atacama Desert.[100] At least 53 solar PV plants over 50 MW were operating by early 2014, in at least 13 countries, and several planned projects are now considered competitive without subsidies.[101] Rooftop solar for homes is also competitive with retail electricity prices in several countries, including Australia, Brazil, Denmark, Germany and Italy. Even at high financing rates, solar PV is now cheaper than diesel generators, often the main alternative in rural areas in developing countries where grid connections are unavailable or cost-prohibitive.[102]

Other options are growing in prominence as well, such as geothermal energy, modern bioenergy (using residues from agriculture and forestry, among other fuels), and energy from waste. The use of solar thermal systems for heat is growing rapidly, with China as the global leader; some countries, such as Brazil and Morocco, are installing solar water heaters in low-income housing.[104] At the same time, hydropower continues to be developed at large scales around the world, and in poor countries from Bhutan to Ethiopia, it is dramatically improving energy access and economic opportunities. (See Box 4 for a discussion of hydropower and nuclear.)

The rapid cost reductions have allowed renewables to continue to grow even as investment has slowed; in 2013, adding the same total non-hydro capacity as in 2011 required 23% less capital.[105] New solar PV capacity was one-third higher in 2013 than in 2012, despite 22% lower investments.[106]

Detailed analyses indicate that cost reductions and performance improvements can continue for many years. For example, the technologies to cut the cost of producing solar PV modules by another half are already developed.[107] Further cost reductions will depend on active R&D, which also is increasing in volume, albeit that higher levels are needed for a range of energy technologies (see Chapter 7: Innovation for a discussion of innovation requirements in energy). They also will depend on continued deployment, which has proven critical in enabling the cost reductions that have taken place to date.

Growing interest in renewables

While continued cost reductions strengthen the case, there already are compelling reasons for countries to invest in renewable energy. As noted above, developing renewables can strengthen energy security, reducing dependence on fossil fuels and exposure to global market volatility. Virtually all countries have renewable energy sources of some type that they can exploit.[108] The technical potential for renewable energy is far greater than current human energy use, and studies suggest it could supply

95% of global energy demand by 2050,[109] and double its current share by 2030, at a relatively low net cost.[110] Apart from biomass, renewable energy also has negligible air pollution impacts and few or no CO_2 emissions. And except for geothermal and large hydropower, new capacity can be built quickly and at a wide range of scales.

Many countries have recognised these potential benefits and adopted policies to stimulate renewable energy growth. More than 140 nations had some form of renewable energy target as of early 2014.[111] Germany has been a pioneer: 80% of its new generating capacity in the last decade came from renewables (50% from solar and wind), with significant resources expended on early deployment when costs were still high to drive technologies towards commercial viability. Spain, Portugal, and Denmark have expanded wind power to more than 20% of electricity over the past decade.

Fast-growing nations are also pursuing renewables. In China, the share of coal power in new electricity generation, 85% in the last decade, dropped to just over 50% in 2013, while 15% came from solar and wind and 30% from hydropower. In 2013 China accounted for 21% of all global renewable investment,[112] adding more than five times more wind and nearly twice as much solar as any other country.[113] Chile doubled its target for renewable electricity to 20% in 2013, seeking affordable, rapidly scalable ways to reduce its dependence on gas imports and on drought-vulnerable hydropower.[114] And as of 2013, almost half of African nations had done national assessments of renewable resources;[115] Ethiopia, best known for its ambitious development of hydropower, also has Africa's largest wind farm and is pursuing geothermal energy, as well as biofuels and off-grid renewable solutions.[116]

Still, both current and likely future renewable energy growth vary greatly across countries. In high-income regions that have prioritised renewable energy, it already contributes 5–25% of total electricity generation (wind, solar and bioenergy, or 10-70% including hydropower).[117] Scenarios also suggest that in those countries, a majority of new electricity generation to 2030 (50–100%) will come from renewables, based on improved economics and existing policies.[118] Many countries have announced policies thaVt would further increase deployment, which could result in renewables providing all new net generation capacity additions in those countries. Overall, depending on the extent to which policies that have already been announced are in fact carried through, non-hydro renewable energy thus could grow to 15%–25% of total generation by 2030 in high-income regions, and higher still for ambitious individual countries.

Fast-growing economies could not realistically achieve such high shares of non-hydro renewables by 2030, given much faster demand growth. In Asia, these sources currently provide only 1–5% of electricity. Scenarios suggest they could account for 10–20% of net growth in electricity supply. The picture is similar in middle-income countries elsewhere. In individual countries, however, large hydro resources can drive the total share of renewables as high as 80–90% of electricity in individual countries.

Yet there is potential for more growth. Countries have often underestimated how quickly renewable energy sources would become more affordable and the contribution they could make to energy and economic objectives. Although national circumstances vary, the evidence suggests that most high-income countries could ensure that renewables (including hydropower where available) could grow to cover all new net demand for electricity to 2030. They could also displace 20% or more of coal-fired generation by not extending plants' lives or closing the most polluting and inefficient units (targets in the EU already go beyond this). Similarly, middle-income countries that now depend heavily on coal could aim to have non-hydro renewables provide 25–30% of net new electricity supply without resorting to high-cost options – higher still for those with particularly good resources and technical capabilities. Additional hydropower growth should also be pursued, where local resources and sustainability concerns allow it. The benefits of reduced lock-in to air pollution and possibly volatile fuel costs mean that such increased ambitions could often be met at low incremental cost.

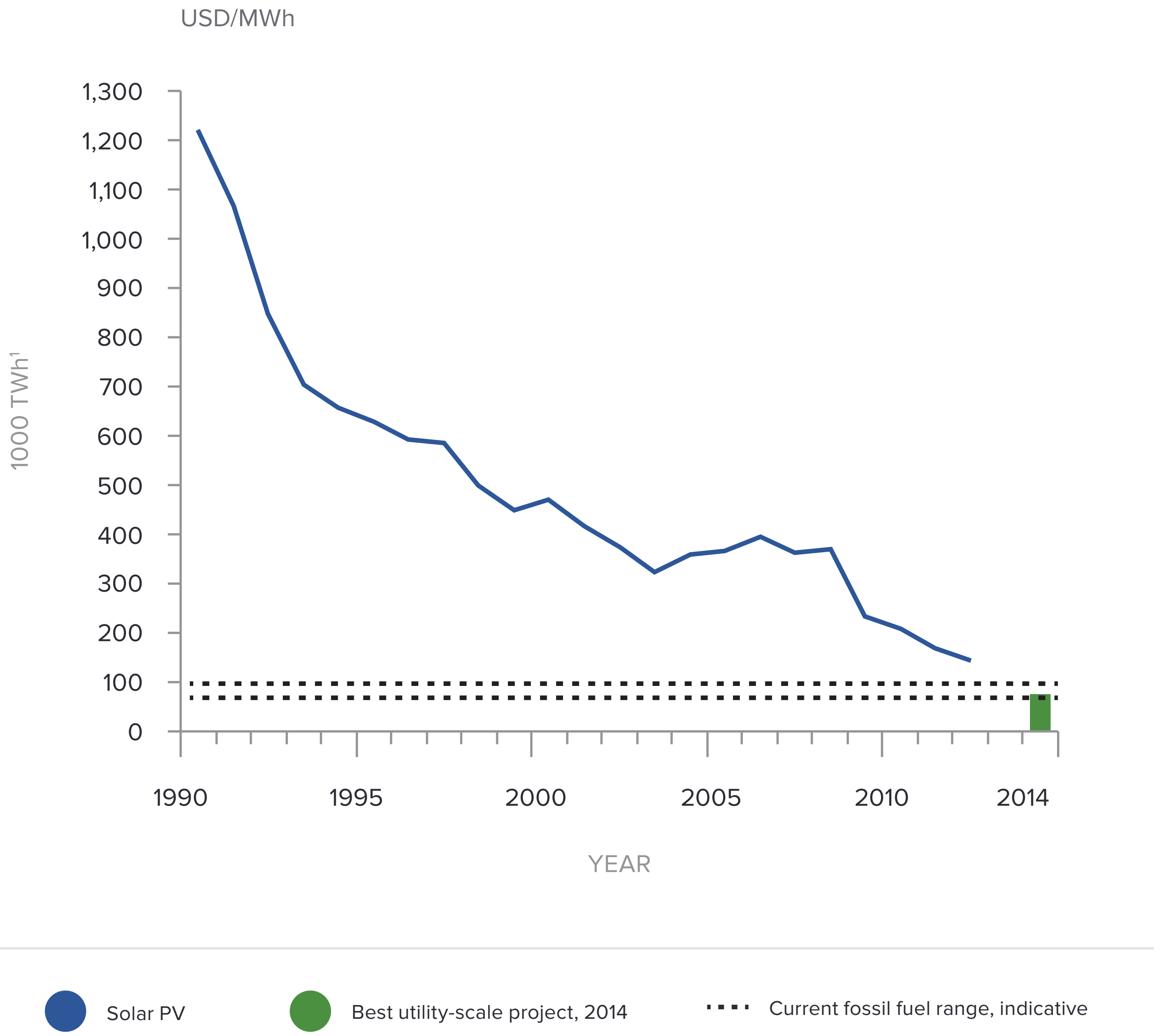
At least 53 solar PV plants over 50 MW were operating by early 2014, in at least 13 countries, and several planned projects are now considered competitive without subsidies.

Overall, the Commission finds, renewable energy is already well positioned to become a mainstay of energy policy – and in some countries, of development more broadly. Yet real barriers remain – some systemic, and some specific to solar and wind power. Below we discuss the biggest issues and potential policy measures to address them.

Overcoming barriers to large-scale deployment

The most salient barrier is cost. Renewable energy can already compete with fossil fuels where resources and supply chains are favourable and low-cost finance is available. As noted, many countries can exploit such

Figure 4
Indicative levelised costs of solar PV electricity over time, and estimated lowest utility-scale cost to date, compared to a global reference level for coal and natural gas



Note: Solar PV costs can vary by ~50% or more up or down depending on solar resource and local non-technology costs, and even more with variations in capital and financing costs. Assuming 9.25% WACC, 17% capacity factor for solar PV, US$70/t coal price and US$10/MMBtu natural gas price. The estimated lowest 2014 utility-scale cost is based on a recent power purchasing agreement by Austin Energy, Texas (adjusted for subsidies).

Sources: Historical solar PV costs: Channell et al., 2012, and Nemet, 2006; illustrative fossil fuel range based on US LCOE for conventional coal from US EIA, 2014 (upper range) and capital cost assumptions from IEA, 2014 (lower range).[103]

opportunities. In most of the world, however, new renewables at larger scale will still require public support – which, in turn, creates political trade-offs, especially when budgets are tight. Done badly, subsidies also can distort markets and result in overpayment. Renewable energy subsidies have grown fast, to more than US$80 billion for electricity in 2012 (60% in the EU).[126] Much of this has been akin to an innovation down-payment, arising from early commitments to deploy technologies when they were still expensive in order to achieve further cost reductions improve performance. Thus, they are not a guide to what future subsidy levels will be needed. For example, achieving Germany's solar PV build-out today would cost a third of what Germany spent over the past decade – and potentially much less in a country with better solar resource.[127]

Assessments now suggest that support will continue to be needed for some time, but that the required support per unit of electricity is falling fast. For example, the IEA now envisions a six-fold increase in non-hydro renewables with just over twice the current subsidies. Other scenarios see renewables scaling faster still, and with lower subsidies. For example, the "REmap" assessment by the International Renewable Energy Agency (IRENA) identifies potential that would give 60% more generation from renewables than is realised in the IEA scenario, and would result in 44% share of renewables in electricity production by 2030.[128] Despite the higher volumes, the estimated subsidies are lower per unit, and the average increase in cost is US$20/MWh.[129] Other assessments have suggested that, by the 2020s, there will be no need for further subsidy of onshore wind and solar PV in Europe.[130]

Where subsidies continue to be necessary, they are often on the same level as the monetary value of the multiple benefits of more diverse and less polluting energy supplies. For example, the IRENA assessment suggests that accounting for air pollution could reduce the true incremental cost to society by half or more.[131] Likewise, the support required would be much lower in the presence of a carbon price.

Another value of deploying renewable energy now is that it helps drive down future costs – not just through global technology improvements, but by improving individual countries' ability to make use of the technologies. Even for similar circumstances, the cost of solar and wind power can vary by a factor of two or three depending on the maturity of local industries, economies of scale, variation in the cost of financing, and the regulatory environment.[132] In other words, the "learning by doing" that helps drive costs down is not just about global technological progress, but also about developing local capacity. One key step in this regard is to ensure that renewables can access finance on terms at least as beneficial as those extended to conventional sources. Costs are now often 20% higher than they would be with financial solutions tailored to the characteristics of renewables rather than fossil fuels (see Chapter 6: Finance for a deep-dive on how improving investment conditions can reduce the cost of renewable power). Countries that want to avail themselves of renewables as they fall in price should thus build the local capacity to do so ahead of time.

Expanding the use of solar and wind power also depends on successfully integrating these technologies into the overall electricity system. Unlike gas, coal, nuclear or hydropower, wind and solar power production is variable and cannot be controlled or fully predicted in advance. Good resources are also can be located far from centres of demand, requiring new extensions of power grids.

Integrating variable renewables thus requires much more active coordination and management. Much has been learnt in the last 10 years as mechanisms to accommodate high shares have been put in place in several countries, such as Spain, Ireland, Denmark, Germany, and some US states. A mix of supply- and demand-side options have been deployed, including flexible conventional generation, new transmission, more responsive demand, and changes in power system operations to maintain the same ability to reliably meet demand as a more traditional "baseload" system. This process has benefited from steady innovations in forecasting, grid planning, market design, and other solutions.[133]

Very high levels of variable renewable power have not yet been attempted, but from a technical perspective, they look increasingly feasible. For example, a modelling 2014 study for a major US electricity market (PJM) concluded that 30% variable renewables could be integrated with modest additions of grid extensions and flexible gas-fired power plants.[134] Detailed modelling for the United States as a whole showed how an electricity system with 80% renewables would be feasible with technologies that are commercially available today.[135] Costs were estimated at 8–22% above baseline developments, including all integration costs, but depending on the rate of continued technology development to reduce generation costs.

Most countries will not have variable renewable anywhere near these levels for a long period of time. For example, putting in place the full set of REmap options only four countries reach shares of variable renewables exceeding 30% by 2030, and most (including India and China) stay below 20%.[136] Starting from a low base, most countries could technically continue to build out variable renewables for many years before hitting levels where costs escalate.

Still, it is important to prepare. Failing to properly plan for the integration of variable renewables can drive up costs and complicate further expansion of wind or solar power even at modest levels of penetration.[137] Problems have ranged from unavailable network connections in Brazil, to strains on the grid from "hotspots" of production in India, or failure to provide incentives to enable fossil fuel plants to vary their output to complement varying wind or solar PV production in China, to failure to anticipate new grid requirements in Germany. Other examples show that many of these problems can be kept manageable with good policy, but integrating renewables clearly increases demands on coordination and institutional capacity. Additionally, countries need to bear in mind that the value (in terms of meeting power needs) of adding more generation with the same time-variability declines as shares increase; for example, solar PV might be very valuable initially as a way to manage peak load, but then have lower capacity value. An important guiding principle to address these issues is that renewables should not be managed separately, but should be built into the power system's design and operation.

Box 4
Nuclear and hydropower: Two proven low-carbon technologies

Both hydropower and nuclear power are well-established energy sources with low local emissions as well as low GHG profiles. While solar and wind power have grabbed the spotlight in recent years, hydropower and nuclear power are still by far the biggest non-fossil sources of electricity, at 16% and 12% of global generation, respectively.[119] Both offer nearly emissions-free energy, with very low marginal costs, and have a proven record at large scales. However, they are also highly capital-intensive, can take a decade or more to plan and build, and come with a range of environmental and social risks.

Hydropower provides clean power that can be ramped up and down quickly, with minimal losses. Its flexibility and storage capacity make it useful in many settings, and it can be a good complement to renewable sources with variable output, such as solar and wind. There is also great untapped potential: current generation is 3,200 terawatt-hours (TWh) per year, but another 1.5 times that could be added at costs not exceeding those of fossil alternatives. These attractive features continue to drive hydropower development, with growing economies in Asia and Latin America adding the equivalent of 3% of existing global capacity per year.[120]

Yet hydropower can also have serious social and environmental impacts. Building dams and reservoirs may displace communities and widely disrupt ecosystems, and can also be contentious when downstream water supplies are disrupted. In addition, reservoirs can be significant sources of methane, a potent greenhouse gas; the GHG emissions of 25% of reservoirs are one-quarter or more of those of an equivalent coal plant.[121]

Nuclear power provides 20% of electricity in OECD countries, having expanded rapidly from the late 1960s to the late 1980s.[122] Its advantages have included stable electricity supply with very low fuel costs, as well as good environmental characteristics if accidents and leaks of radioactive material are avoided. The ability to provide zero-carbon energy has since been added to its list of advantages. However, nuclear power also raises concerns about how to handle radioactive waste, proliferation risks, and severe worst-case accident scenarios. Public support was severely eroded by the Three Mile Island accident in 1979, and then the Chernobyl and Fukushima accidents. Increasingly stringent safety standards and a limited number of approved suppliers have increased construction costs in OECD countries three to seven fold since the early 1990s.[123] Projects now under way in Europe are reaching historic highs in terms of delay and cost escalation.

As a result, deployment of new nuclear capacity has slowed to a crawl, with less than 15% cumulative growth since 1995.[124] Several OECD countries have since announced plans to reduce or phase out nuclear power completely, a process that has firmed after the Fukushima accident in 2011. Nuclear power's continued growth will likely depend on a small number of non-OECD countries, which are aiming to add capacity corresponding to a third of the current total by 2025, 70% of it in China.[125]

Innovations such as small modular reactors and thorium fuel, spurred by increased deployment in non-OECD countries, may improve the outlook for nuclear energy. It does offer many benefits in terms of energy security and avoided emissions, but nuclear energy's challenges – from waste handling, to high capital costs, to public concerns, are likely to persist.

Further innovations will also be needed as renewables' share of energy production grows. These may include new technologies (energy storage, smart grid management), but equally important new business models (e.g. for demand response and for the provision of other flexibility services), as well as new financing mechanisms, regulatory approaches, and market designs. Emerging experience in both Europe and the United States shows that the entry of renewables can prove very challenging to incumbent utilities, and create a need for new mechanisms to ensure that the fossil fuel-fired plants required for system stability can continue to operate in a situation of lower wholesale electricity prices and lower running hours caused by the entry of new renewable sources. A few pioneering countries are acting as laboratories to develop the full solution set, much like early support was crucial for driving down the cost of equipment. Continuing these investments in innovation will be critical to long-term success.

An important guiding principle to address these issues is that renewables should not be managed separately, but should be built into the power system's design and operation.

In addressing these, barriers the first step often will be conceptual: to adjust to the rapid pace of change and start evaluating plans that include much higher contributions for renewable energy than ever considered before. The starting point must be for all countries to evaluate an up-to-date and integrated candidate scenario where renewable energy provides a large share of new electricity production, set against a full suite of energy and other objectives. This, in turn, requires mapping the available resources, understanding additional grid requirements, accounting for future cost developments in both fossil and renewable energy, understanding the impact on energy security parameters, accounting for the value of avoided lock-in to higher-polluting forms of energy, and valuing the reduced exposure to volatile fuel prices. The results will differ, depending on local circumstances and priorities, but the evidence suggests that many countries will find renewable energy much more attractive than currently assumed by comparing project-level costs. Several proven measures can also help make renewables more cost-competitive (see Box 5).

3.4 Opportunities to expand energy access

The people with the most to gain from modern energy are those who still lack it. As noted earlier, 1.3 billion people have no access to electricity and 2.6 billion lack modern cooking facilities. More than 95% of this unmet need is in sub-Saharan African or developing Asia; 84% is in rural areas.[143] Furthermore, in many urban and peri-urban areas in the developing world, large numbers of people have only partial or unreliable access to a grid connection.

Access to electricity allows households to have more productive hours, including time for children to study; with moderate rises in income, it also provides access to welfare- and productivity-enhancing electronics such as mobile telephones and refrigeration.[144] Reliable electricity access also improves business productivity, and provides access to telecommunications, which can facilitate

Box 5
Reducing the cost of renewable energy deployment

Much has been learned about how to deploy renewable energy cost-effectively. Some level of financial support still is needed in most countries, and it should be minimised through best practice:

1. Achieve sufficient scale and efficient operation. Both the cost of developing and operating renewable energy projects vary by as much as 50% between locations. For example, the balance of system costs of solar PV in Germany are half those of the United States.[138] For wind power, maintenance costs and success in maximising production also vary sharply. Achieving sufficient scale and maturity of local supply chains as well as operational expertise are all elements in reducing the effective cost of electricity from new renewables. Ensuring sufficient competition between project developers can be a major driver for such improvement.

2. Mitigate risk and legacy barriers. In many parts of the world, power investment is generally held back by the risk that investments will not be recovered over time. This is amplified in the case of renewables, both because a larger share of the total cost has to be sunk upfront, and because the economic case often depends on government support mechanisms to a greater degree. Identifying and addressing regulatory and other barriers, and streamlining planning and approval requirements, is critical to reducing construction time and removing the risks that either raise the cost of capital or prevent financing altogether.

3. Improve the financing structures. Current investment structures for power generation typically are set up to serve projects with the cost structure of fossil energy, including a large share of ongoing costs and fossil fuel price risk. Adapting financing to the specific features of renewable energy can reduce financing costs, in turn reducing the total cost of renewable electricity production by as much as 20%.[139] The YieldCo solutions pioneered in the United States are an example of this.[140]

4. Use flexible and efficient support mechanisms. With rapidly falling costs support levels risk being set too high. Countries are now increasingly turning to auction mechanisms to enable cost-effective use of support, and also building in automatic revisions of levels and relating support to underlying electricity prices. Done right, such improvements can be made without retroactive changes to arrangements or the introduction of other risk that is damaging investor confidence. In addition, where the objective is centred on greenhouse gas mitigation, renewables deployment should be backed by carbon prices.[141]

5. Plan for grid integration. Ineffective planning for the integration of renewables to the power grid can increase cost substantially. Costs can be kept down even at substantial levels of renewables penetration through greater use of demand response, advance grid construction, increased balancing area size, improved forecasting of renewables output, or market design improvements such as shorter time windows for the planning of electricity production. Failures to adopt these can increase costs substantially. For example, China had to curtail as much as 10% of its wind power production last year due to insufficient grid connections.[142]

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growth in a range of development areas such as health care, institutional access, and political voice. Conversely, lack of access to electricity can impede a range of economic activities.[145]

In the past, electricity access has expanded both through urbanisation and through extension of centralised power grids. China, Thailand, and Vietnam recently achieved near-universal access through these routes,[146] and they will continue to be important to relieving energy poverty. However, in much of the world the process is slow and faces multiple barriers. Without new policies, the total number of people without access to modern energy in fact could increase rather than fall in the next two decades.[147] Overcoming energy poverty also requires upgrading the quality and efficiency of household thermal energy, primarily used for cooking. This has significant benefits by reducing or replacing the need for traditional biomass fuels such as wood and dung.[148] Eliminating the need for fuel wood collection also liberates considerable time for other productive activities, especially for women and girls.

For electricity, there is growing agreement that renewables can complement traditional approaches to overcome barriers to expanded access. Falling costs, new business models, and technological innovations are making decentralised solutions increasingly attractive. For example, a recent IEA scenario for universal energy access by 2030 assumes 56% of the investment would go to "mini-grids" and off-grid solutions, with up to 90% using renewable energy sources.[149] In principle, these technologies are a good fit because they are modular and can be installed at small scales. Inexpensive low-carbon solutions are also emerging to meet specific needs, such as solar mobile-phone chargers and rooftop solar water heaters. Further, the distribution cost of access via grid expansion will be high in many cases. Distributed generation technologies can often provide electricity more cost-effectively in these cases, though care should be taken to ensure that the technologies employed do not imply a lock-in to perpetually low-power electricity consumption.

Renewable energy also can have long-term advantages. Providing universal basic energy access would not significantly increase greenhouse gas emissions, even if only fossil fuels were used.[150] But longer-term, energy use must move beyond basic services, scaling up to productive uses that support community development and income generation. Low-carbon alternatives can therefore be more attractive where the potential future scale of CO_2 emissions, air pollution, and fuel cost and availability is a concern. Conversely, those alternatives will only be viable if they can scale up and fit into a future with the full range of modern energy services.

As with renewables more generally, the Commission's research suggests that effective policies and institutions are vital to the success of low-carbon options for expanding energy access. While the political momentum around expanding energy access and mitigating climate change has been high in recent years, few, if any, countries have aggressively pursued both goals at once. Consultations with policy actors in Africa (see Box 6) suggest that there is a great unmet need for evidence about the feasibility and benefits of low-carbon options; without it, even governments that vocally support climate action will tend to stick with conventional technologies and fossil fuels. Overcoming this inertia will require demonstrating how a low-carbon path can advance not only climate or energy goals, but broader social and economic well-being. There is also a need to understand how off-grid low-carbon technologies take hold "on the ground", and what it takes to build sustainable business models.

Overall, this calls for much accelerated experimentation and demonstration. This needs to go beyond just technologies, and include business models, financing arrangements, and policy environments. Cooperation in other areas, such as the CGIAR model[151] for agricultural applications, can offer lessons here on how to pursue context-specific innovation in a structure of regional hubs and a distributed institutional structure.

Two other key barriers need to be overcome as well: First, access to finance remains limited, hindering the scale-up of low-carbon solutions. Since upfront capital costs are often higher than for conventional options, the risks of investments are notable, and banks are reluctant to offer loans. Overcoming this for utility-scale technologies requires targeted, long-term funding schemes, including a robust and supportive institutional framework on the national level. For distributed energy technologies, it requires business financing products, such as seed capital and working capital, to allow companies offering consumer and commercial energy products to develop and reach the market. There could be significant value from a business incubator approach to underpin the innovation framework mooted above.

Second, while the private sector has a key role to play in bringing low-cost renewable solutions to the market, many businesses struggle to generate revenues and be sustainable over time. Capacity- and skills-building – not just in the technologies, but in business and market development – will be essential.

3.5 Natural gas as a potential "bridge" to low-carbon energy systems

Natural gas has become a preferred fuel in much of the world. Outside a handful of coal-intensive countries, it has provided 60% new energy since 1990, and almost 80% outside transport – increasing its share across electricity generation, heating of buildings, and industrial uses.[153] The

Box 6
Low-carbon options for energy access: African perspectives

In order to better understand how low-carbon options are contributing to energy access expansion, the Global Commission convened a workshop in Nairobi, Kenya, in April 2014 with policy-makers, business and nongovernment organisation (NGO) representatives, and academic experts from across Africa.[152] A key insight from that workshop was that low-carbon options have not (yet) altered the fundamental barriers to expanding modern energy access in the region, including high costs to supply rural households; weak implementing capacity; lack of reliable financing, and low demand and ability to pay on the side of consumers. Participants also noted the wide range of low-carbon options being pushed by different interests, and a lack of evidence for policy-makers to evaluate the suitability of those options.

Morocco was cited as a prime example of successful use of low-carbon options to expand energy access. The country is a net energy importer and heavily dependent on oil, which accounted for 62% of its primary energy consumption in 2011. Its geography also gives it one of the highest potentials for wind and solar in the world. To seize that potential and improve its energy security, Morocco has put in place consistent policy support, including favourable financing options and regulatory frameworks, to support the deployment of renewable energy solutions. Today, about 15% of the population gets energy from a low-carbon source. The impact has been particularly great in rural areas, where the electrification rate increased from 18% to 98% between 1995 and 2012, first through a grid expansion programme and then through off-grid solar PV where grid expansion was uneconomical.

Morocco's success is credited to several factors: 1) strong political commitment to universal energy access, backed by appropriate institutions and incentive schemes for participation; 2) strong financial support, drawing on multiple sources, including a clearly defined programme that attracted international funds, targeted subsidies from the national utilities, and a solidarity tax of 2% paid by all households connected to the grid; 3) a strong public-private partnership designed to deliver power to rural customers at costs comparable to what grid-connected households pay; 4) extensive piloting programmes that gathered detailed data to fully understand the preferences and needs of the end-users, including their willingness to accept the new technology.

The workshop also highlighted several other cases where off-grid, low-carbon technologies have successfully filled a niche, such as the widespread use of rooftop solar water heaters in South Africa, which has also been supported by the government. Some private-sector initiatives have also done well, such as solar-powered mobile phone chargers – individual kits or village charging stations – which are spreading across sub-Saharan Africa, meeting both energy and communications needs.

The success stories highlight the need for sustainable business models, and workshop participants also said that building market-development capacity is a key gap to fill in technology-transfer efforts. Several participants also noted that African countries can learn a great deal from one another, by comparing their energy-access strategies and the ways in which they are using enabling policies, institutions and investments to support the deployment of low-carbon technologies.

versatility of the fuel across a number of end-use sectors is complemented by its ability to reduce local air pollution where it displaces coal. It also has been a major factor in reducing GHG emissions in some countries, including the United Kingdom and Germany in the 1990s, and the United States recently. In electricity production in particular it has been discussed as a potential "bridge technology" in the transition to a lower-carbon economy:[154] electricity produced from natural gas can emit just half the CO_2 as the same amount of electricity from coal, and natural gas has a proven track-record of scaling rapidly where supply is available. At best, turning to natural gas therefore could help avoid new coal construction and even dislodge the preference for coal as the default new option for new power supply. In addition to reducing CO_2 emissions directly, the flexibility of gas in electricity generation makes it a potentially important enabler of higher levels of penetration of variable renewable energy sources.

The expansion of natural gas would be greater still if key challenges were overcome. Natural gas is difficult to transport; the end-to-end cost of transporting liquefied natural gas (the only option where pipelines cannot be built) can be substantial and has been increasing sharply over the last decade as the cost of capital intensive infrastructure has escalated and demand increased. Outside the US, natural gas has also become less cost-competitive, quadrupling in price since 1990 while coal doubled.[155] Energy security is a concern as well, with regional dependence on single large suppliers, and global reserves concentrated in just five countries. For these and other reasons, less than a third of natural gas is internationally traded.[156] In particular, natural gas has made barely made a mark in India and China, where supplies have not been available on terms deemed acceptable.

Shale-gas production has drawn considerable attention as a potential way to overcome these challenges. In the United States, the availability of shale-gas supplies has resulted in a 60% drop in gas prices, a 20% reduction in coal used for electricity generation, and a consequent reduction in national GHG emissions.[157] It even offers the prospect of substantial gas exports. A key question is whether this phenomenon can endure and spread more globally, delivering wider benefits to the economy and climate and make the "bridge" role for gas more likely.

Can greater natural gas supplies be a game-changer?[158]

A number of assessments suggest that the potential natural gas supply is large. Although there is uncertainty about the realistically recoverable reserves from unconventional gas deposits, by some estimates it could provide as much as two-thirds of incremental gas supply over the next two decades. By 2035, the IEA has suggested that China in principle could produce nearly 400 billion cubic metres per year of unconventional gas, as much as the US produces today and 10 times the amount China recently agreed to import from Russia after 10 years of negotiation.[159] In India, production could climb to nearly one-quarter this level. Furthermore, greater globalisation of gas markets through expanded liquefied natural gas (LNG) and pipeline infrastructure would allow abundant, low-cost conventional and unconventional gas resources to reach supply-constrained markets, including those where much of the world's new coal plants could otherwise be built. Such developments would make it likelier that gas could play an important "bridging" role.

Such a scenario is far from certain, however. Not only is the technical potential highly uncertain, but several factors could get in the way. Developing new supplies is capital-intensive and involves long lead times, and at the current rates of development, it may not be possible to increase the supply fast enough to meet substantial new demand. Producers will also need to address social and environmental concerns related to production practices, particularly those associated with hydraulic fracturing ("fracking").

Will natural gas growth benefit the climate?[160]

Moreover, the climate implications of a high-gas scenario are far from straightforward. It matters where low-cost gas becomes available; the benefits will be greatest in regions that would otherwise depend on coal, and greater if natural gas is used for electricity production than for heating and transport applications. Also, if natural gas operations are not well managed, methane emissions from venting and leaks in production and transport can partly offset and even negate the GHG advantages of natural gas (see box). In fact, research for the Commission indicates that natural gas is likely to provide net climate benefits only if it is backed by robust climate policy and environmental regulations, for two key reasons.

First, in the key regions of Asia that now depend on coal, gas – especially imported LNG – is likely to remain more expensive, suggesting that it will be difficult for gas to compete on market price alone, and giving it a very limited role in electricity production in particular. Policies to reflect social and environmental costs, as the US, China and others have pursued, will thus be essential for gas use to increase.

Second, without carbon pricing or other emissions constraints, cheap and abundant natural gas supplies could both increase energy demand and displace lower-carbon options that would otherwise be used. The high initial investment and long life of gas infrastructure also amplify the risk of "locking out" zero-carbon options including renewable and nuclear energy. Meanwhile, coal that is displaced in one geography can be internationally traded, a phenomenon that already has reduced the global GHG emissions reductions resulting from increased gas use in the United States. Several modelling exercises suggest that these factors combined could be enough to negate GHG emissions benefits from displacing coal and oil use in a high-gas scenario.

In other words, policy-makers cannot count on abundant natural gas, on its own, to serve as a "bridge" fuel, nor should they promote gas as a climate solution without strong supporting policies. Active interventions, such as attributing to coal its full social cost, regulating gas production practices to limit fugitive methane emissions (see Box 7), putting a price on carbon emissions, and supporting low-carbon technologies so their development and deployment are not slowed down, will be needed for gas to fulfil this role. Fortunately, such interventions have other societal benefits as well. Making gas a viable "bridge" therefore could be a component part of a general approach to enabling better energy supply, even if it cannot be counted on as a solution on its own.

3.6 Making the most of our energy supply

A final, huge opportunity – also seen as crucial by the IEA – is the potential to improve energy productivity: the value created per unit of energy input. Countries at all income levels have made great strides in recent decades, with the biggest progress in fast-growing economies: China, for example, improved by as much as 6% per year for some time. But even mature economies have seen steady improvements near 2% per year. However, some countries have made little progress, and in a few – most notably in the Middle East, where energy prices are heavily subsidised – energy productivity has in fact worsened.[168]

Getting on track to maximise energy productivity has direct implications for energy demand. Businesses and households do not need energy for its own sake, but rather for the energy services it provides: mobility, heat, lighting, mechanical power, etc. Energy efficiency has steadily improved over the past four decades; without those improvements, energy supplies would have had to grow far more rapidly, magnifying the associated expense and disadvantages (see exhibit). More likely, countries would have had to accept much lower levels of benefits from energy use. It is often overlooked that increased energy efficiency can be the primary mechanism by which countries expand their benefits from energy use over time.

Still, much greater potential exists, at all levels of development: from improved biomass cookstoves, to gains from electrification, to specific opportunities in a wide range of uses across modern economies. Buildings offer particularly large potential, especially with heating and cooling but also with lighting and other energy services. Baseline scenarios project a doubling or tripling of energy demand from buildings; but more efficient technologies are already available that could provide the same energy services to users with barely any increase in energy demand. In the transport sector, energy efficiency and vehicle performance improvements range from 30–50% relative to 2010 depending on mode and vehicle type.[170] Industrial energy use, meanwhile, has stronger mechanisms for ensuring energy use is efficient, but even here a scenario with the global application of best-available technology could reduce energy use by 25%.[171]

Countries' ability to realise this potential will greatly affect their future energy needs. For example, India's 2030 energy demand may be 40% higher in a scenario of low energy efficiency vs. one with (very) high energy efficiency; the difference is equivalent to all the energy the country uses today.[172] This has knock-on effects on many other factors, such as the need to import energy, the capital requirements for low-carbon energy generation, and balance-of-payments pressures. On a global scale, the energy required to provide energy services in 2035 could vary by the amount of energy used today by the OECD, depending on whether a high or low efficiency path is struck.[173]

Boosting efficiency requires upfront investments, but there is much evidence to suggest that the resulting fuel savings for many measures exceed the costs. Specifically, even adopting just the measures that meet criteria of rapid "pay-back" in terms of the price of energy (and thus imply an acceptable cost of capital and discount rate), the IEA has estimated, could reduce demand by 14% by 2035 relative to a reference case. The US$12 trillion total investment required would yield fossil fuel savings almost twice as large over 20 years. This scenario also suggests that energy efficiency would be cost-effective in the sense that it costs less than an equivalent increase in supply. This brings potential for substantial economic benefits. GDP in the 2030s could be increased by 3% for China, 2% for India, and 1.7% for the United States. Total global economic output could increase by US$18 trillion, close to the combined GDP of the United States and China today.[174] These estimates are borne out by experience in several countries. For example, state-level energy efficiency programmes in the United States regularly save consumers over US$2 for every US$1 invested, and in some cases up to US$5.[175]

These magnitudes leave significant room for energy efficiency to remain an attractive option even if there were in fact "hidden costs" or other factors that might dent the estimates proposed by the models.

The potential for efficiency improvements also is growing rapidly. The cost of improving the energy efficiency of buildings has fallen significantly in recent years.[176] Lighting is undergoing a step-change in efficiency with the introduction of light-emitting diodes (LEDs). New opportunities – from much-more efficient air conditioning to automated energy management – promise further reductions (see Chapter 7: Innovation).

Net gains for the climate, but especially for the economy

Some share of the gains may be offset by increased consumption – the "rebound effect". Improved energy efficiency lowers the effective cost of energy services and the prices of goods that require significant energy for their production. This, in turn, reduces the cost of energy services, increasing consumption of such services, and frees up resources to spend on other goods and services, which can further increase energy consumption. The size of the rebound effect is uncertain, and credible estimates range between 10% and 50%, including economy-wide effects such as lower fuel prices.[177] Levels may be higher still in some cases, and especially in countries with significant unmet demand for energy.

This has led some to argue that energy efficiency is less worthwhile, as it does not translate one-to-one into reduced consumption. However, rebound only occurs to the extent that energy efficiency has economic benefits: it means that end-users enjoy still greater levels of energy services due to improved energy efficiency than they would if there were no rebound. The total resulting energy consumption and emissions will depend on a number of factors, including the structure of the economy, regulatory conditions, and energy prices. To reduce GHG emissions, all of these as well as other factors need to be modulated.

Actions to realise higher efficiency gains

Countries vary significantly in their ability to capture energy efficiency opportunities. The very fact that so much cost-effective potential remains untapped is an indication that it often can be difficult to realise within the market arrangements that now prevail. As a starting point to getting there, appropriate energy pricing is particularly important. The IEA estimates that phasing out fossil fuel consumption subsidies over the next decade could reduce world energy demand by almost 4% by the time subsidies are fully phased out, and by 5% in the following 25 years. By 2030, this could imply reductions in global CO_2 emissions of as much as 0.4–1.8 Gt.[178] The influence of prices, moreover, can be deep and structural. For example, cheap fuel in countries with low fuel taxation encourages car-centric development,

Box 7
Reducing methane emissions

The release of methane from energy production is a major source of GHG emissions. Recent estimates put the total released from energy activities in 2010 at around 125–129 million tonnes of methane per year (4.2–4.4 billion tonnes of CO_2 equivalents), with 80–90 Mt from oil and gas supply and distribution (2.7–3.1 Gt CO_2e).[161] For comparison, this is the equivalent of 16–18% of the 17 Gt CO_2 emitted from oil and gas combustion in 2010. However, although estimates tend to be close to one another, data are in fact very poor. Actual emissions levels could in fact be much higher. For example, estimates of leakage from natural gas systems range as widely as 1–5% of total gas produced, with individual studies identifying still higher numbers.[162]

A number of assessments suggest that reducing methane emissions could be economically attractive and offer co-benefits through reduced air pollution, as well as substantial climate benefits. For example, the US Environmental Protection Agency has estimated that methane emissions from oil and gas systems could be reduced by 35% by 2030, or 880 Mt CO_2e, at no net cost once the value of the gas is taken into account.[163] More near-term, the IEA has identified measures in upstream activities could achieve 580 Mt CO_2e of emissions cuts by 2020, as part of a set of GDP-neutral measures to reduce GHG emissions.[164] Other detailed assessments for individual countries similarly show substantial reductions available at negative or low cost.[165] As methane also has adverse impacts on human health and crop yields through its contribution to the formation of ozone, reductions of fugitive emissions also would have other co-benefits.[166] Moreover, reducing methane emissions from natural gas systems, and unconventional gas production in particular, may be a prerequisite to enable a "bridge" function of natural gas in a transition to a low-carbon energy system.[167]

Achieving these reductions would require a combination of better measurement and monitoring to understand the scale of fugitive emissions; increased industry awareness and commitment to options to effect reductions; and sharper incentives to change practices and underpin long-term investment programmes. Some of these may be achievable through voluntary industry initiatives, notably in raising awareness and improving monitoring. Others may require regulation, including increased enforcement of existing regulations (e.g. to reduce flaring of gas) and new regulations to set standards across oil and gas supply chains.

which is a major reason why per capita transport fuel use is nearly three times as high in the United States as in Europe. Likewise, subsidies for energy are a major reason for the Middle East's declining energy productivity.

Yet efficient pricing alone is unlikely to capture all economically efficient energy efficiency opportunities, especially if there is a substantial upfront cost. Countries that have employed effective additional policy interventions, including standards, information, behavioural "nudges" and other means have seen much greater success in improving the productivity of their energy use. Three characteristics stand out among leaders in this field:

- **Effective understanding of their current status:** Countries need to know where they stand, relative to others and relative to where they could be. Measuring and communicating the potential has proven an important step for planning effective interventions and mobilising action.
- **Standards for markets that lack automatic mechanisms to ensure efficiency:** When the costs and benefits of efficiency measures do not accrue to the same actors – e.g. with rental properties – there is reduced incentive to invest in efficiency. Energy efficiency standards are then crucial – e.g. building codes, vehicle fuel-efficiency requirements, and appliance standards. Such standards also help induce innovation over time, especially when they are adjusted over time, as in Japan's Top Runner Program.[179] Governments should exercise caution, however, to ensure that higher upfront costs do not price housing or key services and goods beyond consumers' reach.
- **Effective finance:** Many countries have had success supporting energy efficiency through advantageous finance programmes, such as those of KfW in Germany.[180] Increasingly, new business models also help make finance available, through energy service contracting and other approaches.

The countries that best succeeded in these respects, and which have been able to steer economic activity towards sectors that are more energy productive, are now able to produce twice as much GDP per unit of energy as they did in 1980.[181] In contrast, several other countries have barely improved.

Businesses also can take action to benefit directly from improved energy efficiency. In particular, companies with extensive supply chains have an opportunity to work with their suppliers to increase efficiency. The potential is significant: reducing the energy use of just 30% of the top 1,000 corporations by 10–20% below business-as-usual levels would save about 0.7 Gt CO_2 per year by 2020, and likely more as the economy grows in later years.[182] The impact increases when measures are propagated throughout supply chains: a 10% emission reduction in the supply chains of the same 30% of companies would reduce emissions by another 0.2 Gt. There are already many companies taking such steps, such as the 100 companies in the Better Buildings Challenge in the US, which have pledged to reduce the energy intensity of their buildings by 20% over 10 years.[183] Mutually beneficial agreements between companies and their suppliers, such as innovative financing for energy efficiency investments in return for a share of cost reductions through lower future prices, could provide powerful incentives to improve energy efficiency in a range of businesses.

4. Barriers to a better system

Cumulatively, the developments surveyed above offer substantial promise to relieve a range of pressures on economies by turning to new ways of meeting energy demand. Yet achieving this is far from assured. Today's energy systems are the result of numerous choices made over several decades, by both public and private actors. They will not change easily. Building an energy system fit for the next 25 years will require deliberate effort – and an updated framework for energy decision-making. In this section, we begin to sketch out that new framework, and identify priorities for policy action. But first, we explore the key barriers to change, and how to overcome them.

Capital investments are a big factor in energy-system inertia: The total global value of energy supply infrastructure has been estimated at US$20 trillion,[184] and much of it – from power plants and transmission networks to steel plants and buildings – is very long-lived (multiple decades). Changing the way energy is supplied and used affects the value of existing infrastructure and may lead to "stranded" assets, with implications for both the energy sector, and those invested in it (see Chapter 6: Finance). Thus, there can be great political resistance to actions that affect energy-sector assets. Conversely, there is a penalty associated with not acting in time, as infrastructure choices today "lock in" dependencies and impacts for a long time in the future.

Governments also have a direct stake in how energy systems work. Many states own substantial stakes in energy companies, and governments derive substantial revenues from energy activities, through taxes and fees. Large numbers of jobs may be on the line.

Moreover, changing energy supplies requires changing laws and regulations, which can be slow and politically fraught. Energy is a heavily regulated sector, not only in terms of energy network monopolies, but also price controls, licenses for new energy activities, standards for energy-using devices, and parameters for how different types of energy supplies are used for power and other purposes. If reforms cannot be achieved, or the regulatory framework is unstable, it will be more difficult to attract capital to new classes of investment.

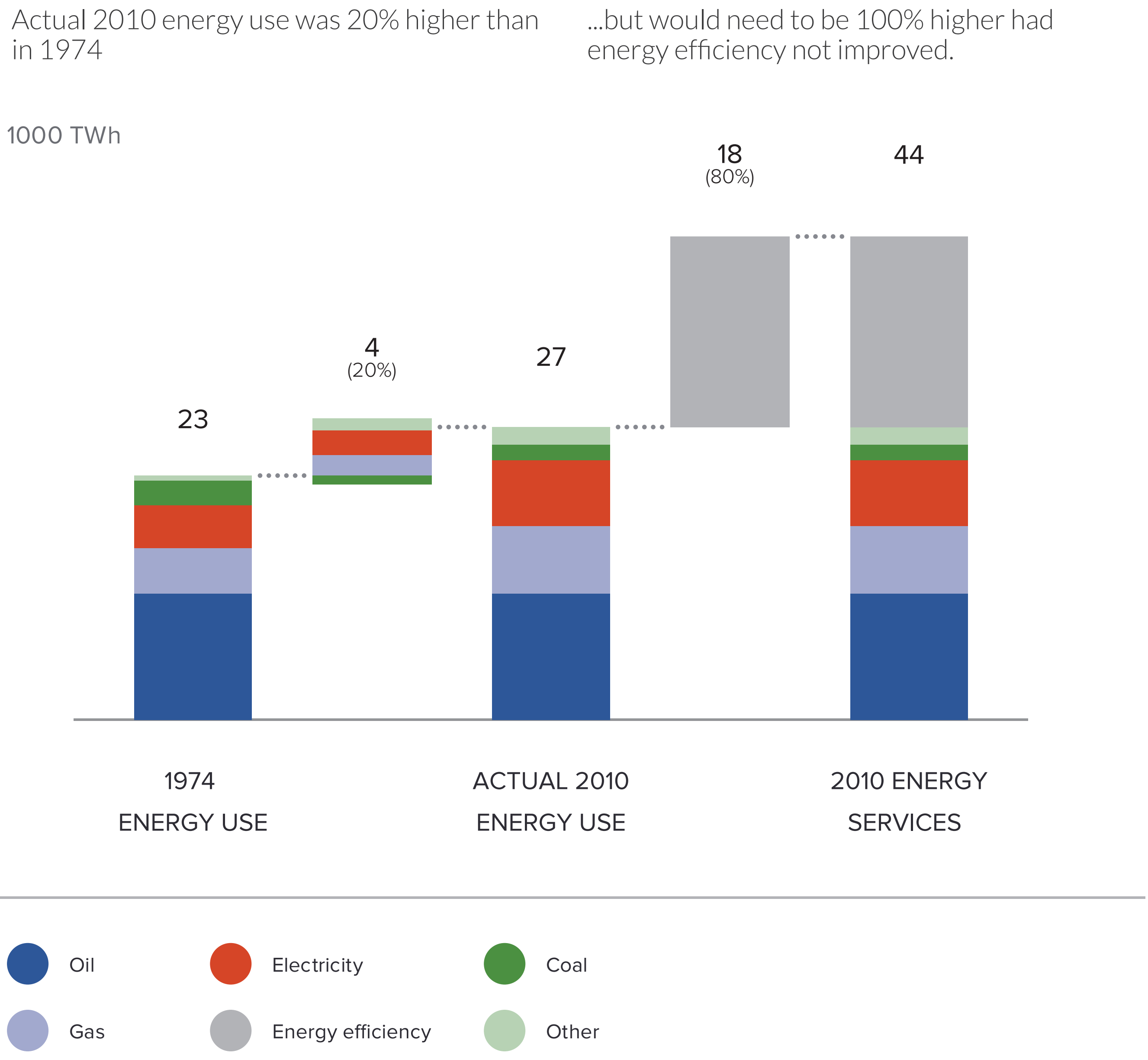
Another major obstacle to change, already mentioned, is artificially low energy pricing. Prices around the world are set through highly political processes, and often include direct subsidies, lower rates of taxation, or price controls to keep energy affordable. The total gap between the market value of fuels and the prices at which they are sold is more than US$500 billion per year.[185] The influence of low prices goes deep: often they have realigned economic priorities, favouring energy-intensive sectors when their overall costs would not justify it; they have rewarded energy inefficiency and waste; and they have even reshaped the physical landscape, encouraging sprawling cities. They have also depressed energy investment in many countries, magnifying energy access and supply problems. Correcting price distortions is thus crucial to building more productive, robust, flexible and sustainable energy systems. Yet doing so can be very difficult; the most successful efforts have been accompanied by careful measures to avoid negative social and economic impacts.

In addition, today's energy systems have been shaped by multiple market failures that allow companies and consumers to benefit from individual choices that together harm the economy or society at large. The most visible is the environmental impact of pollution from fossil fuel extraction and combustion, but it extends further, to land and food systems (e.g. for the production of bioenergy) or water (e.g. hydropower, hydraulic fracturing, or thermal-power plant cooling). Less visible, but also significant, is that design choices that affect energy consumption often are out of end-users' control. Rental properties and urban design are prime examples: in some cases, poor choices made decades ago still limit options and hinder change today. This is a significant challenge for cities, as discussed in Chapter 2: Cities, but also extends to many other energy uses. Over time, energy use patterns are embedded in culture, becoming even harder to change.

Finally, the attractiveness of energy options in one country depends strongly on what others do. For example, a small group of countries pioneered the energy innovations that now create opportunities for all others. Likewise, as noted, widespread action to increase energy efficiency and adopt low-carbon alternatives could take pressure off fossil fuel prices, but countries acting individually do not have enough market power. Overall, cooperation on energy matters can have many benefits, but it is hard to achieve.

These barriers are not a cause for despair or inaction. There are numerous examples where deliberate strategic direction has yielded rapid results, such as the rapid switch to natural gas in the UK and the Netherlands, the build-out of nuclear power in France or Sweden, the reduction in overall energy import dependence in Denmark, and the recent success in extending energy access in rural China. What these examples show, however, is that overcoming inertia in energy systems requires deliberate action. This need not mean government control over energy sectors, but it means governments need to put in place the prerequisites to enable new solutions.

Figure 5
Impact of energy efficiency on energy consumption in 11 countries, 1974–2010



Note: The figure shows the actual increase in annual final energy consumption, and the energy that would have been needed without energy efficiency improvements. Energy services doubled, but energy use went up by only 20%. The countries surveyed are Australia, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Sweden, UK, and US Energy efficiency was four times more important than any actual fuel source for enabling growth in energy services.

Source: IEA, 2013.[169]

4.1 Rethinking energy priorities

These changes must be underpinned by a framework for decision-making fit for a new energy situation and a broader set of priorities. Energy systems need to be more flexible and nimble, able to grow and adapt to fast-changing conditions. They must be better able to meet demand through productivity and efficiency improvements, not just increased supply. They must be able to accommodate a wider range of energy sources, through new business models and trade relationships, and at different scales of operation. They must be able to drive investment and innovations to meet the next wave of demand. And they must be grounded in a full understanding of the costs and benefits of different options, with prices that reflect the true cost of energy, including its impact on security, volatility, balance of payments, pollution, and the climate. Climate in particular, though likely not the top priority for energy decision-makers, is a highly time-sensitive consideration, since choices made over the next 5–15 years will have long-lasting impact on cumulative CO_2 emissions.

Decision-makers also need to be more forward-looking, alert to potential environmental or economic missteps that could require expensive corrective action, and conscious of rapid technological change when setting policy. A better handling of uncertainty and risk must be an indispensable part of this. Energy decisions need to account for the value of insurance against adverse scenarios. This will place a greater value on keeping options open until major structural uncertainties are resolved. Early diversification is also an important way to approach the dilemma of making long-term commitments in a situation of irreducible and growing uncertainty.

The next 5–10 years are critical for the future of energy systems. No single approach can meet all countries' needs; each will have to choose its own pathway, with the best technologies, policies and investment strategies to meet its people's needs. Still, the Commission has identified broad areas that offer particular promise, with benefits within the next decade. All are areas where near-term policy decisions can make a large medium- to long-term difference. Action in these areas will help countries keep their options open, be flexible, and be able to adjust to a range of future scenarios.

5. Recommendations

- Get energy pricing right: Implement energy prices that enable cost recovery for investment; remove subsidies for fossil fuel consumption, production and investment; avoid lock-in to wasteful economic structures and consumption patterns, and better reflect national wider priorities.

In implementing such reforms, countries should:

- Eliminate price distortions that perpetuate the under-investment that in turn imperils growth in energy access;
- Account for social objectives, including by complementing reform with compensating measures to protect the poor; and
- Put an effective price on carbon emissions as a foundation for overall efforts to reduce climate risk and a more.

- Reverse the "burden of proof" for the construction of new coal-fired power, and adopt an improved framework for energy decision-making.

Governments should ensure that new coal fired power is built only when other options have been proven not to be viable when considered against the full set of energy objectives. In high-income countries, commit to avoiding further construction of new unabated coal as a minimum first step to avoid further lock-in to high GHG emissions and accelerate retirements of old plants. In middle-income countries, take steps to limit new construction, and consider avoiding new construction altogether beyond 2025. In all countries, make decisions on the understanding that unabated coal infrastructure cannot be expected to operate beyond 2050.

Such strategies should be underpinned by appreciation of uncertainty rather than single scenarios, and include the following key elements:

- Start now to build the capacity to use new sources of energy, accounting for the value of having a greater range of options given future uncertainty;
- Place a value on insurance against adverse scenarios, whether geopolitical or in terms of energy prices;
- Evaluate the cost of taking future corrective action, including to undo lock-in to high levels of import dependence or air pollution;
- Incorporate a valuation of exposure to fossil fuel price volatility that cannot be hedged in markets;
- Account for the ongoing trends in cost, including continued systematic shift in favour of renewable energy sources; and
- Adopt policies which impose a price on pollution – explicitly through taxation or implicitly through standards or other regulation – with damages from coal-fired power priced at least at US$50/MWh, or more for plants without local air pollution controls.

- Raise ambition for zero-carbon electricity.

Without a deliberate reassessment many countries risk continuing to treat renewable energy as a marginal or experimental part of energy supply, even where it can be a core contributor. The steps and degree of ambition will vary across countries, but include:

- In fast-growing countries, adapt electricity system planning to enable the integration of renewables;
- In high-interest countries, enable lower-cost finance and address key risks as the most cost-effective ways to channel public support;
- In mature economies, adapt market arrangements to support the next wave of innovation to enable a higher share of renewables;
- Include off-grid and mini-grid solutions in approaches to expanding energy access;
- Design support systems to create regulatory

certainty, minimise distortions to electricity markets, and transparently adjust support levels as costs and circumstances change.

- **Launch a platform for public-private collaboration for innovation in distributed energy access.**

Governments should collaborate to establish and provide resources for a network of regional institutions for a) publicly funded R&D in off-grid electricity, household thermal energy, and micro- and mini-grid applications; and b) incubation of businesses that apply new technologies and new business models for new distributed energy technologies.

This network can build on the strengths of the CGIAR model[186] for key agricultural applications, including public financing of R&D to develop innovations with stronger social outcomes and a distributed institutional structure, through regional hubs, that allows context-specific innovation.

It can further improve on the CGIAR model by adopting a business incubator approach complemented by context-specific social and behavioural approaches:

- Adopt a portfolio and venture approach, with tolerance for failure of individual businesses as opposed to the risk-minimising approaches often taken in public initiatives;
- Provide relatively small amounts of seed capital to multiple companies, to help each innovator with a promising new business model or technology grow to scale;
- Build on social impact investment by using financial leverage to achieve social objectives;
- Address economic and behavioural hurdles to dissemination of new technology, and develop approaches that are context-specific; and
- Complement with cash transfers to enable access by the very poor.

- **Adopt energy demand management measures, to address the barriers that prevent the development of energy-productive economic activity and energy-efficient end use.**

A key first step is to get energy prices right, as discussed above. Energy decision-makers should also:

- Map the potential by creating national roadmaps that identify and prioritise energy efficiency opportunities: countries, companies, and consumers need to know where they stand, relative to others and relative to where they could be.
- Monitor and develop benchmarking targets for the energy intensity of key industries, extending to voluntary or mandatory programmes, depending on circumstances;
- Set and frequently update standards where market barriers stand in the way or prices to drive efficiency cannot be implemented, including for buildings, appliances, and vehicles. Standards need to balance the benefits of efficiency against costs to ensure net higher access to key energy services for low-income consumers.
- Provide concessional and other finance to ensure that measures to improve efficiency at a minimum benefits from the same support that is extended to enable the expansion of energy supply.

- **Address non-CO_2 GHG emissions from energy, starting by accelerating efforts to identify and curtail fugitive methane emissions.**

Policy interventions are needed to improve measurement and monitoring, accelerate voluntary initiatives that help raise awareness, create incentives for higher-cost measures, and introduce new standards for maximum fugitive emissions from oil and gas systems. Enforcement should also become increasingly stringent over time.

Methane emissions from oil and gas supply and distribution have a significant climate impact and can be reduced at negative or low cost, and with co-benefits from improved air quality. Several measures can help spur action:

- Launch a major initiative to improve understanding of methane leakage levels around the world, through increased measurement and monitoring, and use the resulting data to inform decision-making and GHG mitigation strategies.
- In the near-term, put in place the requirements (industry initiatives, incentive schemes, and enforced and sufficient regulation) to enable changes to practices and support selected investment initiatives in the upstream oil and gas sector.
- Over a longer period (decade or more) make methane leakage reduction a core component of network construction and maintenance.

Endnotes

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57 The estimated range is likely cost-effective reductions of 4.7-6.6 Gt CO_2 / year, through a combination of policies already announced (2.9 Gt), energy efficiency potential (0.9-1.8 Gt) and fuel switching away from coal in the power sector (0.9-1.8 Gt). The energy efficiency potential is based on modelling studies including the IEA Efficient World scenario (IEA, 2012), and accounts for overlaps with the analyses of potential through specific energy efficiency opportunities in buildings (See Chapter 2), energy efficiency opportunities in manufacturing (see Ch 7), and modelling studies of the impacts of removing fossil fuel subsidies (see section 3.6). The estimate assumes that 50-100% of the potential identified as cost-effective in these studies is cost-effective once accounting for reasonable 'payback' periods for investment and factors such as potential 'hidden' costs, the potential for greater rebound effects, and co-benefits such as reduced air pollution. The fuel switching potential corresponds to a further 20-40% fuel switching away from coal over and above policies already announced (as per the IEA New Policies scenario), motivated by a combination of reduced air pollution health effects (see section 3.2), as well as the increasing potential for cost-effective use of renewable energy (see section 3.3, and in particular the discussion of the IRENA REmap options). For further discussion of the scope and limitations of these estimates, see: New Climate Economy, 2014 (forthcoming). Quantifying Emission Reduction Potential. New Climate Economy contributing paper. London.
To be available at: http://newclimateeconomy.report.

58 Personal communication with EBRD, August 2014.

59 For a brief discussion of CCS "readiness" and CCS retrofitting, see, e.g., Box 8 of International Energy Agency (IEA), 2013. Technology Roadmap: Carbon Capture and Storage 2013. Paris.

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Also: IPCC, 2005. IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change (Metz, B., O. Davidson, H.C. de Coninck, M. Loos, and L.A. Meyer, eds.). Cambridge University Press, Cambridge, UK, and New York. Available at: http://www.ipcc-wg3.de/special-reports/special-report-on-carbon-dioxide-capture-and-storage.

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63 See IEA, 2013. Technology Roadmap: Carbon Capture and Storage 2013.

64 EOR involves pumping an inert liquid or gas such as CO_2 into an oil reservoir, and using the pressure to force hard-to-recover oil towards the production well. For a detailed explanation, see: http://energy.gov/fe/science-innovation/oil-gas-research/enhanced-oil-recovery. [Accessed 18 August 2014.]

65 See Global CCS Institute, 2014. The Global Status of CCS.

Available at http://www.globalccsinstitute.com/publications/global-status-ccs-february-2014.

Confirmed here means that an investment decision has been taken (as of February 2014). The total increases to more than 80 projects and 115 million tonnes of CO_2 per year when including proposed projects with no investment decision, though the CO_2 in most cases would be used for enhanced oil recovery, which might not include the confirmed permanent storage and monitoring assumed in the IEA roadmap.

66 Analysis by the NCE project team, based on interpolation of numbers from IEA, 2012, Energy Technology Perspectives 2012.

67 IEA, 2013. Technology Roadmap: Carbon Capture and Storage 2013.

68 IEA, 2013. Technology Roadmap: Carbon Capture and Storage 2013.

69 See Chapter 7: Innovation, as well as IEA, 2013. Technology Roadmap: Carbon Capture and Storage 2013, Box 3.

70 Abellera, C., and Short, C. / Global CCS Institute, 2011. The Costs of CCS and Other Low-Carbon Technologies. In Global CCS Institute Issues Brief 2011, no. 2. Available from http://decarboni.se/sites/default/files/publications/24202/costs-ccs-and-other-low-carbon-technologies.pdf.

71 For a detailed account of air pollution impacts; see: Kuylenstierna, J.C.I., Vallack, H.W., Holland, M., Ashmore, M., Schwela, D., Wei Wan, Terry, S., Whitelegg, J., Amann, M., and Anenberg, S., 2014 (forthcoming). Air Pollution Benefits of Climate Strategies. New Climate Economy contributing paper. Stockholm Environment Institute, York, UK. To be available at: http://newclimateeconomy.net.

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Available at: http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/.

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75 Based on analysis for the Commission of a range of studies. See: Hamilton, K., Brahmbhatt, M., Bianco, N., and Liu, J.M., 2014. Co-benefits and Climate Action. New Climate Economy contributing paper. World Resources Institute, Washington, DC.

Available at: http://newclimateeconomy.report.

76 See Klevnäs and Korsbakken, 2014. A Changing Outlook for Coal Power.

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Available at http://newclimateeconomy.report. The paper estimates costs of US$57.5/MWh, which corresponds to US$49/MWh for a coal plant with 40% efficiency. The number is an emissions-weighted average.

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health-damaging particles have a diameter of 10 microns or less, which can penetrate the lungs; these are referred to as PM10. In many cities, the concentration of particles under 2.5 microns is also measured; this is PM2.5. See: World Health Organization, 2014. Ambient (outdoor) air quality and health. Fact Sheet No. 313. Geneva. Available at: http://www.who.int/mediacentre/factsheets/fs313/en/.

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86 Teng, F., 2014 (forthcoming). China and the New Climate Economy. New Climate Economy contributing paper. Tsinghua University. To be available at: http://newclimateeconomy.report.

87 See Wang et al., 2014 (forthcoming), China's Coal Envelope, and Teng, F., 2014 (forthcoming), China and the New Climate Economy.

See also Strambo, C., Chen, B., Hallding, K. and Han, G., 2014 (forthcoming). The Greater Beijing Region Air Quality Control Programme: Prospects and Challenges. New Climate Economy contributing paper. Beijing Normal University, Beijing, and Stockholm Environment Institute, Stockholm. To be available at: http://newclimateeconomy.report.

88 This box summarises a study produced for the Commission: Strambo et al., 2014 (forthcoming). The Greater Beijing Region Air Quality Control Programme: Prospects and Challenges.

89 For context, Hebei was found to have a Human Development Index of 0.691 in 2010; the United Nations Development Programme's latest HDI analysis puts the cut-off for "high human development" at 0.7, and China qualifies, with an overall HDI of 0.719 in 2013. For national rankings, see: http://hdr.undp.org/en/content/table-1-human-development-index-and-its-components.

For the China study that estimated HDIs for different Chinese regions, including Hebei, see: UNDP China and Institute for Urban and Environmental Studies, 2013. China Human Development Report 2013: Sustainable and Liveable Cities: Toward Ecological Civilization. United Nations Development Programme and Chinese Academy of Social Sciences, Beijing.
Available at: http://www.cn.undp.org/content/china/en/home/library/human_development/china-human-development-report-2013/.

90 See, for example: Xinhua, 2013. Xinjiang to launch huge coal gasification project. 6 October. Available at: http://news.xinhuanet.com/english/china/2013-10/06/c_125488499.htm.

However, after a surge in coal-to-gas projects, the government has recently tried to rein in "irrational" development of large-scale projects. See: Xinhua, 2014. China to curb blind investment in coal-to-gas. 22 July. Available at: http://news.xinhuanet.com/english/china/2014-07/22/c_133502992.htm.

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See: International Renewable Energy Agency (IRENA), 2014. REmap 2030: A Renewable Energy Roadmap. Abu Dhabi.
Available at: http://irena.org/remap/.

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(see http://www.worldenergyoutlook.org for an archive of WEO reports). Similar trends are seen in scenarios made by the U.S. Energy Information Administration (EIA) and many others in the last two decades.

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REN21, 2014. Renewables 2014 Global Status Report. Paris: Renewable Energy Policy Network for the 21st Century.
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International Energy Agency (IEA), 2013. Technology Roadmap: Wind Energy – 2013 Edition. Paris.

Available at: http://www.iea.org/publications/freepublications/publication/name-43771-en.html

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103 Channell, J., Lam, T., and Pourreza, S., 2012. Shale and Renewables: a Symbiotic Relationship. A Longer-term Global Energy Investment Strategy Driven by Changes to the Energy Mix. Citi Research report, September 2012.

Available at: http://www.ourenergypolicy.org/wp-content/uploads/2013/04/citigroup-renewables-and-natgas-report.pdf.

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107 IEA, 2014. Energy Technology Perspectives 2014.

108 International Renewable Energy Agency, n.d. IRENA Renewable Energy Country Profiles. http://www.irena.org/menu/index.aspx?CatID=99&PriMenuID=47&mnu=cat. [Accessed 11 June, 2014.]

109 IEA, 2013. World Energy Outlook 2013.

Also see: Turkenburg, W. C., Arent, D. J., Bertani, R., Faaij, A., Hand, M., et al., 2012. Chapter 11: Renewable Energy. In Global Energy Assessment – Toward a Sustainable Future. Cambridge University Press, Cambridge, UK, and New York, and International Institute for Applied Systems Analysis, Laxenburg, Austria. 761–900. Available at: http://www.globalenergyassessment.org.

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126 IEA, 2013. World Energy Outlook 2013.

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http://www.eia.gov/forecasts/aeo/electricity_generation.cfm.

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149 IEA, 2011. Energy for All.

150 This is both because the absolute amount of energy required is small and because increased CO_2 emissions would be offset in part by reduced emissions of non-CO_2 GHGs. See Pachauri et al., Pathways to achieve universal household access.

Country estimates confirm the global findings; for example a study in coal-heavy South Africa found that connecting 3.4 million households to the grid to ensure universal access to electricity by 2020 would add 13Mt of CO_2 emissions, about 1.8% of the country's total projected GHGs for that year; see Tait, L. & Winkler, H., 2012. Estimating greenhouse gas emissions associated with achieving universal access to electricity in South Africa. Energy Research Centre, University of Cape Town. Available at: http://cdkn.org/wp-content/uploads/2012/08/12Tait-Winkler-Emissions.pdf.

151 See http://www.cgiar.org and discussion of it in Chapter 3: Land Use.

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158 This section summarises the findings of an NCE background paper on the conditions under which natural gas might act as a bridge fuel to a low-carbon future. See Lazarus et al., 2014. Natural Gas: Guardrails for a Potential Climate Bridge.

159 For comparison, 400 billion cubic metres (bcm) is equal to 3.5 times China's current gas use, 20% of its current coal use, and greater than recent projections for the growth in coal over the next 20 years. It thus could be a very major element in a transition away from coal.

See: International Energy Agency (IEA), 2012. Golden Rules for a Golden Age of Gas. World Energy Outlook Special Report on Unconventional Gas. Paris. Available at: http://www.worldenergyoutlook.org/goldenrules/.

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170 Analysis for the Global Commission, drawing on scenarios discussed in: GEA, 2012. Global Energy Assessment, and: Bruckner et al., 2014. Chapter 7: Energy systems.

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The emission reduction estimate is based on the reduction in energy usage reported in World Energy Outlook 2011, which corresponds to c. 2.3 Gt for 2030. The lower range results from adopting a more conservative assumption and also accounting for overlap with other measures recommended in this report. See: New Climate Economy, 2014 (forthcoming). Quantifying Emission Reduction Potential. New Climate Economy contributing paper. London. To be available at: http://newclimateeconomy.report.

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Chapter 5

ECONOMICS OF CHANGE

Main points

- The next fundamental transformation of the global economy can deliver strong economic growth and poverty reduction, and at the same time reduce the growing potential risks of climate change.
- Many of the perceived short- to medium-term trade-offs between economic growth and climate action disappear when policy is examined in a dynamic context of change, and when existing economic inefficiencies and the multiple benefits of action are taken into account.
- The multiple benefits of low-carbon policies, such as health benefits from reduced fossil fuel use and increased fiscal efficiency through recycling of revenues from carbon pricing, could offset the costs of climate action. Agile labour markets and just transition policies for workers can also reduce the economic costs, including limiting the impact on aggregate employment.
- Many model-based assessments do not consider these multiple benefits and market dynamics. Notwithstanding these limitations, recent modelling suggests economic costs of climate action for a 2°C path are likely to be small, at around 1.7% (median) of baseline global GDP in 2030. This is equivalent to reaching the same level of baseline GDP around 6 to12 months later.
- Delay raises costs, potentially cutting global consumption growth by around 0.3% per year in the decade 2030 to 2040, compared to less than 0.1% per year over the same period if we act now. Delay may also lead to greater climate damage in the long-term, which could impact the drivers of growth and hit sovereign credit ratings of vulnerable countries.
- To manage change and realise growth opportunities, clear and credible policies are needed to align expectations, guide investors, stimulate innovation, and avoid locking in to carbon intensive infrastructure and behaviour. Policy frameworks will differ by country but should aim to include a price on carbon as part of wider fiscal reform and phase out of fossil fuel subsidies, estimated at around US$600 billion per year.

1. Introduction

Throughout history economies have constantly had to adapt to changing preferences, politics and technologies. Such shifts have driven changes in investment in energy, cities, land use and transport. Public institutions and financial services have had to innovate to adapt. Over the past few decades economies and technologies have changed rapidly and profoundly, and the next few decades will see continuing transformation. Countries now face radical choices that will shape their economies, including their cities, energy systems and land use, in decisive ways for decades to come. This chapter is about these choices.

Some change is more predictable and this knowledge can help governments plan. Coming changes are likely to include: a continued, strong rise in the share of output from emerging markets and developing economies; a world population that may increase by an estimated one billion or more people by 2030; rising pressure on resources as the world industrialises; continuing, rapid urbanisation; population aging and a decline in the working-age population in many countries; and the building and rebuilding of energy systems. At the same time the world has seen and will see increasing risks from global climate change. Some change is less predictable, however, for example as a result of technological or other innovation breakthroughs, resource price shocks or geopolitical conflict.

Countries face radical choices that will shape their economies, including their cities, energy systems and land use, in decisive ways for decades to come.

The structural transformations that will take place may be handled well or badly. If they are handled well they will be less costly and stimulate more innovation and opportunity. Lessons from economic history are helpful here. We have the advantage of learning from several transformations since the industrial revolution, including from a rich Schumpeterian tradition of analysis, discussed in Section 5.3. The opportunities and risks from the structural changes different countries face are highlighted in Chapter 1: Strategic Context.

Institutions and policies are central to transition. Economies with accountable institutions and responsive policy frameworks will be better placed to adapt, evolve, embrace and manage change, to reallocate resources more efficiently, and to foster growth opportunities. They will have the flexibility to tap new markets and adopt new innovations. The alternative – of resisting change, protecting vested interests, propping up declining industries and delaying action – risks locking in less productive growth and leaving investors, firms and households vulnerable to shocks. Resisting change may enable economies to squeeze a little more out of their existing structure in the short-term, but it is unlikely to benefit them in the medium- to long-term.[1]

This chapter outlines the policies that governments could implement over the next 15 years to steer the next transformation of the world economy in a low-carbon direction.

The view that there is a rigid trade-off between low-carbon policy and growth is partly due to a misconception in many model-based assessments that economies are static, unchanging and perfectly efficient. Any reform or policy which forces an economy to deviate from this hypothetical counter-factual baseline incurs a trade-off or cost. In fact, there are a number of reform opportunities that can reduce market failures and rigidities that lead to the inefficient allocation of resources and hold back growth, including excessive greenhouse gas emissions. Indeed, once market inefficiencies and the multiple benefits of reducing greenhouse gas emissions, including the potential health benefits of reduced air pollution, are taken into consideration, the perceived net economic costs are reduced or eliminated. But tackling market failures and taking advantage of these multiple benefits requires ambitious and coherent policy.

This chapter focuses its analysis on the three key drivers of growth: resource efficiency; better infrastructure investment; and innovation. These will be critical for determining the pace and shape of change. It illustrates this through reference to the three critical systems highlighted throughout the report – energy, cities and land use – which are at the heart of structural change. Governments can provide clear and credible policy incentives to stimulate these drivers of growth in a way that guides a structural shift to a low-carbon economy.

It should be viewed alongside the rest of the report. For example, Chapter 1: Strategic Context, describes the story of structural change in different economies and explains how this motivates the analytical bases of this report. Chapter 6: Finance describes how to drive low-carbon investment, taking forward analysis here of a low-carbon policy framework. Policies to tackle market failures are discussed further in Chapter 7: Innovation, regarding research and development.

The chapter starts by outlining the key elements of a strategy for low-carbon growth. Section 3 discusses the broad policy mix, focussing on fiscal reform including carbon pricing and fossil fuel subsidies. Section 4 discusses policies to ease the transition for the poorest and most vulnerable. Section 5 analyses how to achieve clear and credible policy signals, including better metrics and models, to guide expectations, and provides lessons from history. Section 6 concludes with recommendations for policy-makers.

2. A framework for economic growth that also tackles climate risk

2.1 The framework

This chapter and report discusses how to achieve "better growth" that increases quality of life across key dimensions, including incomes, social stability, equality, and better health, while also achieving a "better climate". By "better climate" we mean reducing the risk of dangerous climate change by cutting greenhouse gas emissions.

The economic framework presented in this chapter for "better growth" and a "better climate" recognises that economies are not "static" but are dynamic and constantly changing. As such the economic analysis and tools deployed must be appropriate for this context.

The framework has four main building blocks:

- The short-run opportunities to tackle market imperfections that hurt economic performance and increase climate risk;
- Investment, growth and structural change in different country contexts;
- Flexible approaches to managing transition, especially given political economy challenges, and distributional issues that need to be tackled; and
- The development and deployment of improved measurement and modelling tools that can improve economic decision-making and lead to better policy choices.

Tackling market imperfections and steering innovation

Economic principles inform us that there are opportunities to pursue strong economic growth today that are also good for climate because a range of market failures persist with immediate social, economic and environmental costs.

Greenhouse gases are a market failure as the emitter does not bear the costs of the damage and disruption from their activities. Some have suggested that greenhouse gases may be the largest market failure of all.[2] Beyond the long-run impact of greenhouse gases on the climate and thus the economy, emissions from burning of fossil fuels cause severe local air pollution today which damages the health and productivity of millions of people, particularly in urban areas in rapidly developing countries. Outdoor air pollution caused 3.7 million premature deaths in 2012, according to the World Health Organization (WHO). Emissions from transport, industry and power generation are a major source of this pollution.[3]

Other market failures include imperfections in risk and capital markets, for example a failure to consider the full range of investment costs and benefits. Such market failures misprice risk; limit access to finance; and reduce investment in infrastructure. Another failure is in early stage research and development (R&D), where technical knowledge "spills over" to others. This prevents the innovator from capturing the rewards of their efforts and deters investment in innovation. Market failures around the provision of information and networks are also crucial. For example, poor awareness of the potential for long-term energy savings would result in under-investment in energy efficiency (see Section 3.3).

These combined market failures imply that policy reforms are possible today that can effectively and efficiently boost productivity and growth. Policy to reduce fiscal distortions from unpriced greenhouse gases will enhance resource efficiency and deliver multiple other benefits including reduced local air pollution. Policy to tackle market failures in capital markets will boost productive infrastructure investment. And policy to tackle the spillover problem can stimulate innovation, the benefits from which can often come through more quickly than expected. In economic terms, policy to tackle market failures can give rise to the possibility of a Pareto improvement, where at least one person is made better off with nobody worse off.[4]

The cost-effectiveness and efficiency of such a strategy will be enhanced further if it is well-coordinated and complemented with policies to promote economic flexibility, including more responsive labour markets; a better educated workforce; and open and free trade. Strong and trusted institutions that align expectations on the direction of change and which reduce policy risk are also important.

But this framework goes far beyond an exercise in "comparative statics", where the limitations of the existing economic system are stated and the policies that can correct market failures are described. This approach is about the dynamics of change: recognising that the transformation is likely to be non-marginal, and embracing this change through a broad suite of social and economic policies to steer the economy onto a low-carbon path. In other words, this is about combining the economics of market failures with the economics of change and transformation.

Investment, growth and structural change in different country contexts

Policies to foster low-carbon growth and realise the multiple benefits discussed throughout this report may require additional investment in the next 15 years, above what would be required without climate action (see Section 4.3). The appropriate way to consider these additional investment costs is the "dynamic net economic cost".

The dynamic net economic cost includes the additional up-front investment, for example, the cost of upgrading and constructing new networks and new low-carbon energy infrastructure. These are monetary costs and must be financed (see Section 3.3 and Chapter 6: Finance).

The additional investment may also impose a resource cost if it ties up additional inputs to produce the same amount of output, e.g. an off-shore wind farm may require more skilled labour and more physical resources than a fossil fuel plant to produce a megawatt of electricity. This would reduce total output as it uses up existing productive resources.

However, this resource cost does not reflect the final economic cost. For example, climate policies are likely to incentivise substitution away from more to less carbon-intensive goods, often with attractive fuel savings. The more substitution opportunities available in the short-term, and as innovation makes more substitutes available, the lower the economic cost.

But calculating the final dynamic net economic cost requires us to consider the full range of costs and benefits, including the returns to the up-front investments. These include a reduction in long-run climate risk but also short- and medium-run benefits such as health, congestion, security and innovation (see Section 3.1). In fact, there is evidence that low-carbon investments may have greater scope for learning- and innovation-driven cost reductions than high-carbon alternatives, and also greater scope for spillover into other sectors.[5]

Where political and institutional realities are difficult to overcome, countries have adopted pragmatic "second-best" approaches

The full dynamic net economic cost must also reflect net economic benefits that will be forgone if action is delayed. Taking action later to derive the same economic returns will require a larger investment, and with high-carbon infrastructure, technologies and behaviours further locked-in, the dynamic costs will rise.

Therefore this is not a "free lunch" - some additional upfront investment is needed to pay for the attractive benefits and this may have an economic cost in terms of additional resources. But after considering the net benefits it is a "lunch worth paying for" - these investments have attractive economic returns and could quickly pay for themselves. Delay raises the dynamic net economic cost.

The precise policy framework required to drive investment for low-carbon growth will differ from country to country, depending on their individual contexts. For example, industrial policies have often been favoured in the past by countries, such as South Korea, trying to progress rapidly from middle- to high-income. When well-targeted, such policies have helped to foster investment in new and productive low-carbon industries. Another approach is tax reform to boost demand for environmental goods and services. Vietnam adjusted tax rates on polluting goods and services, such as fuels and chemicals, to reflect their environmental damage. This reform boosted investment and domestic demand for goods and services, but better recycling of the additional tax revenues could have reduced the costs of the reforms for particular groups.[6] China has incorporated growth and low-carbon objectives into its 5-year plans, with the 12th plan containing a range of measures to reduce emissions growth and promote investment in strategic high-tech, low-carbon industries.[7] The shape of its 13th plan (2016-2020) is likely to strengthen this transformation.

This chapter has many relevant lessons for least developed countries. However, their special circumstances demand additional analysis and focus. For example, a study prepared for the Commission examines the role that agriculture can play in addressing poverty reduction in Africa. It discusses how transformative adaptation in agriculture could present opportunities for "triple-win" outcomes with benefits for economic growth, poverty reduction and environmental sustainability. Crop intensification, minimum tillage, agroforestry coupled with designation and maintenance of protected for¬ests, support for social protection and development of insurance markets, are examples of techniques and policies that can deliver these outcomes. Such adaptation also presents an opportunity to tackle long-standing barriers holding back productivity gains in agriculture, including restrictions on regional trade, under-investment in infrastructure and limited provision of social protection.[8]

Managing the challenges of transition

In practice, governments have found it difficult to implement the most cost-effective and efficient policies for growth and reducing climate risk, such as legislating an explicit carbon price coupled with productive use of the resulting auction or tax revenues. This difficulty is partly a result of political economy pressures, including powerful vested interests in a fossil fuel-based economy, concerns around competitiveness, and concerns around any regressive impact of these policies on households. In a low-carbon transition, the specific costs, trade-offs and benefits that affect particular groups need to be carefully analysed. Dedicated, transparent measures are likely to be needed to reduce the costs and trade-offs for workers and firms. Managing change also requires strong institutions that can set clear and credible policies to guide expectations on the direction of change. Weaknesses in institutions and policy uncertainty raise the costs of change and slow the transition.

In cases where political and institutional realities are difficult to overcome, many countries have adopted pragmatic "second-best" approaches where the alternative may be no policy at all. Governments may need to take a step-by step approach, to discover the right combination of instruments and institutions to advance overall welfare. Where possible, governments could maintain flexibility in these policy frameworks, so that they can move towards more efficient and effective approaches over time - second best policy is only useful if it moves policy in the right direction. To ensure a continuing transition towards more optimal policy design, governments can legislate provisions to review the effectiveness and efficiency of policies.

Metrics and models for better policy

The appropriate metric for judging an economic policy intervention is its impact on overall welfare. If the policy creates a net welfare gain, it will still be important to consider the possible negative impacts on different groups, and whether some mechanism for redistributing the benefits of the policy is needed, e.g. assistance for some groups towards adjustment costs. Sometimes a policy may appear costly because not all its benefits are included in the balance of costs and benefits or are not easily identified. It is also of great importance to consider the counter-factual baseline with which a new policy is compared. In the case of low-carbon policies, the usual baseline assumption of "business as usual" growth may not hold due to the transformation that is coming anyway and the risks from future climate impacts. An appropriate counter-factual for comparison should reflect the economic costs of climate change and other impacts of continued growth in fossil fuel combustion, such as worsening air pollution.

Ministries of Finance need to tackle such shortcomings in their decision-making by adding several steps to routine policy evaluation. First, they could take an economy-wide view of costs and benefits. Second, they could recognise classes of costs and benefits not traditionally included in cost-benefit analysis, such as health costs from air pollution. Third, they could provide guidelines for how to incorporate these wider costs and benefits into planning and cost-benefit analysis tools.[9] Fourth, they could consider longer term returns rather than focus solely on up-front costs, as is standard practice when assessing investments in education or infrastructure. Governments can formalise this wider consideration of costs and benefits in economic policy-making through better use of metrics and models for monitoring and assessing the impacts of policy and change on quality of life, as discussed in Section 5.

Welfare must be approximated and gross domestic product (GDP) is often used. But GDP remains just one indicator among many attempting to measure changes in welfare. Supporting indicators are also necessary. For example, measuring the risk of overuse and damage to the natural world requires metrics beyond GDP. Governments and firms can incorporate such risks into decision-making by monitoring cumulative human impacts on various types of natural capital, including, water, ecosystems, species, minerals, the atmosphere and oceans. Monitoring would require governments and firms to include natural capital in national and corporate accounts (see Section 5). A failure to measure and manage natural capital is likely to result instead in its depreciation and possible destruction, with direct impacts on productivity, growth and output.[10] On the other hand, in recognising and measuring the value of natural capital, efficient environmental management can become a productive investment that is comparable with investments in physical or human capital. In this way there is a real opportunity to boost medium- to long-term growth through policies that increase the productivity of natural capital, including the atmosphere. Chapter 3: Land Use illustrates how this can happen in practice, through better management of degraded agricultural lands and by curbing deforestation.

To conclude, with economies constantly changing and transformation of the world economy likely over the coming decades, it makes sense to start to manage this change now. The framework for growth presented is a realistic one that can be implemented over the coming 15 years. The proposed approach would tackle the factors impeding economic growth today, while also accelerating a low-carbon transition. It will help to avoid the lock-in of long-lived high-carbon infrastructure, promote resource efficiency, reduce fiscal distortions, tackle pollution-related health issues, enhance energy security, drive low-carbon innovation, and increase the momentum for more effective and ambitious mitigation measures in the future.

The policy decisions taken in the next 15 years will be crucial for both long-term growth and the climate. There are huge opportunities for human welfare if change is managed well, and huge risks if managed badly. Sustained policy efforts will be needed beyond 2030 to ensure that these short- to medium-term reforms achieve the long-term, internationally agreed goal of reducing greenhouse gases to levels consistent with keeping global average temperature rise to below 2°C compared with pre-industrial levels.

2.2 The broad policy mix and institutions to enable change

Countries which anticipate and plan for change are likely to perform better. Various policy instruments will be needed to manage change. This does not mean more or unnecessary regulation, rather better policies and institutions for more efficient markets and for managing the type of change that countries will likely experience over the coming decades. The main types of policies and tools examined in this chapter are: fiscal policies such as carbon pricing and subsidies; policies to complement carbon pricing, such as standards; adjustment policies to ease the transition for households, workers and businesses; and models and metrics to manage change better.

Putting a price on greenhouse gas emissions is perhaps the most important policy, in particular to keep the costs of action low. Efforts should be focused on getting the design of such carbon pricing policies right, including applying the price across a wide base of different sectors, establishing a reasonable and robust price that rises over time, and using the revenues raised in productive ways, for example for fiscal reforms which make the broader tax system more efficient. But, carbon pricing is one among several instruments, to tackle a range of market failures, including in innovation, which should play an important role in the policy mix (see Section 3.3).

Additional policies to create a more flexible and responsive economy can also help to facilitate change more cost-effectively and efficiently. They will cover a broad range of areas including competition and product market policy, trade and investment policy, labour market policy, and human capital and education policy, among others. These additional policies will increase the flexibility with which resources are deployed and support the conditions for growth. Campaigns against corruption, graft and fraud will ensure more responsive policy-making. More rigid economies, for example with inflexible labour and capital markets, will face higher costs of adjustment to structural changes, including those needed for a transition to a low-carbon economy.

A competitive product market is essential for a more responsive economy. This will lower entry barriers for new, more efficient and cleaner firms and products that can challenge incumbents. It will also allow inefficient firms to decline and exit. To encourage enterprise and boost productivity, product market regulation should be set in a way that does not hamper competition and is combined with a clear and effective antitrust framework to ensure a fair, level playing field among firms.[11] Openness to trade also makes economies more agile and adaptable, by making them less constrained by the limits of domestic markets.[12]

Progressive labour market policies similarly enhance economic flexibility, providing firms with the ability to adapt to ever-changing market conditions, on the one hand, and workers with adequate employment rights, on the other (see Section 4 below). Providing adjustment assistance for workers in declining industries will be an important task of transition policies. An affordable and flexible housing market facilitates labour mobility so that workers can move from regions with declining industries to expanding ones, aiding cost-effective economic transformation. Human capital and education policies ensure that workers have the right education and skills to benefit from structural change. Without training and re-skilling opportunities, some workers may find their existing skills are mismatched to those demanded in new growth industries.[13]

Finally, any discussion of efficient and effective policies must take into account the nature of existing institutional frameworks and governance structures of individual countries. Effective and supportive institutions are crucial as they can help to shape expectations, strengthen policy co-ordination, and manage and resolve political economy challenges.

Carbon pricing is one among several instruments which should play an important role in the policy mix.

Political institutions that are trusted by citizens to execute policies in the public interest will perform better, as they better guide public expectations, and will be held accountable for their successes and failures. To take one example, governments in Scandinavia have long been expected to invest in long-run issues relating to childcare, education and the environment, and will be held electorally liable if they do not. By contrast, institutions which are not trusted, for example because they are subject to corruption and graft or because they fail to innovate and are not responsive to a changing economy and society, will not be trusted to deliver policies in the public interest. Opposition even to policy reforms in the public interest may arise on the assumption that the benefits will not reach citizens. This expectation itself reduces incentives for policymakers to implement reforms in their country's long-run interest, especially when the costs to upsetting the beneficiaries of a corrupt system are high, and so the spiral continues.

Strong, trusted and responsive institutions can align expectations and reduce the costs of change by sending clear and credible policy signals across the economy on the direction of change. This will give the private sector the confidence to deliver the necessary efficiency gains, infrastructure and innovation that will drive productivity of all forms of capital and growth. Box 1 describes institutional structures that can reinforce policy credibility. Clear policy signals lower the risk of premature stranding of infrastructure investments, while helping to accelerate and scale investments in more efficient products, new business models, new markets, new skills and jobs, and more productive ways of working and operating. Policies that send weak, absent or muddled signals slow or hinder change and increase costs.

Box 1
Institutions for policy stability and credibility

Given that governments are often in power only a few years, it is important to consider how longer term commitments to policies for managing change could be made more credible, recognising that total certainty can never be guaranteed.

Some institutional and legal structures can provide policy stability and credibility, and lower uncertainty. For example, Britain's statutory climate adviser, the Climate Change Committee, recommends decarbonisation targets 15 years or more ahead, under legislation which has a 40-year horizon. Similarly, Australia's statutory adviser on infrastructure investment, Infrastructure Australia, recommends long-term investment strategies to state and federal government. The National Institute for Health and Clinical Excellence (NICE) in the UK helps government to design health policy more effectively by providing evidence-based guidance and advice, quality standards and performance metrics, and information services.[14] National development banks can also help to reduce policy risk and give credibility (see Section 4.3).

Policies to tackle market failures do, however, create their own risk of government interventions that are poorly designed or lock us into the wrong path. The story of path-dependency amplifies the potential size and duration of any such policy failure. This makes the need for accountable, trusted institutions, and credible, cost-effective and transparent policies, designed to make markets work well and achieve well-specified (emissions reduction) goals, all the more important.

3. Policy and coordination

3.1 Fiscal reform – carbon prices

Greenhouse gas emissions cause long-term climate change and economic damage. The most economically efficient way to tackle the greenhouse gas market failure is by requiring polluters to pay a price per tonne emitted.[15] This approach discourages emissions and incentivises investment in low-carbon infrastructure, efficiency and innovation. Carbon pricing should also be part of a broader fiscal reform package, where taxes are shifted away from things we want to encourage such as labour and business activities, towards taxing "bads" such as pollution and resource use. This will help markets to guide resources away from declining and less productive activities, toward growing, more flexible and productive activities, leaving economies better able to prosper and absorb shocks.

The primary tool to tackle the damage from greenhouse gas emissions is an explicit carbon pricing instrument: a

Box 2
What price for greenhouse gas emissions?

The social cost of carbon (SCC) is a theoretical measure which attempts to value the full social cost of damage from an additional tonne of greenhouse gas emissions. Theoretically, it is the appropriate welfare-based measure of greenhouse gas externalities, and should ideally be applied as a carbon price across all greenhouse gas emissions sources and countries, with international finance provided to ensure equity.[16] It signals what society should, in theory, be willing to pay now to avoid the future damage caused by incremental greenhouse gas emissions.[17]

There is ongoing debate and uncertainty around how to calibrate the factors that determine the SCC. These factors include climate sensitivity, climate damages and discount rates. Recent discussions have recommended a declining discount rate, which would see carbon costs rise over time.[18] Some studies have emphasised the need for two discount rates: a social and private discount rate.[19] Estimates of SCC values range anywhere from a few dollars per tonne of greenhouse gas emissions, measured in carbon dioxide equivalent (CO_2e), to several hundred dollars.[20]

In practice, a global carbon price is unlikely to be agreed in the near term. Individual countries and regions will decide a price (in the case of a carbon tax) or an emissions cap (in the case of an emissions trading system) which reflects their climate ambition, other climate and energy policies, and a range of other political and economic factors. The key is that the price sends a clear, credible signal that aligns expectations, and so shifts investment toward low-carbon infrastructure and activities over time.

In the absence of more universal carbon pricing, but in the expectation that this may one day arrive, a number of government agencies, companies and organisations have applied "internal" or shadow carbon prices to their critical investment decisions. For example, the US government has established a SCC of around US$35 today, rising to around US$50 in 2030, and recommends that US government agencies use this price in cost-benefit analysis of regulatory actions that impact emissions.[21] (See Section 5.2 for a discussion on the models that produce these estimates). More than 100 major businesses worldwide have disclosed that they use an internal carbon price in their operations.[22] In the United States, around 30 companies indicated that they used an internal carbon price ranging from US$6 to US$60 per tonne of CO_2e. Most of these were energy-intensive firms such as BP and Exxon-Mobil, but also included were Google, Microsoft, Disney, Walmart, and Delta Airlines.[23]

Box 3
Multiple benefits from carbon pricing

Local environmental benefits

Carbon pricing reduces greenhouse gas emissions and local air pollution from the burning of fossil fuels. This generates significant benefits for health, quality of human life and labour productivity. The health benefits arise because burning fossil fuels produces pollutants including ozone, a result of the reaction of organic compounds in sunlight, and fine smoke particles called particulate matter, both of which contribute to lung and heart disease. These potentially large benefits accrue mainly to the country taking action, and are realised in the short-term.

There is extensive literature assessing the value of these non-climate benefits. In total, outdoor air pollution in cities and rural areas was responsible for 3.7 million premature deaths annually in 2012, according to the World Health Organization.[27] Much of this pollution was particulate matter emitted from burning fossil fuels in transport, industry and power generation. A review of 37 studies, published in 2010, found the value of air quality benefits from climate change mitigation ranged from US$2-128 (average US$44) per tonne of abatement of greenhouse gas emissions in developed countries, and US$27-196 (average US$81) in developing countries.[28] Developing countries tend to have high emission rates (including less use of emissions control technologies) and greater population exposure.

In its latest review of climate science, the Intergovernmental Panel on Climate Change (IPCC) reported an estimate for the global benefits of avoided mortality from less burning of fossil fuels, which uses new relationships between mortality and exposure to ozone and particulate matter, at US$50-380 per tonne of CO_2e abatement.[29] Another study by the International Monetary Fund has estimated the value of the benefits by country, accounting for externalities including air pollution and traffic congestion, net of any pre-existing fuel taxes and subsidies. The total value of such un-priced, local externalities associated with burning fossil fuels was around US$58 per tonne of CO_2, on average, across the top 20 global greenhouse gas emitters.[30] All these indicative estimates show potentially very large multiple, monetised benefits from reducing greenhouse gas emissions.

While it may be possible to tackle local air pollution and vehicle congestion more cheaply directly, this approach would not necessarily help reduce climate risk. For example, coal plants may be required to fit equipment which reduces emissions of sulphur dioxide, but this would not reduce CO_2 emissions. Recent studies show that doing the two together is best, meaning that the net total benefits of a combined policy are larger than either of the separate policies.[31] (See Chapter 1: Strategic Context).

Reduced local air pollution also has significant benefits for ecosystems which have been impacted for decades by pollution: sulphur dioxide and nitrogen oxides acidify soil and waterways and reduce tree health and productivity; ground-level ozone reduces crop and forest productivity; mercury decreases reproductive success and changes fish and wildlife behaviours.[32] The Economics of Ecosystems and Biodiversity (TEEB) study published in 2010 analysed approaches for the valuation of ecosystem services and biodiversity.[33]

Enhanced energy security in fossil fuel importing countries

A stable and affordable energy supply is critical for economic development. In the short- to medium-term, carbon taxes can drive a switch from imported fossil fuels, such as coal, oil and gas, to domestic, lower carbon sources such as wind, solar, hydro and geothermal power. In such cases, energy security can be enhanced and the risk of supply disruption reduced. In the longer term, an increasing share of low-carbon energy in the domestic mix will result in less volatile energy prices. Carbon prices and efficiency standards can also incentivise investments in energy efficiency, reducing total energy consumption and thus demand for imports.

carbon tax or emissions trading system.[24] Our focus here is on explicit carbon pricing, but it is also possible to ensure that prices of fossil fuels reflect their full costs to society through the extension of existing fuel taxes, with the tax rate adjusted to reflect the carbon and pollution content of the particular fuel. Many developing countries may find this an attractive alternative, while they develop the necessary institutions to support explicit carbon pricing, because such taxes are already in place and are easily administered.[25]

New work from the International Monetary Fund (IMF) calculates "corrective" tax estimates by fuel across 156 countries, and shows large differences between "efficient" fuel taxes that would reflect their carbon, environmental and other impacts, and the actual, current tax levels. Their research also provides some rough estimates of the fiscal, environmental, and health benefits that "efficient" prices could bring.[26] Some of the multiple benefits from carbon pricing are outlined in Box 3.

Carbon pricing also provides dynamic efficiency benefits in the short-, medium- and long-term. These include motivating continued emissions reductions by providing incentives for innovation, and increasing macroeconomic efficiency through the recycling of carbon tax revenues. These are briefly summarised.

- *Incentives for innovation*

  Carbon prices provide incentives for innovation toward less emission-intensive products and processes, because companies are motivated to innovate continuously to reduce their carbon tax liability. For example, a case study analysis of the United Kindom's Climate Change Levy found that firms subject to the full rate of the levy submitted more technology patents than firms subject to a reduced rate.[34] Expectations of high future carbon prices are an important factor affecting innovation, as reflected in patenting activity.[35] The benefits from innovation in one sector can also spill over and benefit other sectors. This is a key reason why carbon pricing is an extremely cost-effective instrument, particularly in the medium- to long-term.

- *Revenue-raising for government*

  If developed countries used carbon pricing to implement emissions cuts as pledged in Cancun under the United Nations Framework Convention on Climate Change, they could raise more than US$400 billion annually by 2020.[36] Many countries are already moving to higher rates of auctioning of permits in cap-and-trade systems. For example, about 40% of permits were auctioned in the European Union Emissions Trading System (EU ETS) in 2013, compared to very little auctioning in the second phase of the scheme from 2008-2012. Around 90% of allowances are auctioned in the Regional Greenhouse Gas Initiative (RGGI) in the north-eastern United States, and a growing share are auctioned in California.

  However, as carbon prices rise, they are likely to incentivise consumers and businesses to shift their behaviour to avoid the tax, through adopting low-carbon products and practices. As this happens, the net revenues from carbon prices can be expected to fall.

- *Macroeconomic efficiency through the recycling of carbon revenues, under wider fiscal reforms*

  Carbon tax or auction revenues can be recycled through the economy. Such uses can reduce the economic costs associated with a carbon price and potentially lead to increased employment, thus increasing political acceptability of the policy. In practice, the potential for reducing the economic cost of carbon pricing will depend on the nature of pre-existing distortions or inefficiencies in a country's tax system and the nature of the revenue recycling (Box 4).

  The best use of carbon tax or auction revenues should be guided by good principles of public finance, including efficiency, distribution, and incidence. Some potential uses include: reducing existing distortionary taxes; funding innovation; financing international climate action; and public support for infrastructure investment, for example by capitalising green investment banks. A share of the revenues will also be needed to compensate vulnerable households and businesses, for example for higher energy prices.

Carbon prices provide incentives for innovation toward less emission-intensive products and processes, because companies are motivated to innovate continuously to reduce their carbon tax liability.

A well-established literature has examined the pre-existing distortions and the most effective revenue recycling options.[37] A clear message from the literature is that revenues must be put to good use, e.g. to reduce existing distortionary taxes rather than giving out emissions permits for free, as their use has a large impact on the cost-effectiveness of carbon pricing. In this way, the appropriate way for most countries to view carbon pricing is not as a choice between policy and no policy, but between different ways of raising and returning revenues.

Explicit carbon prices in practice

The use of carbon pricing as a policy instrument is already widespread, both nationally and regionally. About 40 national and over 20 sub-national jurisdictions have implemented or have scheduled a price on carbon[40] (Figure 1). The use of carbon pricing also appears to be expanding. Twenty national and six sub-national jurisdictions are considering a price on carbon.[41]

Together, the actual, scheduled and considered schemes cover around 12% of global greenhouse gas emissions.[42] The highest carbon prices are found in Sweden. These were introduced in 1991 at a relatively low rate, but are currently as high as US$168 per tonne of CO_2e in some sectors.[43] The Swedish scheme raises annual tax revenues of almost US$3.7 billion.

There are several technical lessons that can be learned from countries with experience of emissions trading systems or carbon taxes. These examples show that carbon pricing has indeed created incentives to reduce emissions. In the Australian National Electricity Market (NEM), carbon dioxide (CO_2) emissions reductions attributable to the carbon price, implemented on 1 July 2012 and repealed in July 2014, were between 5 to 8 million tonnes of CO_2 in the fiscal year 2012-13, and between 6 and 9 million tonnes in 2013-14.

Box 4
Recycling carbon tax revenues

A range of modelling studies, including new analysis for the Commission as well as empirical evidence, suggest that smart revenue recycling can reduce or eliminate the short-run costs of carbon pricing.

New analysis prepared for the Commission simulates fiscal reform for 35 developed and developing countries, with revenues raised from carbon prices recycled through either lump sum transfers, deficit reduction, cuts in labour taxes or increased government investment.[38] The results show that recycling options that influence the supply-side of the economy, such as government investment that increases the capital stock or personal income tax cuts that increase the supply of labour, reduce the impact of carbon pricing on short-run growth, and in some countries, e.g. Brazil, could offset any impact and boost short-run growth. Using carbon tax revenues to pay down government debt had the most negative impact on short-run growth. A country's economic structure and sources of energy also influence the results.

Over the medium- to long-term, modelling evidence suggests that the economic cost of efficient climate policies is likely to be small; for example, in the range of about 0.5–2% of a country's gross domestic product (GDP) in 2030 (compared with baseline) in most studies, with costs varying in part based on how tax or auctioning revenues are recycled.[39]

These modelling exercises are useful tools but their results must be interpreted carefully as they are likely to overstate the costs to GDP for a range of reasons. For example, they are unable to capture the full range of economic distortions in the existing tax system. In real life, therefore, greater welfare gains are likely from revenue recycling to reduce existing taxes. They also largely ignore the value of the other benefits from carbon pricing. And GDP impacts only reflect part of overall welfare impacts. Some of the modelling results cited in this report overcome some of the reasons models tend to overstate costs, for example by allowing for capacity gaps and unemployment, but all models face some limitations (see Section 5.2).

The reductions represent 3 to 6% of total emissions in the NEM in each of those years.[45] See also the example of British Columbia in Box 5.

However, their effectiveness has been limited in a number of cases, for example because prices were too low, a lack of credibility around the future of the policy, or key energy-intensive industries were either exempted or given overly generous compensation. For example, some of the recent emissions reductions in the European Union Emissions Trading System (EU ETS) were achieved primarily through other policy instruments or the economic downturn, rather than the carbon price. Experience also shows the importance of considering the potential overlap and interaction with other policies, such as feed-in tariffs for renewable power and energy efficiency regulations, as this has the potential to reduce the efficiency and effectiveness of carbon pricing (see Section 3.4).

Regarding emissions trading, market surprises may call for adjustments to emissions caps. Examples include EU provisions for setting aside some permits, to remove a surplus generated during the financial crisis, and a proposed "market stability reserve". The north-eastern US Regional Greenhouse Gas Initiative (RGGI) scheme used cap tightening to achieve an objective of faster emissions reductions.

Emissions trading systems can also be designed as "hybrid" schemes, in some ways mimicking a bounded carbon tax. Price floors can ensure a minimum level of effectiveness in emissions trading, as is the case in California and in seven Chinese pilot schemes. Price ceilings can limit the costs of permits, which can be important in terms of ensuring industry acceptability.

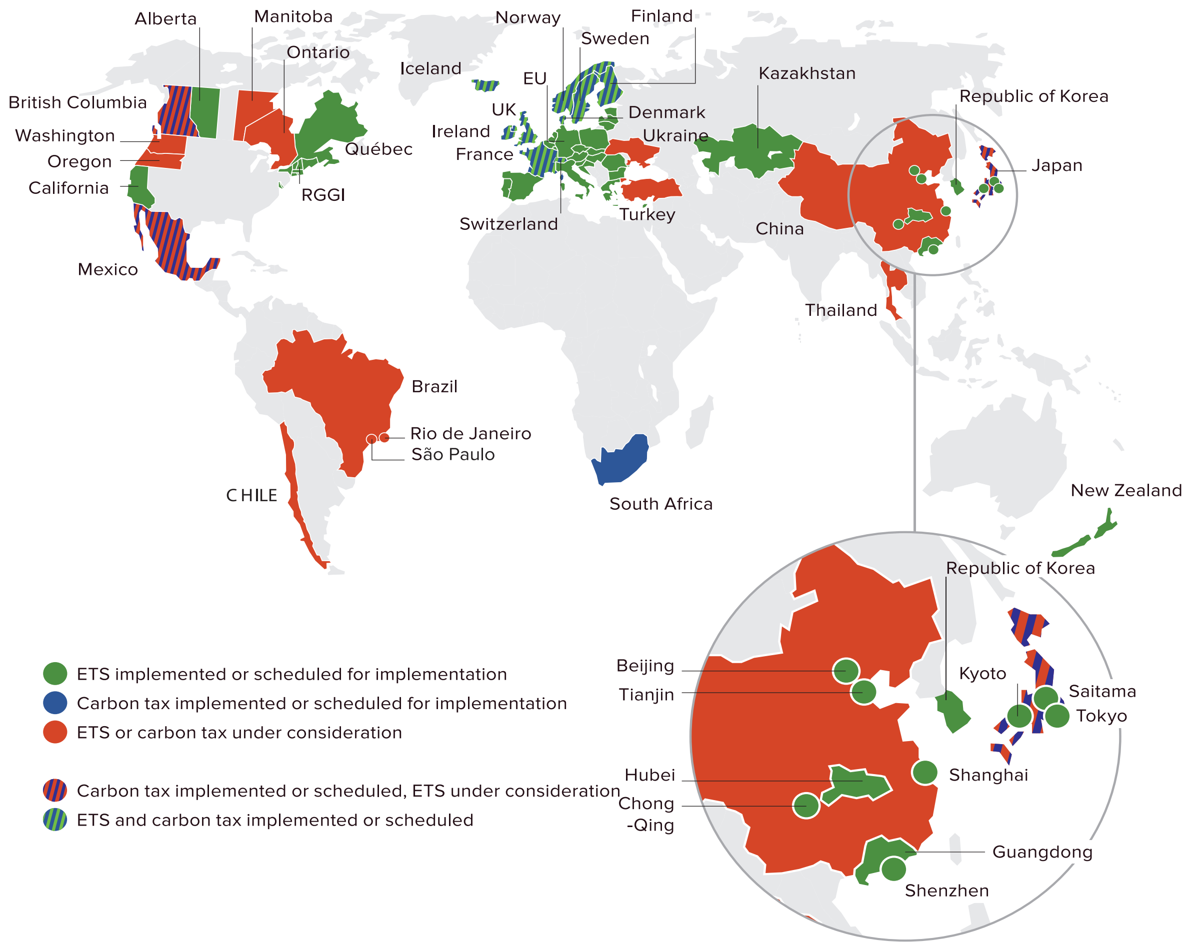
Among governments which are auctioning or selling a significant amount of allowances, or applying a carbon tax, some are using the revenues to cut income taxes for low income earners or corporate taxes, with evidence that these fiscal reforms can achieve distributional objectives and economic efficiency gains (for example British Columbia). Other governments are recycling the revenue into emissions reductions programmes (California and RGGI), innovation programmes (EU), or for international climate action (Germany, in the EU ETS).

It is common practice that permits are allocated for free to industry. This increases the costs of carbon pricing as it fails to realise the efficiency benefits from the recycling of revenues, but may increase political acceptability in the short-run. However, this practice is increasingly confined to shielding trade-exposed and emissions-intensive industries from adverse effects on their international competitiveness, as in the EU. Free permits to the power industry are now largely confined to situations where power producers cannot pass on carbon costs (as in China) or to support large and politically influential coal-fired generators (in Eastern Europe).[46]

3.2 Fiscal reform - subsidies.

Just as it is efficient to price negative externalities, or "bads", it is inefficient to subsidise them. Many countries start from a position of negative carbon prices because of subsidies for fossil fuels. But subsidies go beyond fossil fuels: they are likely to total over US$1 trillion globally per year in energy, water, steel and food alone.[49] Any serious attempt by a country to get fiscal policy right for both growth and climate change should start with a reassessment of these distortions.

Figure 1
Carbon pricing around the world



Source: © 2014 International Bank for Reconstruction and Development - The World Bank.[44]

Any serious attempt by a country to get fiscal policy right for both growth and climate change should start with a reassessment of subsidies to fossil fuels

The International Energy Agency (IEA), International Monetary Fund (IMF) and the Organisation for Economic Co-operation and Development (OECD) have estimated and reported on various fossil fuel subsidies over a number of years, and assessed the impacts of their phase-out.[50] The group of 20 leading global economies (G20) has been discussing the removal of fossil fuel subsidies for the past five years.

The OECD has estimated the value of support for fossil fuel production and consumption in OECD countries at around US$55-90 billion per year over the period 2005 to 2011, with most of this in the form of tax breaks for consumption.[51] Even countries which are now re-evaluating their support for renewable energy still have fossil fuel subsidies in place. For example, Germany provided €1.9 billion in subsidies to its hard coal sector in 2011.[52] The IEA estimated fossil fuel consumption subsidies in emerging and developing countries at around US$540 billion in 2012.[53] The majority of these were for energy consumption in net fossil fuel exporting countries (Figure 2).[54]

Countries subsidise fossil fuel consumption in various ways. Governments may keep local energy prices below international market prices, or provide grants or vouchers to make energy more affordable. Such subsidies are

Box 5
British Columbia, Canada: an example of a well-designed carbon tax[47]

An explicit carbon tax was introduced in British Columbia on 1 July 2008 at C$10 per tonne of carbon dioxide equivalent (CO_2e), rising by C$5 per year until it reached C$30 in 2012. The tax applies to nearly all fossil fuels, including petrol, propane, natural gas, and coal. It covers nearly 80% of the province's greenhouse gas emissions from residential, commercial and industrial sources. It is designed to be revenue neutral; all revenues raised are recycled to reduce other existing taxes, with a focus on corporate and labour taxes, and tax relief for vulnerable households.

In the 2012-2013 fiscal year, the scheme raised revenues of around C$1.2 billion, from a tax rate of C$30 per tonne. That is equivalent to 0.7% of 2012 nominal GDP. After 5 years of operation, the government has delivered C$500 million more in tax cuts than total carbon tax revenues raised. Petrol prices rose around 7 cents per litre over the period 2008-2012; this price rise has cut per capita consumption of petroleum fuels subject to the tax by around 17%, compared to a 1.5% increase in the rest of Canada. From vvzzemissions fell by 10%, compared to a 1.1% drop in the rest of Canada. Over the same period, GDP per capita declined by 0.15% in British Columbia, compared to a 0.23% fall for the rest of Canada.

As the tax rate has increased, however, evidence has emerged that the tax is becoming more regressive.[48] Such an outcome would call for higher compensation for vulnerable groups.

particularly popular in developing countries, for example as a way to distribute the benefits of a country's natural resource wealth to the general population. This is particularly important in countries without social safety nets or other means of delivering support for their populations. These motives are powerful and make reform politically difficult. It is therefore important to understand the costs of these subsidies and the benefits of reform, as this may help to identify more efficient ways of achieving the same social objectives.

The limitations and costs of fossil fuel consumption subsidies fall into five key categories.

- Inefficient - They are often economically inefficient. Subsidies artificially incentivise greater use or production of fossil fuels than is economically efficient for a given welfare level.
- Budget impact - There is an opportunity cost from selling energy domestically below its international price, assuming there are further international market opportunities in the case of oil exporters. There is a real cost for a country which taxes fossil fuel energy at a lower rate. These foregone revenues represent 5% or more of GDP in some countries.[56] By this measure, Indonesia and Mexico have spent more on energy subsidies than on health or education in recent years.
- Environmental impact - Increased consumption of fossil fuels, in response to subsidies, increases air pollution, including indoor air pollution where fossil fuels are used for cooking and heating. Lower energy prices can also lead to excessive pumping of groundwater, as for example in India. And subsidies accelerate climate change by increasing carbon emissions.
- Lock-in - Subsidies promote fossil fuel dependence and long-term lock-in to a high-carbon economy, for example they encourage greater reliance on private vehicles and urban sprawl.
- Regressive - Subsidies tend to favour well-off urban middle classes, who can afford large cars and multiple electric appliances, at the expense of taxpayers or the poor who would benefit more from targeted pro-poor public spending. An example is Mexico where 80% of electricity subsidies for irrigation water pumping accrued to the richest 10% of farmers.[57] The poorest 20% in Mexico capture only 11% of residential electricity subsidies and less than 8% of transport fuel subsidies. Price controls can also undermine electric grid investment, and therefore energy access for vulnerable people, as utilities have less incentive to invest and fewer financial resources.

Subsidy reform reduces an economic distortion and increases fiscal revenues, which leads to gains in real incomes and GDP from more efficient resource allocation. Reform also leads to higher energy prices and stronger incentives to invest in energy access and renewable energy. Higher energy prices also encourage investment in energy efficiency and conservation, cut carbon emissions from fossil fuel combustion, and yield other, related benefits including lower air pollution. The impact of subsidy removal on global greenhouse gas emissions is uncertain, but some estimates exist. One study reports that if all 37 countries covered by the IEA fossil fuel subsidy database removed their subsidies by 2020, global greenhouse gas emissions could be around 8% lower in 2050, compared with a baseline projection.[58]

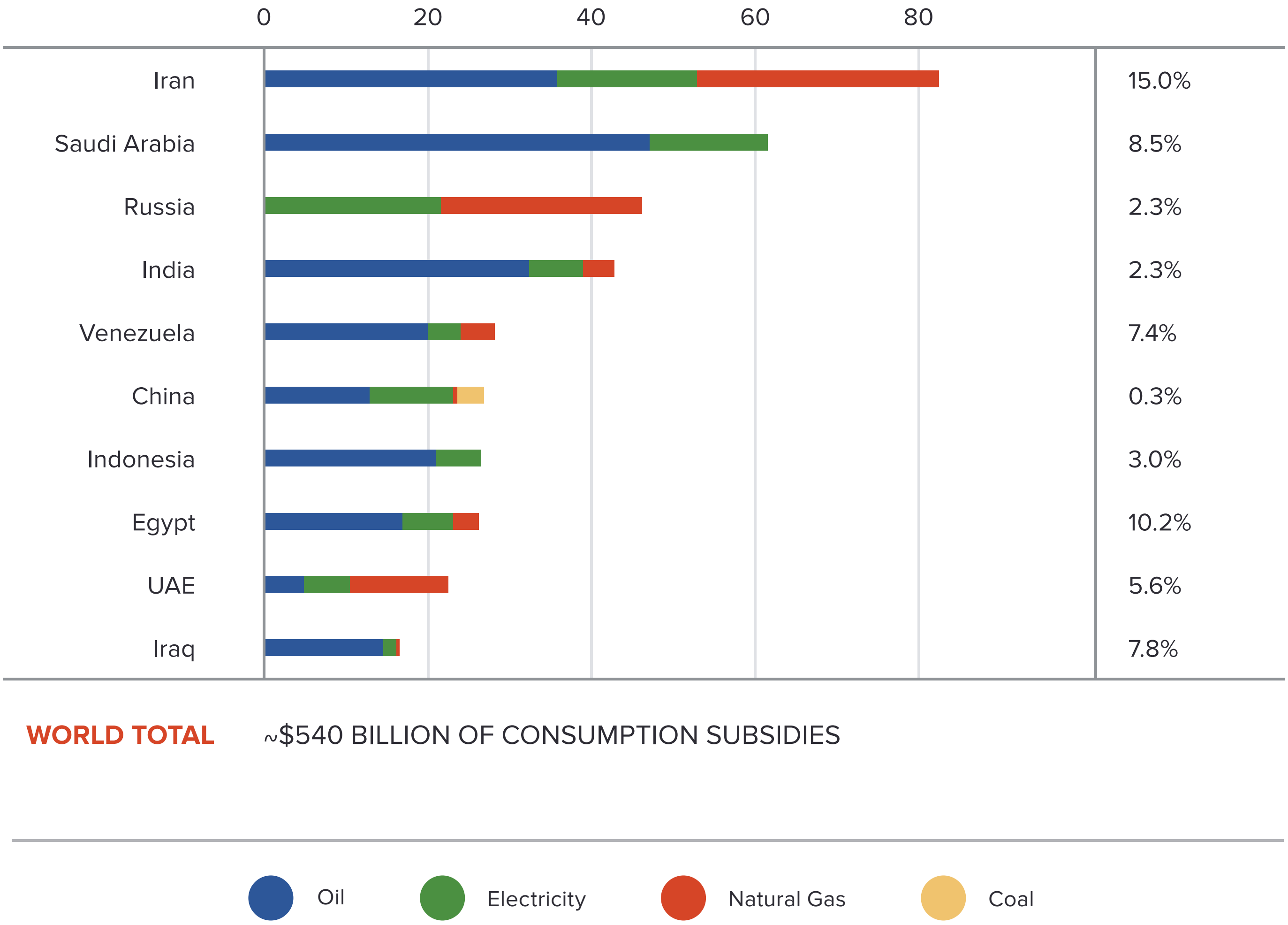
It is vital to tackle equity issues arising from fossil fuel subsidy reform, such as the impact of rising energy prices on vulnerable people, who may be below or just above a defined poverty line. Such problems can be tackled through cash transfer payments, funded by a share of the savings from reduced subsidies. However, in some countries administrative challenges could prevent these payments being made effectively, suggesting fossil fuel subsidy reforms will need to be accompanied by institutional reforms. Also, given the lack of trust in the

Figure 2

Fossil fuel consumption subsidies in emerging and developing countries, 2012.

TOP 10 COUNTRIES WITH THE LARGEST FOSSIL FUEL CONSUMPTION SUBSIDIES, BILLION US$ IN 2012

PERCENTAGE OF GDP



Source: IEA, 2013.[55]

political process in many countries, governance reforms that increase fiscal transparency and trust in government institutions will be a vital. To build trust, some support may need to be provided for vulnerable people through up-front financing before implementing the reforms. Reductions in subsidies are unlikely to be supported if there is no expectation of receiving compensation, if revenue savings are expected to line the pockets of elite groups, or if they are simply returned to the public coffers.

Experience in reducing fossil fuel subsidies

Many countries have experimented with reforms to reduce subsidies. These have often proved politically challenging and there are many barriers, but reform is possible and some useful lessons emerge.

International organisations have proposed a range of measures that can support successful subsidy reform. The components for successful fossil fuel subsidy reform include: a comprehensive reform plan integrated with broader fiscal reforms; credible and targeted measures to protect the poor; a clear communications strategy; appropriately phased and sequenced price increases; and improvements in the efficiency of state owned enterprises.[59] Box 6 provides some further lessons from five countries that have undertaken subsidy reform.

Innovative ideas are also emerging that may help governments overcome some of the barriers to reducing fossil fuel subsidies. A recent example is the idea of a "subsidy phase-out and reform catalyst" (SPARC) bond. Such bonds would enable governments to raise money from private investors, with only a small contribution from government to cover some of the risk. The proceeds would provide the up-front finance necessary to demonstrate the benefits of reform and build public acceptance. The

Box 6
Lessons learned from reform of fossil fuel consumption subsidies

The examples of Ghana, Tunisia, Bolivia, Nigeria and Indonesia provide useful lessons from fossil fuel subsidy reform in practice.[60]

Ghana – an example of a successful reduction in the overall level of subsidies. Ghana carried out an impact assessment prior to the reform, and a widespread advertising campaign. The government increased fuel prices by around 50% in 2006, followed by several more increases to bring prices in line with the international market price. The revenues saved were partly used to compensate the poor for energy price increases. A new petroleum authority (NPA) was introduced to depoliticise the price-setting process.[61] This was not a structural policy reform in isolation. Ghana has implemented a comprehensive fiscal reform package that is transforming its economy.

Tunisia – an example of countering the impacts of fossil fuel subsidies with support for renewable energy. Tunisia implemented an innovative reform programme from 2005 that encouraged households to shift away from water heaters run on subsidised fossil fuels, to solar water heaters. The scheme tackled the key local challenges hindering the shift. First, it provided subsidies to reduce the upfront costs of the solar system. Second, it developed the supply chain, such as training installers and creating accreditation and quality certification programmes. Third, it raised community awareness and confidence in the alternative technology. And fourth, it used the state utility to act as debt collector, guarantor and enforcer, overcoming credit market weaknesses.[62]

Bolivia - an example of unsuccessful reform. In 2010, the Bolivian government announced a dramatic 70% increase in prices for fossil fuels. This quickly led to riots and civil unrest and the reform was abandoned. [63]

Nigeria – another example of poor communication. The Nigerian government had to scale back initial price increases of 117% for gasoline in 2012, to around 50%.[64] Concerns in Nigeria included fear of loss of competitiveness, loss of income for low and middle income households and job losses.

Indonesia – an example of public opposition, despite a compensation scheme. The Indonesian government doubled the price of diesel and nearly tripled the price of kerosene in 2005, while offering compensation in the form of an unconditional cash transfer programme and cash payments to low-income individuals. Despite the compensation programme, subsequent attempts to phase out energy subsidies and provide compensation have faced strong public opposition.[65]

future savings from reduced fossil fuel use would repay the bond over time. The World Bank or other international financial institutions could potentially act as guarantor and intermediary for the bonds.[66]

3.3 Policies to tackle other market failures and political economy barriers

A well-coordinated portfolio of different policies is needed to tackle different market failures, boost productivity and growth, and to lower the costs of emissions reductions.[67] We now discuss targeted policies to tackle the market failures beyond greenhouse gases. The failures are categorised into three broad areas: innovation; infrastructure investment; and networks.

It should be noted that other chapters in this report provide further detail on these market failures and policies to tackle them, for example in Chapter 6: Finance and Chapter 7: Innovation. They are introduced here.

Policy for market failures in innovation, investment and networks

Innovation is crucial for productivity and growth.[68] But there are market failures throughout the innovation chain, in particular in the early stages of R&D, which hold back investment in low-carbon innovation. When a firm invests in early stage R&D, it produces technical knowledge that can be replicated across many firms at very low cost. This knowledge spills over from one firm to another through imitation and learning.[69] Knowledge spillovers cause firms to under-invest in R&D compared with the public optimum, because innovators do not fully appropriate the returns to their investment.[70] Policies that can help to remedy this include direct government investments in R&D, innovation prizes, patenting systems, and carefully targeted tax breaks and subsidies.[71]

Analysis for the Commission finds innovation is generally path-dependent, meaning that the type of innovation path we follow will depend on our expectations of future technologies and the initial conditions of the innovation process.[72] Government thus has an important role not only to tackle market failures, but also to help set the initial conditions that can shift innovation from high- to low-carbon. Direct subsidies for low-carbon R&D can be an effective tool to deal with the spillover externality, and in combination with carbon prices, can shift expectations for the innovation process to low-carbon.

Support for early-stage R&D for renewable energy and energy efficiency has risen rapidly in recent years and is starting to overcome a long legacy of government R&D support for fossil fuels. In 19 countries in the OECD, renewable energy and energy efficiency R&D increased from around 15% of total government energy R&D spending in 1990 to nearly 50% in 2011.[73] Government R&D spending on fossil fuels fell from 20% to 12% of total energy R&D over the same period.[74]

A second market failure concerns investment in the deployment of clean energy infrastructure. In this case, market failures include a failure to price risk properly, including some important social costs and benefits, and policy uncertainty, which together raise risk premiums and deter clean energy investment. Experience across most countries shows that a mix of economic, fiscal and financial incentives are needed to tackle these failures in a way that reduces the costs of debt and equity and unlocks investment in deployment of low-carbon technologies. Specific policies will differ depending on individual country risk characteristics and the type of technology. Two complementary instruments that can be used to support low-carbon deployment are feed-in tariffs and concessional debt. Chapter 6: Finance provides more detail on the types of policies to boost low-carbon investment, according to national income characteristics.

Concessional debt is particularly useful in countries where governments are unable to provide clear and credible policy signals. However, such credit may not always provide investors with the level of risk reduction necessary. In such cases feed-in tariffs (FITs) can provide renewable energy generators with a fixed long-term price, and so can reduce market risks further. FITs can function simultaneously as a policy de-risking instrument (through guaranteed grid access and "must-take" requirements) and a financial de-risking instrument (through a guaranteed price over a period of years). Much has been learned over recent years on how to design FITs better.[75] But problems remain. For example, they are still more costly compared to a carbon price (Box 8). And as a form of subsidy, they should be limited in their use, and time-bound with transparent and pre-announced plans for how they will be phased out over time as more efficient options become feasible. Many countries, such as China and Saudi Arabia, are starting to use auctions to ensure that price incentives are economically efficient and to avoid excessive subsidies. In some countries, these economic incentives may need to be supplemented by other fiscal and financial incentives, to tackle remaining investment risks, as discussed in Chapter 6: Finance.

A third market failure is around networks. Lack of suitable networks or access to them can provide a barrier to new technology uptake by would-be adopters, and prevent new technologies from competing on a level basis with incumbent technologies.[76] For example, the widespread uptake of the current generation of electric vehicles is dependent on access to a reliable network of charging stations. Policies to tackle network-related market barriers include public investment in smart electricity grids, public transport and broadband, and to open existing networks, for example to allow local renewable energy generators to sell electricity into existing grids.

The importance of networks is pervasive and crucial for fostering innovation and the transition to a low-carbon economy.[77]

The challenge with support for low-carbon technologies and systems is therefore one of designing the optimal policy package that includes the appropriate combination of economic, fiscal and financial incentives to ensure effectiveness at the lowest cost.

The role of regulations and standards in tackling market failures

Regulations such as standards (see Box 7) can tackle a range of market failures and provide confidence and clear signals. If designed well, they can help to make carbon pricing schemes more effective and efficient.

A market failure that regulation can help tackle is that of split incentives. One example is in the rented building sector. In this case, landlords may not reap the benefits of investing in better insulation, because they do not pay the electricity bills, while tenants are reluctant to make such long-term investments, as they do not own the property. As a result, energy efficiency investments are missed, even when the returns are high. Examples of relevant regulations include a requirement that tenants qualify for subsidised insulation, or the introduction of minimum building efficiency standards in buildings. Split incentives apply in other sectors such as in shipping, where owners of fleets often have little incentive to improve efficiency, because customers pay fuel costs. Regulations can mandate shipping fuel efficiency standards.

Regulations can also help to tackle existing restrictions and barriers that reduce competitiveness, such as barriers that prevent new products from accessing established markets, and which can hinder innovation. These barriers are already proving powerful in the case of electric vehicles, with, for example, car dealerships in many US States blocking Tesla from bypassing the dealer network and selling their electric vehicles directly to the public.[79]

Regulations are particularly useful where there are systematic behavioural biases and preferences that can reduce the effectiveness of explicit carbon prices.[80] Understanding consumer and household behaviour is central to cost-effectively reducing the demand for energy, which helps limit emissions, lower resource costs and enhance energy security. Such behavioural biases include an excessive focus on the short-term among consumers in their purchase decisions, which can undervalue the benefits of energy efficiency. Regulation can tackle such behavioural bias, for example through standards which draw attention to energy savings, and so emphasise long-term benefits. Mandatory or voluntary energy efficiency labelling on appliances has proved a particularly effective way to shift consumer behaviour.[81] A review of energy demand reduction experiments around the world finds that providing additional information on electricity bills - such as advice on energy efficiency, feedback on energy usage, information on potential cost savings and social comparison -can be effective at motivating energy

Box 7
Standards

Standards can provide clear signals and policy certainty for the private sector. If they are announced sufficiently in advance, they can drive private investments in R&D and innovation in low-carbon technologies. They can influence the design of new products and R&D strategies, as seen in the car industry. They have also been found to positively affect consumer preferences and social norms.

Performance standards may also have greater political acceptability compared with policies such as carbon pricing, for a variety of reasons:

1. In most sectors, standards do not immediately affect existing industries and equipment, only new investments, so incumbents are less likely to object to their introduction.

2. Many countries already have performance standards, and these may only need strengthening and better enforcement to reduce emissions further. Thus governments can avoid the trouble of creating entirely new policy tools.

3. Performance standards achieve measurable results more rapidly than carbon prices, and their benefits can thus be observed over shorter timescales.

4. Performance standards convey a positive message and focus on achievements and progress, for example contributing to development goals such as moving domestic manufacturing toward higher value-added products, rather than focusing on limits and constraints.

There is criticism of the cost-effectiveness of standards, particularly in the auto industry. The literature evaluating Corporate Average Fuel Efficiency (CAFE) Standards in the United States suggests that increased fuel duties and taxes would be a more cost-effective way of reducing emissions.[78] However, standards can be designed to overcome some of these concerns through incorporating price ceilings and floors. The price ceilings can contain compliance costs, while the price floors provide ongoing incentives for improvement in periods when the costs of meeting the standard falls.

savings.[82] One of the most powerful forms of information on bills is social comparison. Comparing household energy bills to energy uses of neighbours can "activate" social norms and pro-environmental attitudes and "nudge" households towards lower energy use.[83]

The role of regulations and positive subsidies in tackling political economy and institutional barriers

Regulations including standards can be useful where political realities and institutional factors prevent the implementation of explicit carbon pricing. Such hard-nosed realities which can obstruct the legislation of carbon pricing include resistance from powerful pressure groups, more obvious short-run consumer costs compared with relatively opaque costs of standards and rebate schemes, a lack of institutional capacity domestically, and a particular difficulty agreeing carbon pricing schemes internationally.

Pressures from powerful vested interests have been particularly effective in delaying the wider use of explicit carbon pricing, even in countries like the United States, Canada and Australia where carbon pricing at the regional level has proved successful. The resistance is generally based on competitiveness and equity concerns, as discussed in Section 4 of this chapter. Pressure groups that resist pricing are often well-mobilised, well-resourced and influential.

Standards may offer an easier alternative, especially where governments already have the legislative authority to use these; the use of vehicle standards in the US is one example. And standards may pave the way to carbon pricing in the future; proposed US regulation of emissions from power plants allows states to use some form of carbon pricing.

Regulations including standards can be useful where political realities and institutional factors prevent the implementation of explicit carbon pricing.

Other policy instruments, besides standards, may attract less political resistance than carbon pricing. For example, "feebates", which have proved popular with consumers. They impose a fee on a dirty product and offer a rebate on a clean substitute. The "feebate" can be closely aligned with the market failure that they are tackling and, unlike standards, they provide a constant incentive to improve efficiency.[84] They have proved effective in driving the switch to more efficient vehicles. Investment subsidies, for example for home insulation or purchase of energy efficient equipment, are also popular. Many governments also provide subsidies to clean energy.

It is noted that while policies such as standards and subsidies may, in certain cases, attract less political and public resistance than carbon pricing, this may be because the costs associated with these instruments are often diffused or hidden in the detail of income tax regulation, general fund expenditure, utility financial regulation,cost-pass through arrangements and energy bill levies. As a result, these advantages may disappear over time, as the costs become more obvious. The result could then be a political backlash. Examples include the opposition to the costs of subsidising offshore wind farms in many EU countries.

Policy-makers can make the real cost of standards more transparent using the concept of an implicit or "effective" carbon price. Box 8 presents estimates of "effective" carbon prices for different policy instruments. Economic costs may be reduced over time by leaving flexibility in the system to move toward a more cost-effective mix of policies as the political and institutional barriers to implementing such measures are overcome. This could involve, for example, conditions that any new type of subsidy needs to be well targeted and gradually phased out over time. Failure to ensure such a condition could see policy become less efficient over time and distortive, for example where the subsidy fails to fall in line with technology costs.

Besides industry opposition, carbon pricing may also be obstructed by weaknesses in institutional capacity. Regulations can be useful in countries without the capacity to support and administer carbon prices, including some developing and emerging economies. China is an example of a country that uses regulations extensively, but is now experimenting with carbon pricing and starting to build the necessary institutions to support this. The World Bank Partnership for Market Readiness is helping in this regard, providing support for countries preparing for fiscal reforms that include carbon pricing and reducing fossil fuel subsidies.[86]

Regulations may also be easier to agree nationally and internationally. The "en.lighten" initiative is one example of an international approach to efficiency standards. Some 55 countries have committed to implement policies and measures that will reduce inefficient lighting by 2016. The initiative aims to eliminate inefficient lighting by 2030, a goal which could save about 1,000 terawatt hours (TWh) per year in electricity consumption; cut carbon emissions by some 500 million tonnes of CO_2 annually in 2030; and shave more than US$100 billion from electricity bills. Another example is the Global Fuel Economy Initiative (GFEI), which is working to help 20 countries increase their vehicle fleet efficiency. If these countries committed to doubling the fuel efficiency of passenger vehicles by 2030, they could avoid at least one billion tonnes of CO_2 per year in 2030, achieve fuel savings worth up to US$2 trillion, and secure large health benefits from reduced air pollution in cities.[87] Chapter 8: International Cooperation provides more detail of multilateral initiatives to drive cuts in greenhouse gas emissions.

3.4 Coordination across the policy mix

The policies discussed above, and indeed throughout this report, will be most effective and efficient when carefully integrated in a well-coordinated policy mix. They will be better at driving short- medium-run growth and reducing greenhouse gas emissions.

Planning policies in cities provide a clear example of coordination benefits. For example, carbon or petrol taxes are much more effective at reducing emissions when an effective, reliable public transport system is in place.[88] Carbon taxes would have to be higher to achieve the same level of emissions reductions if there is no suitable public transport alternative.

While policies such as standards and subsidies may, in certain cases, attract less political and public resistance than carbon pricing, this may be because the costs associated with these instruments are often diffused or hidden.

In the power sector, emissions reductions are more cost effective when coupled with strong investment in energy efficiency, with evidence of this relationship in the Regional Greenhouse Gas Initiative (RGGI) in the north-eastern United States.[89] Adequate grid capacity will ensure low-carbon electricity can be utilised when the wind blows strongly.

An uncoordinated approach to policy can potentially lead to overlap and negative interactions between policies.[90] The coexistence of the European Union Emissions Trading System (EU ETS) and its renewable targets is often given as an example of overlap. The EU-wide renewable energy target, underpinned by subsidies, aims to reduce emissions in the energy sector, rather than allowing the EU ETS to allocate emission reductions where they are cheapest.

The EU made a choice to structure its policies in this way in order to incentivise early investment in the deployment of renewables, as they are central to decarbonisation of the energy system and investments now will bring down their cost, potentially enabling greater ambition in future years. In addition, the carbon price required to incentivise sufficient renewables deployment to meet EU emissions targets without these supporting policies and targets may be too high politically.

As the emissions cap in the EU ETS is fixed, driving emissions reductions in the energy sector in this way may reduce demand for permits elsewhere, reducing permit prices and creating space for other sectors to emit more. One solution to this perceived problem would be to adjust the cap downwards, but attempts to do this have proved politically difficult. However, recent evidence finds that this overlap is not the main cause of low EU ETS carbon prices. This research shows that the recession, which has led to emissions below the level of the cap, renewable support policies, and international credits, can only explain around 10% of the EU ETS price decline from almost €30 in 2008 to less than €5 in 2013.[91] A lack of long-term

Box 8

The cost of carbon abatement according to policy instrument, using the example of the electricity sector[85]

The OECD has analysed the cost-effectiveness of various approaches for cutting carbon emissions in the electricity sector, and found wide variation. For each policy approach, the study calculated the total cost per tonne of CO_2 abatement, or the so-called "effective" carbon price. These estimates have several limitations: they do not account for the value of additional benefits from these policies, such as improved air quality; and they don't compare different approaches to energy taxes. This is also a static analysis; it doesn't consider the dynamic incentives of each approach for inducing innovation over time. Nevertheless, the estimates are still informative.

1. Carbon trading systems and broad-based taxes have so far proved to be the most cost-effective and economically efficient policy tools.

2. Taxes on fossil fuels are also cost-effective in reducing greenhouse gas emissions. Vietnam is an example of an emerging country that has taken this route. Fuel duties can be a fairly good proxy for explicit carbon pricing and have been shown to be effective. For example, they can have a high impact on reducing emissions in the transport sector.

3. Regulations are more costly, with an average cost of around €50 per tonne, including considerable variation around this average. Feed-in tariffs and investment subsidy instruments are the most commonly used instruments in practice, and some of the most expensive, costing an average of over €150 per tonne of avoided CO_2. They are often the easiest policy instruments to put in place, due to political constraints on carbon pricing and their popularity with those who benefit from the subsidy payments. A greater understanding of their implied and often hidden costs could inform more efficient policy mixes.

This discussion should not imply that only the "cheapest" policy option should or can be used in all cases; for example, regulations are likely to be needed to tackle other market failures beyond greenhouse gas emissions. But, in general, using regulations and subsidies as the main tool to tackle the greenhouse gas market failure is likely to be more expensive than a well-designed mix of policies, with regulations and other measures used to support explicit carbon pricing, and where carbon pricing revenues are recycled to productive uses.

A key point from the OECD analysis is that these policies are often applied in a piecemeal fashion within countries today. As a result, effective carbon prices vary widely across countries. For example, for the electricity sector, the average effective carbon price in Korea is around €200 per tonne of CO_2 abated, around €100 per tonne in the UK and Germany, and below €50 for Australia, the US, Chile and China. Policies could be coordinated in more effective and efficient ways to better tackle the market failures.

credibility around the future of European climate and energy policy appears the likely explanation of most of the decline.[92]

More research is required into the most effective and credible coordination of policies across a wide-range of areas relating to energy, climate, competition, fiscal management, innovation, development cooperation, agriculture, investment policies, competition policy and trade policy.[93] It is clear that coordination is best applied across sectors, such as cities, transport, energy and land use. Poor coordination, coupled with an incomplete range of policy instruments to tackle the relevant market failures, will raise costs, impact credibility, and lower the effectiveness of policies. For example, the presence of fossil fuel subsidies raises the carbon price needed to achieve a certain level of emissions reductions. Another example of competing policies is trade rules, which are not always compatible with support for low-carbon energy. This is discussed in Chapter 8: International Cooperation.

Better coordination of policy could transform efficiency and accelerate the pace of change. In May 2014, Ministers of Finance and Economy requested the OECD and the IEA to provide recommendations on how to align policies to achieve a low-carbon transition. Such work will be an important follow-up to this report.

4. Managing and monitoring change and learning from experience

4.1 Policies to ease the transition

Policies can help firms and households manage and adapt to the structural change associated with a low-carbon transition. This will minimise the economic and social costs. Countries that have a record of proactively managing change and easing the costs of transition will do better and experience less resistance to reforms.

Managing change requires recognising where there will be winners and losers, and smoothing the transition for affected groups. Some workers and firms may face higher costs or dislocation. Some firms and industries will decline. Governments have a role to identify the most effective policies to reduce these costs without impeding change. Phasing in policy reforms according to a pre-announced schedule, after public consultation, can provide time and clarity for businesses and workers to adapt or identify new opportunities.

Three key challenges are identified, related to the structural shifts associated with policies to boost growth and reduce climate risk:

- Equity, to distribute the benefits and burdens of change fairly;
- Employment, to help workers re-skill and retrain; and,
- Competitiveness, to help firms benefit from change, and not be put at a disadvantage relative to competitors.

Each is examined in turn below.

Equity

Carbon taxes and fossil fuel subsidy reforms can have regressive impacts when they raise domestic energy prices. Poorer households may take a relatively bigger hit than others.[94] Targeted compensation policies can alleviate these costs for households, for example, through cash transfers or social security payments, or by reducing marginal income tax rates for households.[95]

Poorer households may not have benefited so much from fossil fuel subsidies. While energy consumption subsidies are often intended to help the poor, they are often proportionate to the level of energy consumption, which is generally higher for rich households, who then capture most of the benefit. The subsidies also tie households to purchasing fuel or electricity if they wish to benefit. By contrast, poor households can use direct income support, rather than subsidies, for other needed spending, such as on clothing, food and education.[96] These support packages can be adjusted over time as the carbon price level and the structure of the economy changes.

One policy challenge in making compensation transfers is to devise appropriate mechanisms, given the lack of social safety nets in many developing countries. A lack of such mechanisms and institutions is often part of the reason why such countries relied on fuel or electricity subsidies in the first place. Much experience has been gained in recent years with the introduction of cash payment schemes, and the World Bank is assisting a number of countries to introduce these. The introduction of the "Aadhaar" proof of identity and address scheme in India has enabled better targeted support to poor households and has been an essential factor in recent energy subsidy reforms, despite implementation issues that have reduced public trust in the scheme. In countries that have social safety nets, governments must be careful to ensure additional support is in fact required. For example, social security payments often adjust automatically to price levels, including the impact of higher energy prices.

Jobs and unemployment

Workers are at the centre of economies, and will be directly affected by any form of structural change. As economies develop and grow, labour will continually transition from declining sectors to more profitable and productive activities.

> *Policies can help firms and households manage and adapt to the structural change associated with a low-carbon transition. This will minimise the economic and social costs.*

Various policies can ensure a just transition for workers. They can take many forms but should minimise unemployment, promote job creation in growing sectors and tackle labour market distortions efficiently, while also providing protection for the most vulnerable. They should tackle the wide range of factors related to the risk of job loss and impacts on the communities in which workers live.[97] Such measures are a central part of the integrated framework for managing change described in this chapter. These policies can increase the responsiveness of the workforce to change and new opportunities in a way that benefits both employees and employers: it is not about making it easier for employers to hire and fire workers. They include:

- Pro-active training to equip people for change by acquiring new skills. Sweden, the Netherlands and Germany have demonstrated successful training and re-skilling policies to prevent long-term unemployment. Singapore actively promotes structural change through public policy to encourage knowledge-intensive skills and activities.
- Unemployment benefits must be designed to motivate workers to re-enter the workforce, in particular because learning on-the-job remains an effective way to prevent skill atrophy. This means finding the right level for benefits that incentivise re-entry into the labour market without creating financial distress for the unemployed, and provision of in-work credits or wage subsidies to get people back to work. It may also be more efficient to promote job creation in new sectors rather than protecting old jobs.[98]
- Assisting workers is harder where job losses are concentrated in particular geographical regions, such as a remote coal mining town, or where losses hit older or less skilled workers. Recent experience shows that these workers can end up among the long-term unemployed for many years, or drop out of the labour

force altogether. In these cases, the government may need to provide unemployment benefits, resources for job search, relocation assistance, improve the flexibility of the housing market, and provide geographic mobility programmes to get people back to work. In cases where long-term workers are unlikely to be able to retrain or relocate, the provision of social protection mechanisms to ensure workers receive adequate pensions and health insurance is key to a just transition and to overcome resistance to change.

- Reforms to ensure strong labour market institutions, to protect the most vulnerable workers, such as minimum wages and collective bargaining, are also important for a well-managed transition.

Experience has shown a range of risks that governments should be aware of when implementing such policies. For example, severance payments or loans need to be linked to suitable training that improves employability. Poorly designed training programmes and work creation schemes can develop the wrong skills and fail to increase employability of workers. Inadequate schemes can send negative signals to employers, who then avoid employing these workers. Multiple training programmes can reduce the motivation of workers to search for new jobs, and so these should be limited and well-targeted. And retrained workers can end up displacing existing workers.

Despite the complexities and pitfalls of such transition programmes, experience has shown that propping up declining sectors rather than actively managing structural change is counterproductive. Following are some brief examples from around the world.

- The **UK** experience of trying to shield its ailing shipbuilding, steel and car-making industries from adjustment in the 1970s illustrates the risks, including the heavy social cost of subsequent rapid restructuring of the economy

- **Germany** has in the past managed structural change by welcoming an appreciating exchange rate, which has put less productive firms under increasing pressure to innovate, as part of a process of "Schumpeterian" or continual change.

- **Japan** provides a good example of actively managing structural change in industries that are in decline. From 1987, the government provided long-term support to smooth the decline of what it called "structurally depressed" industries, including textiles and ship-building. This support reallocated resources within and outside the depressed industries; provided financial assistance to troubled firms; and mitigated negative impacts on the labour force.[99]

- In **Poland**, starting in 1990, the government restructured its loss-making mining sector through debt restructuring, mine closures and a radical reduction in employment. Initial reforms were resisted as they did not provide adequate support for miners. From 1998 the employment reduction programme was accompanied by incentives for firms to hire ex-miners; free retraining programmes financed by the European Commission; social benefits and severance payments, which were effective but very costly for government; loans and credits for ex-miners, which were mainly used for household consumption; job guarantees for miners close to retirement; and benefits for miners with long tenure, such as five-year voluntary vacations at 75% pay. These measures were designed in cooperation with the unions, which helped overcome resistance to the reforms. From 1998 to 2002 alone, some 53,000 workers left the industry and 33,000 received some form of support (total coal mining employment in Poland fell from around 390,000 in 1990 to 120, 000 in 2006).[100] The total cost of the 1998 programme was around €1 billion, which was probably far less costly than propping up the ailing industry for years to come. In 1998 the industry made a net financial loss of around US$ 1.5 billion but by 2004 had returned to profitability with a net financial profit of around US$730 million.[101]

- The **United States** instituted the US Trade Adjustment Assistance (TAA) programme several decades ago to help workers adjust to trade liberalisation. The programme provides: income support for over 100 weeks; training expenses; health coverage tax credit; wage insurance that "tops up" a potential lower income in a new occupation for up to two years for workers over 50 years of age; and costs associated with job search and relocation. This assistance package is designed to be targeted and calibrated to worker needs. However, recent assessment of its effectiveness finds mixed results.[102]

Evidence from the OECD suggests that a combination of a carbon price with revenue recycling to productive uses, and fair transition policies which help workers adjust to change, could help offset the employment impacts of a low-carbon transition.[103] They model the economic costs of a carbon price across OECD countries, assuming a moderate carbon price in 2030 with lump-sum transfers, and find that markets with just transition policies and more responsive labour markets as a result, could see as little as a 0.78% fall in the level of GDP and a 0.32% fall in employment. In one scenario with revenue recycling through reduced labour taxes, there was a small but net positive impact on employment. In contrast, rigid labour markets could see a 2% fall in GDP and a 2% fall in employment in 2030 compared with the baseline. The modelling suggests that ensuring a just transition for workers could significantly reduce the economic costs of transition.

A number of reports suggest that policies can boost the gross number of jobs in new and less polluting sectors. A recent study commissioned by the International Trade Union Confederation (ITUC) suggests that investing 2% of GDP in the green economy could create up to 48 million jobs in five years.[104] Bottom-up analyses, for example a recent study by the World Bank, finds that if Brazil sent all solid waste to sanitary landfills, with methane and biogas produced for electricity, it could create 44,000 new jobs and increase national GDP by over US$13 billion, and if India built 1,000 kilometres of new bus rapid transit lanes, it could create 128,000 new jobs and save 27,000 lives from lower air pollution and accidents.[105]

However, many such studies focus only on gross job gains in green sectors, and do not consider economy-wide impacts such as job losses in other, declining industries, or consider skill or location mismatch that could prevent workers filling these new jobs. Studies that do account for economy-wide effects, and take a general equilibrium approach, tend to confirm that the net employment impacts from a low-carbon transition would likely be small over the medium- to long-term. For example, a major survey of the literature for the European Commission in 2013, regarding a shift to low-carbon energy in 2050, concluded that there was no clear consensus about whether the overall net impact on employment would be positive or negative, but in almost all cases the impacts were small at the macroeconomic level. As indicated above, depending on how the revenues from carbon taxes are recycled back, fiscal reform could lead to a small net employment gain.[106]

That net effects are found to be small should not be surprising, given that the policy framework presented here is likely to induce a substitution between different types of production and consumption, away from more polluting and toward less polluting activities. Overall net employment gains or losses from such policies should be small. However, there will be changes in the numbers and types of jobs across and within economic sectors and, as is the case with all industrial change, workers will need to move from declining to expanding sectors, firms and job types. This gives rise to the need for policies to support workers in their transition.

Risks to competitiveness for early movers

Many governments and individuals are concerned that taking early or ambitious action to reduce greenhouse gas emissions will increase energy costs and leave an economy, sector or firm at a relative economic disadvantage, compared with peers in jurisdictions with less strict carbon regulation.

This concern needs careful consideration. Carbon pricing and investments in energy efficiency and renewable energy will raise costs for certain sectors. In response to climate legislation, firms and sectors producing carbon-intensive, globally traded goods and services could reduce their cost base by relocating production to countries with more relaxed environmental regimes. This is known as carbon leakage and it will limit the effectiveness of climate action as emissions do not fall but are merely displaced.

There is substantial evidence suggesting that the direct competitiveness impacts are small for a country which is an early mover in legislating climate policy.[107] Other factors, such as labour costs and access to materials and markets, are the primary drivers of firms' investment and location decisions, rather than climate change policy. In addition, relocation of physical plants or investment will make sense only if investors expect the asymmetric application of climate policies across trade competing countries to endure long enough to cover a sufficient part of the lifespan of the new capital. Otherwise, future policy changes might render such relocation decisions costly and unnecessary.

Many governments and individuals are concerned that taking early or ambitious action to reduce greenhouse gas emissions will increase energy costs and leave an economy, sector or firm at a relative economic disadvantage.

However, there is general agreement that a few carbon-intensive globally traded sectors and sub-sectors, which account for less than 5% of GDP in most countries, may see competitiveness impacts if stringent climate policy is enacted in one country but not in trade partners. These sectors include metals, cement, paper, and chemicals. Even for these carbon-intensive sectors, however, most studies fail to find evidence that current policies as applied, for example in the European Union or California, have had a significant effect on business competitiveness.[108]

Generally, ex-post econometric studies using empirical data from actual policies have found a smaller competiveness impact than was predicted by ex-ante models.[109] This is partly because carbon pricing and other environmental policies introduced so far have not been very stringent, as for example in the EU ETS, and partly because a large swathe of compensatory measures or preferential treatment was provided to energy-intensive industries to limit competitiveness impacts. In the

Box 9
Border carbon adjustments

Border Carbon Tax Adjustments (BCA) or Border Adjustment Measures (BAMs) are measures that would apply a tax on the carbon embedded in traded products and services, based on the CO_2 emitted in their production. Some commentators and governments have promoted them as a way to level the playing field and tackle competitiveness concerns given the lack of climate policies in some countries. They have also been suggested as a means to spur countries towards more comprehensive global climate action. But such BCAs are very controversial, especially where they are seen as discriminating against developing countries.

In economic theory, applying a BCA could internalise the costs of greenhouse gas emissions in their production, enhancing the efficiency of unilateral climate policy.[113] However, some modelling studies have found that carbon leakage would in any case be low, except under scenarios where very few countries took climate action. BCAs may therefore have a limited impact in reducing carbon leakage.[114] A recent cross-model comparison under the Energy Modelling Forum found that full BCAs could reduce leakage rates on average only by one-third.[115] Given growing climate action worldwide, even if patchy and uneven, it is increasingly unlikely that BCAs would have much effect in protecting energy-intensive industries or reducing global emissions.[116]

There is extensive discussion in the literature on whether and how BCAs could be designed in a way that is compatible with international trade rules, for being non-discriminatory in their application and applying a consistent measurement of "comparable effort". A number of approaches to ensure WTO compatibility have been suggested, but such amendments may further limit the effectiveness or efficiency of the measure.

Recent guidance on how a BCA could be applied in practice highlights a number of significant technical challenges, in particular measuring production-related emissions and in setting the right tax levels.[117] Establishing an appropriate BCA would require identifying a carbon tax level commensurate with the local tax in the importing country, and accurate measurement or benchmarking of the production-related greenhouse gas emissions in the exporting country. The latter can be complicated. For example, regarding steel production, a basic oxygen furnace technology emits over four times as much CO_2 per unit of steel produced than standard electric arc furnace technology. One resolution could be to base the BCA on the carbon intensity of best available technology.[118] This may be seen as fairer, as it does not require discrimination among like products according to production processes.[119]

Ideally, a BCA would discount any explicit or implicit carbon "price" that may already be applied in the producing country, via regulations or other policies, but this would be incredibly difficult given the number and variety of different policies affecting greenhouse gas emissions. Recent analysis of "effective" carbon prices of various policy instruments has found the average costs of some regulations are over €400 per tonne of CO_2 abated.[120] Such uncertainty about the implicit carbon price in exporting countries, coupled with uncertainties about the exact emissions associated with production processes in countries without extensive emissions monitoring, may make the practical challenges and administrative costs of applying even a very narrow BCA prohibitive.

European cement industry, for example, the EU ETS has not forced carbon emissions cuts in addition to those the sector would have made anyway as a result of general gains in best practice, because of the allocation of free permits and a low-carbon price. [110] Also, as a result of this compensation, the scheme has not yet prompted relocation of cement production abroad. Indeed, energy- and carbon-intensive industry may have profited from the scheme as a result of large opportunities for firms to make windfall profits from carbon trading.[111] This compensation may have served to achieve early buy-in from industry, but it makes for a wasteful use of public funds in the long-run. A recent study of competiveness impacts on the European Chemicals Industry found that there are significant opportunities to reduce emissions by 80-95% in the sector by 2050, while at the same time maintaining or enhancing competitiveness.[112]

Concerns about the potential competitiveness impacts of climate policies remain, however, and governments must tackle them. The best option, from an efficiency point of view, is to apply climate policies across more countries, so that significant trade effects do not arise.

Another option, where international coordination does not exist, is the application of so-called border carbon tax adjustments, as described in Box 9. Given the absence of strong international coordination currently, it is inevitable that these are being discussed and examined. But they are "second" or "third-best" instruments, and the primary policy effort should be on achieving internationally coordinated policymaking, or targeted measures to mitigate impacts in the small number of sectors where differential carbon regulation makes a genuine difference.

Compensation schemes to smooth the low-carbon transition for truly vulnerable sectors can help to level the playing field and mitigate the impacts of asymmetric policy application across countries. Lessons from recent experience and economic theory include:

- This protection should not be provided through exemptions from carbon pricing, as this would reduce the incentives to reduce emissions, improve efficiency, and shift consumption toward lower carbon alternatives. Indeed, even energy intensive sectors are likely to become more productive in the long-run as a result of incentives to improve efficiency. Instead, some of the revenues raised through carbon pricing could be recycled back to companies in proportion to output. One study suggests that recycling approximately 15% of revenues to carbon-intensive, tradable sectors in the United States might be sufficient to eliminate any negative impact on profits.[121]

- Compensation to affected industry reduces the revenues available for other productive recycling purposes, such as cuts in distortionary taxes. Therefore, it is important that compensation mechanisms are well-designed and well-targeted, to avoid encouraging rent-seeking. Failure to recycle revenues in the most productive manner, for example by allocating allowances for free, will raise costs.

- In the case of cap and trade, most countries have opted for some free allocation of permits in emissions trading systems, given the relative simplicity and political popularity of such measures to level the playing field and protect against competiveness impacts for carbon intensive tradable products. In the EU, RGGI, and other schemes, there is now a shift towards decreasing the percentage of permits that are allocated for free.

- In the case of carbon taxes, compensation to selected affected industries could take the form of lump sum rebates. Other support could include grants to re-skill and retool production, especially for smaller firms, or support investment in low-carbon and energy efficient technologies.

- Industry compensation should be transparent, temporary and avoid overcompensation and rent-seeking. It can be designed in ways that enable industries and investors to adjust proactively, for example by consulting in advance with stakeholders, pre-announcing the policy and starting with low levels of carbon pricing but with agreed ratcheting up. This allows firms to plan investments accordingly, including investments in clean solutions, without prematurely scrapping carbon-intensive capital and shifting production to other areas.

In summary, how carbon pricing policies change comparative advantage will depend on skill levels, innovation and flexibility to respond to structural change and reallocate resources toward new markets. The impacts also depend on expectations: if others are expected to also take climate action soon, the competitiveness opportunities for early movers will be larger than if they are not. China and other countries have realised that a low-carbon economy can provide new business opportunities and help tackle growing resource challenges. This should encourage other countries to adopt stronger policy as both the expectations of costs of waiting and of opportunities rise.

Managing structural change requires strong institutional frameworks that are able to set clear and credible polices to guide expectations on the direction of change.

4.2 Strong institutions for clear and credible policy signals to align expectations around future growth

As introduced in Sections 2 and 3, managing structural change requires strong institutional frameworks that are able to set clear and credible polices to guide expectations on the direction of change. This is a prerequisite for cost-effective, low-carbon investment across the economy. Countries such as the UK and Mexico have legally enshrined climate change acts which provide a credible underpinning to the legislative process, tying the hands of future governments to the extent that they must accede to amend or repeal legislation if they are to renege on climate policy targets. Such institutions set clearer signals that align expectations on the future direction of growth and development.

Clear signals are especially important because of the long-lived nature of physical networks and infrastructures, in particular in energy generation, transport and the urban form. Because such infrastructure becomes entrenched in an economy and society, the pattern of development of infrastructure therefore builds on what went before, or becomes locked-in. Such "path dependence" is a common phenomenon in behaviours, technologies and networks. For example, some major road and rail networks in England were determined by choices made by the Romans two thousand years ago. Path dependence is also relevant to innovation, where new technologies tend to be based on existing networks. Path dependence can lead to positive synergies, through the development of new systems and networks. For example, the creation of cycling and walking paths and the presence of good public transport can, in time, drive a modal shift: politicians will then invest more in cycling and walking paths and public transport infrastructure, because there are more users, as shown in Amsterdam and Copenhagen.

The degree to which populations embrace a shift from historical norms will depend on their expectations. For example, people are more likely to embrace a shift towards low-carbon growth if they understand its virtues, policies are clear and credible and they expect others to move in tandem. They will see the benefits of supplying new markets; expect technology costs to fall; and anticipate easier access to finance for a sector that is no longer considered niche. Once enough decision-makers act in this way, the expectations become self-fulfilling: technology and business costs come down as a result of experience, learning and deployment. Political institutions and groups not making the transition can then find themselves at a competitive disadvantage. For example, China's significant investments in renewables in recent years have helped drive down technology costs and this has opened large new markets. The scale of other similar developments may be sufficient to start a domino effect, where by a critical mass of countries move, prompting all the others to move in an unstoppable transition.[122]

By contrast, if businesses expect no one else to move, they are less likely to be proactive. They will see high risks in the prospect of new markets, and the costs of acting are higher and the decision to hold back looks sensible. Many business leaders are calling for governments to provide this signal and adopt a clear, credible and predictable long-term price on carbon, against which they can plan investment.

The degree to which populations embrace a shift from historical norms will depend on their expectations.

Expectations determine which path countries take, whether they move quickly to innovate and take advantage of the opportunities of a low-carbon and resource efficient transition, or remain stuck in a hedging or waiting game. Both paths can look rational to individual agents, depending on expectations, although as the risks of climate change mount with time and new technologies emerge, the incentive to tip toward action will increase.

4.3 Policy risk and muddled expectations delay investment

As highlighted in Chapter 6: Finance, the infrastructure investment requirements for growth will be large over the coming decades. Global infrastructure investment required to achieve a broad-based, low-carbon transition is likely to be in the region of US$93 trillion (constant $2010) over the period 2015 to 2030. The estimated infrastructure investment required under a business as usual, high-carbon path is around US$89 trillion over the same period. Therefore an extra US$4 trillion will need to be invested over the next 15 years to shift the world onto a low-carbon path. The appropriate way to consider these additional investment costs is in the wider context of the dynamic net economic cost, as discussed in Section 2.1.

Government induced policy uncertainty from vacillation, inconsistency, sudden shifts in policies, or a belief that there may be such shifts in the future, can prevent or delay financing for these investments. Along with market failures and the risk of government failure, this is one of the biggest barriers to investment. Some European countries, notably Spain, have dramatically reduced renewable energy support recently, sometimes retroactively. Investors are confronting the risk that policy changes will render some investments less profitable or even loss-making. This policy risk is likely to reduce investments in renewable energy compared to what would otherwise be the case. It should be noted, however, that many of these European countries have faced extraordinary budgetary pressures in the wake of the financial crisis, and there is an argument that renewable energy developers should share some of the burden of austerity.

Government induced policy risk can prevent or delay financing for low-carbon investments. Along with market failures and the risk of government failure, this is one of the biggest barriers to investment.

Chapter 6: Finance explores in detail how governments and international finance institutions can take some share of the financial and regulatory risk of developing low-carbon technologies. Such assistance can provide a signal of the government's commitment to the policy: if the policy were reversed or failed to deliver, the public sector would stand to lose. Government-backed infrastructure banks and green investment banks have a particular role. As well as increasing a government's financial commitment to the policy, such banks can develop dedicated expertise in clean infrastructure finance, something that is often lacking in the more traditional private finance sector. They can draw on strong networks to convene different coalitions and sources of finance. And their capital structure allows them to take a long-term view. If they are combined with well-coordinated, clear and credible policies, and strong institutional governance, they can foster rapid change.[123]

For much of the world, now is a good time to support resource-efficient investment. There is no lack of private money seeking positive returns, with real, risk free interest rates at record lows, or even negative. There is, however, a perceived lack of opportunity, and developing a bankable pipeline of viable projects is always a challenge. The World Bank Energy Group is helping countries identify upstream renewable investment opportunities. With many economies forecast to operate below capacity for the foreseeable future,[124] the potential to crowd-out alternative investment and employment is much smaller now than when the economy was operating close to full capacity.[125] Clear and credible structural policies now could restore confidence and generate growth, and accelerate the transition to a low-carbon economy.

4.4 Overcoming barriers to change

Political economy and institutional barriers

Political economy and institutional barriers prevent reforms and hamper efficient long-term decisions. Entrenched networks and technologies, as well as behaviours, institutions and lobbies work to resist change, even where it is in the economic interests of society. Powerful vested interests, with political influence, actively seek to prevent or delay these changes. Distributional impacts, a feature of any transition on this scale, create often vocal losers in the short-term, even when the long-term aggregate impact of the transition is largely positive. So-called entanglement with the existing high-carbon economy, for example where governments derive a large share of their fiscal revenues from fossil fuels, can also stand in the way of reforms (Box 10).

These types of barriers have been present throughout history. In the case of low-carbon change, the losers are generally concentrated and well-defined, and include carbon intensive fossil fuel industries and particular entangled governments, while the beneficiaries are dispersed and unorganised or cannot yet easily understand the gains. This is particularly true given that most of the gains from climate action now will be to the benefit of future generations, in the avoidance of costly climate damage.

In that this affects policy decisions it is the institutions and politics which are the key barriers to aligning expectations and embracing change. Many politicians and commentators have ruled out the most efficient market-based policies, in particular explicit carbon pricing, based on judgments of what might be politically feasible, without those judgements being made explicit and their validity examined. Some of the underlying assumptions are being challenged, however, in countries that are forging ahead and learning how to compensate losers and manage existing vested interests effectively. Such lessons include designing transitory support with a pre-announced phase-out to avoid creating a new class of vested interests. In the future, the barriers countries face today may be viewed in the same light as other reforms once perceived as politically impossible, such as public bans on smoking.

Behavioural psychology provides broad and high level lessons and ideas for how to overcome political economy barriers to change.[127] A combination of the following may be needed, beyond evidence that this is good policy:

- Trusted leaders across society, including community leaders, Heads of Government and Ministers, and labour, military and religious leaders, telling a convincing story that appeals to the public intuition, thereby empowering and inspiring people to take action;
- Key countries (and businesses) taking the lead and acting strongly, encouraging others to act through the power of example, with leaders recognising "moments of power", where people are more willing to listen, consider the arguments, and commit;
- Smaller communities, cities and regions setting strong examples and providing social proof for others, through experimentation, learning and discovery, of the benefits of more locally controlled networks for distributed energy, food production, waste management, transport coordination and stewardship of natural capital. Some relatively poor regions may turn out to be pioneers of this new, more ecological economy;[128]
- Involvement and actions by key decision-makers who have a reputation for "getting things done";

Box 10
Carbon entanglement

For some governments royalty payments, taxes, and other revenue streams from upstream oil and natural gas rents are a major source of income. This can represent as much as 90% of total government revenues in some oil-producing countries, such as Saudi Arabia, Iraq, and Libya.[126]

In such countries, the structure of the economy and the government revenue base is highly dependent on continued fossil fuel production. Even in countries where fossil fuel revenues are much smaller, such as in Australia, Canada, and the Netherlands, where they represent under 4% of total government revenues, there are often policies in place to actively discover and exploit new fossil fuel reserves. This is likely to increase dependence on this source of revenue.

- Engagement of the young, including their power to pressure leaders to do more. Examples include the UN Major Group for Children and Youth;
- Encouraging public discussion and reasoning on policy and standards of behaviour, including a better understanding of social and personal responsibility and values. This includes discussion on the multiple benefits of policy and transparency on the short-run adjustment costs and on our willingness to confront the challenges.
- Social compacts between governments and community organisations, labour unions, civil society groups, to ensure an inclusive and just transition.

Government liability risk, as insurer of last resort

Overcoming barriers may require a greater awareness of the risk of the alternative from inaction or delay, including large contingent liabilities for governments. Private insurance covers only a fraction of the possible climate-related or severe weather event losses. Governments would end up bearing the residual risk, as insurers of last resort. That residual risk is often hidden, but it is likely to grow, for example as homes and other infrastructure lose their value as a result of climate impacts including rising sea levels and more frequent floods and storms.

There is a related risk that the long-run impacts of climate risk could hit government credit ratings in some countries. Downgrades are likely to manifest through lower economic growth, weaker external performance, and increased burdens on public finances. This is likely to be most damaging for low-income countries, particularly in Africa and Asia, in part because of their higher exposure to climate risk, and also because of their inherently more fragile credit ratings. A measure has been devised to assess potential sovereign vulnerability. The measure is composed of three variables: share of population living in coastal areas below 5 meters of altitude; the share of agriculture in national GDP; and a vulnerability index measuring susceptibility to adverse climate impacts, based on exposure, sensitivity and adaptive capacity. The 10 most vulnerable nations are Cambodia, Vietnam, Bangladesh, Senegal, Mozambique, Fiji, Philippines, Nigeria, Papua New Guinea and Indonesia.[129]

Overcoming barriers to low-carbon change may require a greater awareness of the risk of the alternative from inaction or delay, including large contingent liabilities for governments.

A recent study attempted to quantify local and national US government costs from climate change.[130] The "Risky Business Project" focused on the impacts of storm surges, heat waves and sea level rise on particular regions and sectors, such as agriculture in the Mid-West, and coastal infrastructure in the Gulf of Mexico. One of the main conclusions was that climate change would put government budgets at risk, as the insurer of last resort, in the same way that countries were forced to use government balance sheets to bail out the banks in the financial crisis of 2007-2008. Illustrating the scale of potential risk, the report estimated that current trends in global greenhouse gas emissions would see stronger storms that could result in an additional US$2 billion to US$3.5 billion in property losses per year by 2030, along US eastern and Gulf coasts.

5. Better metrics and models for better macroeconomic management

Better metrics and models are necessary to steer a low-carbon transition. Regarding metrics, as is often stated, we cannot manage what we cannot measure. Regarding models, we cannot assess the likely impacts of what we struggle to predict.

5.1 GDP is a limited measure of changes in welfare

There is a growing realisation that macro-economic statistics, such as those based on GDP, are useful but do not provide policy-makers with a sufficiently detailed picture of economic and societal well-being. For example, an overreliance on the GDP statistic can promote an excessive focus on increasing this measure, potentially at the expense of other important aspects of welfare and development.

The GDP measure has advantages and disadvantages, here briefly described.

GDP has merit as a key indicator of living standards. Shrinking GDP implies lower incomes, and possibly idle factories and rising unemployment. Furthermore, GDP is a well-known indicator and is consistently measured. It also correlates fairly well with many elements pertinent to social welfare such as happiness, poverty reduction, gender equality and social mobility. On the other hand, GDP is a measure only of the flow of production, income and expenditure, not the stock of assets or wealth. As a result, it will fail to register deterioration in a country's natural resources. Furthermore, some services derived from these assets as flows are not adequately valued or priced, and so are not registered or are under-represented in the income accounts. Such flows include environmental goods and ecosystem services. Nevertheless, as relative prices change and appropriate policies such as carbon pricing are implemented, the value of environmental services will begin to rise, increasing their price weight in the measure of real GDP.

Even where market prices are absent, statistical agencies can value non-marketed activities and bring them formally within the national accounts. For example, until recently there were few direct estimates of the output of the public sector activities that were not generally sold on the market, including for example police output or education. As a proxy, inputs were used to estimate output, with no explicit measure of productivity change. Since then, statistical agencies have developed a range of measures from educational attainment, medical results and crime statistics, to capture public sector value. Similar improvements can be expected to evolve to measuring environmental services, and include these within GDP.

However, GDP remains just one indicator among many attempting to quantify the variables that society cares about, and its limitations make it important to develop and use other, complementary indicators. A number of countries and organisations have been making progress in establishing a more representative set of indicators to measure progress, building on the recommendations made in 2009 by the Commission on the Measurement of Economic Performance and Social Progress, also known as the Stiglitz-Sen-Fitoussi Commission. Those recommendations recognised that no informative assessment of welfare can be reduced to a single dimension. A practical and informative alternative would be to monitor several indicators, in addition to GDP.

Macro-economic statistics, such as those based on GDP, are useful but do not provide policy-makers with a sufficiently detailed picture of economic and societal well-being.

There are many suggestions on how to expand and improve the range of metrics for better decision-making. Some are being implemented.

- Studies by the OECD have proposed broad frameworks of indicators, to assist decision-makers manage growth while at the same time considering social and environmental dimensions.[131]
- The World Bank has developed an adjusted net savings (ANS) metric, which measures the net rate of saving after taking into account investments in human capital, depletion of natural resources and damages caused by pollution.[132] The indicator provides an assessment of an economy's sustainability based on the System of National Accounts (SNA), a framework finance ministries use on a regular basis.
- Countries have established through the United Nations a System of Environmental-Economic Accounting (SEEA), which contains internationally agreed concepts, definitions, classifications, and accounting rules for producing internationally comparable statistics on the environment and its relationship with the economy.[133] A multi-year process to revise the SEEA is underway, with the participation of various international organisations. The first element, a Central Framework, was adopted by the UN Statistical Committee in 2012.
- The US states of Vermont and Maryland have adopted the "genuine progress indicator" (GPI), an adjusted economic measure, to monitor welfare, and are using it to inform legislative and budgetary decisions.[134] The GPI uses personal consumption expenditures, which is a measure of all spending by individuals, as its baseline and makes more than 20 additions and subtractions to account for factors such as the value of volunteer work, and the costs of divorce, crime and pollution.[135]

The choice of metrics needs to reflect the specific demands of decision-makers. In the case of change over the coming decades, various specific indicators will be needed to allow decision-makers to evaluate progress in transitioning toward a low-carbon economy. For example, an indicator such as environmental tax revenue as a share of GDP could be useful to monitor progress in internalising environmental externalities.[136] A list of specific indicators could span carbon and energy intensity, share of renewables, pollution and environment indicators, as well as economic indicators linked to low-carbon policies, to provide a comprehensive picture.

Some countries are starting to measure natural capital. England's Natural Capital Committee (NCC) is tasked with advising on how to integrate natural capital into the English economy and the UK Office of National Statistics (ONS) has released some preliminary work valuing part of the UK's natural capital assets.[137] The valuation of natural capital in government accounts would enable a more comprehensive assessment of the total wealth of a country, and better identify where policy is needed to improve the quality and quantity of natural capital.[138] In parallel, better measures of exposure to climate and other environmental risks are also needed, covering intrinsic vulnerability, system resilience, and contingent liabilities affecting the public balance sheet.

The private sector can also be involved, through the development of corporate natural capital accounts that document an organisation's ownership and extended reliance on natural capital, together with related assets and liabilities. This would allow for a more comprehensive assessment of the value of corporate assets and enable better management of business operations.[139]

The financial statements produced by firms also fail to provide all the information investors need so they can assess risks and opportunities and allocate their capital efficiently. For example, there is no standardised system of sustainability accounting that provides an interested investor with reliable information on an automobile company's investments in fuel efficiency and electric vehicles. This is not disclosed in a standardised way, and may not be disclosed at all.[140] Cities face a similar but currently much greater problem, given the lack of standardised accounting frameworks to measure economic and environmental impacts at the urban level.

5.2 Economic modelling can significantly undervalue the net benefits of climate action

Researchers working in academia, policy institutes, and Finance Ministries use a range of economic models to provide economic forecasts, and to simulate the effects of policy or other developments. Relevant questions that they seek answers to include, how would the economy change if a policy was introduced, relative to some counter-factual, for example with the introduction of a carbon price? Or how might the economy respond to an energy price spike?

There are many different types of applied economic models with different strengths and weaknesses. Applied economic models are essentially simplified frameworks to describe the workings of an economy. They are an essential tool to help us formulate, examine and understand interactive relationships.

Economic modelling can help to shed light on what types of policy measures are likely to be lower cost, or more effective. Cross-model comparison exercises such as those undertaken for the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), or through Stanford University's Energy Modelling Forum, can provide insights about, for example, the driving forces behind different cost estimates of climate change policies, as well as about the range and nature of the uncertainties involved. However, economic models also have a number of limitations, and when used inappropriately or without a proper understanding of their assumptions and relevant caveats, can lead to poorly informed policy decisions.

Climate modelling involves the use of Integrated Assessment Models (IAMs). They are "integrated" because they bring together science (climate and impact) and economics models. In this way their aim is to utilise information from diverse fields of study including climate science, economics and technology in order to assess the impact of actions such as policies on human welfare through time. But there is no rigid specification for an IAM; the term describes a whole array of diverse heterogeneous models developed by different groups in different ways that try and capture features pertinent to the climate story. Increasingly, decision-makers are turning to IAMs to inform options for tackling climate change.

Two main kinds of economic models have traditionally been deployed in IAMs when they are used to assess the impact of energy and environment polices on the economy. These are commonly referred to as "top-down" and "bottom-up" economic models. More recently, a number of "hybrid" models have also been developed, combining features from top-down and bottom-up models. Most economic models used in IAMs have reduced form equations to characterise the drivers of key variables such as greenhouse gas emissions, global mean temperatures, the damages caused by temperature changes and their impact on social welfare, as well as the costs of abating emissions.

Bottom-up models contain a detailed, technological treatment of the energy system. The models aim to minimise the costs of a policy goal by choosing the cheapest technologies to meet final energy demand for a given level of energy services under certain greenhouse gas emissions constraints. They do not contain a behavioural component, and often ignore partial as well as general equilibrium costs and trade effects.

Top down models attempt to characterise overall economic activity by applying a theoretically consistent description of the general economy. Because they try to represent the entire economy, by simulating selected representative households and the production and sale of goods and services, they are by necessity less detailed than bottom-up models when it comes to individual components, and tend to aggregate technologies into a simple production function. Three types of top-down models dominate estimates of climate policy costs: computable general equilibrium (CGE) models; macro-econometric models; and neoclassical growth models, including so-called overlapping generation models. They all provide simplifications of reality by condensing complex relationships into a few equations that are easily

Economic models have a number of limitations, and when used inappropriately or without a proper understanding of their assumptions and relevant caveats, can lead to poorly informed policy decisions.

understood and manipulated. This helps simulate key relationships, but means they often miss the full array of dynamic substitution options available in the transition to a low-carbon economy.[141]

Notwithstanding the limitations of models, GDP costs of climate action look like "background noise" when compared with the strong underlying growth that the global economy is likely to experience over the coming 15 years.

Most CGE models start from the assumption of an economy where resources are already efficiently allocated, for the good reason that it is not easy to model properly the real and dynamic world of multiple imperfections and numerous market failures. The effects of policy reforms are thus judged against the assumed starting point of an efficient economy. Such results, while interesting, need to be used cautiously as a guide to policy when one is judging the results of reform versus non-reform in a highly imperfect and inefficient world.

Such shortcomings have been examined, regarding the use of UK Treasury's CGE model to assess the short-run cost of UK climate policies. This analysis illustrated the limiting assumptions of the model. It showed that including the values of health benefits from reduced air pollution and the value of carbon emissions that are not traded in the European Emissions Trading System (EU ETS), would reverse the model results - the benefits of the policy would exceed the costs.[142]

Notwithstanding these limitations, the most recent modelling, highlighted in the Intergovernmental Panel on Climate Change 5th Assessment Report, finds the economic costs from taking ambitious climate action consistent with a 2°C path are in the order of 1-4% of global GDP (median: 1.7%) in 2030, relative to a baseline without climate policy.[143] GDP costs of this magnitude look like "background noise" when compared with the strong underlying growth that the global economy is likely to experience. For example, the next 15 years could see the size of the global economy increase by around 50%. And when the benefits of acting are factored in, including variables such as better local air quality, the net costs are likely to fall further.

While the costs of climate action are small, they will vary by country. They are also likely to rise sharply with delay. If global action to reduce emissions is delayed until 2030, global CO_2 emissions would have to decrease by 6-7% per year between 2030 and 2050 in order to have a reasonable chance of staying on a 2°C path.[144] Such rates of reduction are unprecedented historically and are likely to be expensive (estimates of delay suggest an average annual consumption growth loss of around 0.3% in the decade 2030 to 2040, compared to a loss of less than 0.1% over the same period if we act now).[145] In addition, many of the modelling scenarios assume the immediate implementation of an efficient, globally co-ordinated policy response, for example they assume a uniform global carbon price is implemented simultaneously across all countries and all technologies specified in the model assumptions are available. Delay in immediate implementation of a single global carbon price or technology constraints raises the economic costs, as does misguided, inconsistent or poorly designed policy, including poor coordination with the wider policy framework for managing change. In contrast, providing a clear, well-coordinated and early policy-direction can help build investor confidence and encourage innovation, which should bring economic costs down in the long-run.

A number of recent modelling efforts have started to make progress in better reflecting the benefits of climate action, including the multiple benefits of reduced air pollution and related health costs, which are usually ignored in such modelling. Others have made progress in recent years in better modelling endogenous technical change, a critical factor in understanding the potential economic growth and greenhouse gas impacts of long-term climate policies. But significant data limitations and technical challenges remain (Box 11).

As further progress is made to improve and enhance the modelling frameworks, they will be able to capture better the net economic benefits of efficient and ambitious climate action. Even so, no single model will ever tell the full story of how an economy could transition dynamically to a low-carbon economy. These models adjust at the margins based on our current understanding of the economy. As a result they tend to over-estimate costs. Ex post analysis of the costs of environmental policies tend to find that they are significantly cheaper than ex ante analyses suggest, because models fail to capture the broad range of innovations in technologies, behaviours and institutions that may occur as a result of strong and coherent policies. Models therefore need to be seen as just one input to inform analyses and discussions about policy reforms; they do not constitute a fully comprehensive assessment.

5.3 The history of change

Quantitative models are one part of the tool-kit required to understand the relationship between growth and climate policy. History can also help to better understand the long-run transformation story described in this chapter and report, providing valuable insights on

Box 11

Challenges and progress in modelling the net economic benefits of climate action.

There is an extensive literature on modelling the costs of policy action and the avoided damage costs from reduced climate impacts, most notably the quantification of costs and benefits of policy action outlined in the 2007 Stern Review.[146] Much less has been done to analyse how climate impacts and mitigation might affect economic growth in specific sectors.

Regarding climate risks, difficulties encountered when integrating an appropriate assessment of impacts into economic models include continued uncertainty regarding the magnitude of and probability distribution of climate impacts, especially at the regional level, and challenges in converting the impacts to monetary values. The traditional approach of valuing static damages from climate change fails to account for the impacts of these damages on the drivers of future economic growth. For simplicity, growth is usually, and implausibly, assumed to carry on at some predetermined baseline rate. This leads standard modelling to systematically underestimate the case for urgent action.[147] A recent study found that reflecting some of the potential impacts of climate change in a dynamic CGE model incurred global GDP losses (damages) of 0.7% to 2.5% by 2060, and with much larger sectoral and regional variations.[148]

Regarding the net costs of mitigation, another set of challenges emerge. One problem is that many standard Integrated Assessment Models (IAMs) do not adequately model the drivers of innovation.[149] Many recent climate economic models have attempted to incorporate innovation.[150] However, these models usually treat innovation as an economy-wide, aggregate phenomenon rather than firm-level and sector-specific process with complex spillovers and interactions across sectors, institutions and behaviours. These could lead to a number of complementarities and scale economies which enhance the low-carbon impact of innovation. Hence, predictions of IAMs are biased towards innovations that seem more likely from the point of view of today, thus underestimating their likely impact on costs.

Properly accounting for path dependencies makes early intervention in the innovation system more desirable, even under the higher discount rate assumptions made by some economists. This is because if we delay intervention, then as time progresses, conventional technologies will become more entrenched and making a low-carbon transition more expensive. Inadequate modelling of innovation has the potential to significantly over-estimate the cost of future low-carbon technologies. See the discussion in Chapter 4: Energy on the underestimation of the recent large declines in renewable energy costs.

The empirical literature on how changes in climate variables affect economic activity is slowly growing, and will help further improve future modelling exercises. The OECD is presently undertaking a multi-year exercise to incorporate climate change and environmental degradation including air pollution, water scarcity and biodiversity loss into an in-house dynamic CGE model. The aim of the CIRCLE project (Cost of Inaction and Resource Scarcity; Consequences for Long-term Economic Growth) is to identify the impacts of environmental degradation and resource scarcity on long-term economic growth. The adjusted baseline projections for GDP, reflecting the impacts of climate damage, have been already included in the OECD@100 project, which informs the OECD Economic Department growth projections.[151]

managing change. We have the advantage of learning from several transformations since the industrial revolution,[152] including the current information and communications technology (ICT) revolution, and there is a rich Schumpeterian tradition of analysis on medium- to long-run technological transformations.[153] This tradition argues that capitalism develops through innovations by entrepreneurs, namely, the creation of new production technologies, new products and new markets, with new and innovative firms and progressive ideas displacing existing firms and ideas from the previous period.[154] Box 12 provides an informative neo-Schumpeterian interpretation offered by Carlota Perez, a member of the Global Commission's Economics Advisory Panel (EAP). Today the world is likely to be mid-way along an economic transformation driven by the ICT revolution, blending digitisation with distributed energy and more circular business models.

Overcoming barriers to low-carbon change may require a greater awareness of the risk of the alternative from inaction or delay, including large contingent liabilities for governments.

As described in Chapter 7: Innovation, the present ICT transformation has significant implications for the shape of future economic growth and development, and for opportunities to tackle climate change. This is of profound significance for all countries, in particular for emerging nations such as China, which is keenly aware of

Box 12
Lessons from economic history: a neo-Schumpeterian view

In the middle of the depression in the 1930s it was difficult to recognise the vast range of viable innovations connected with plastics, energy intensive materials, energy using devices and the new mass production methods that were capable of creating a consumerist way of life that could fuel economic expansion for decades. Today an equivalent, perhaps even greater, technological potential resulting from advances in information and communications technology (ICT) is yet to be unleashed and its consequences are equally difficult to prefigure. The potential of ICT to transform industries and activities has barely been realised.

Historically, every technological revolution has led to a radical change in consumption patterns, reflecting the range of products shaped by new technologies. However, as with every other aspect of paradigm shifts brought by each technological revolution, the processes of change are slow and uneven and only intensify when society in general assimilates the new possibilities and gives a clear impulse to the transformation. What is lacking today is a policy direction that will tilt the playing field, in a manner similar to the way in which policy for suburbanisation did in the post-war boom. It is not easy to steer such change. It requires deep understanding and bold leadership. Both businesses and politicians need to be persuaded that it is in everybody's interest – medium and long-term – to build a new positive-sum game. It was not any easier to set up the conditions for the flourishing of the previous mass production, suburban revolution. But measures taken then, such as public roads, mortgage guarantees, subsidies, new taxes, official labour unions, expansion of public services, incomes policies and unemployment security, created the demand conditions for mass consumption as well as for tax-funded military innovation. Structural change in a low-carbon direction globally needs systematically important countries to take policy action that tilts the playing field decisively. With clear, credible and stable policies stimulating energy and resource saving, a massive wave of mutually reinforcing low-carbon innovations driven by ICT could be stimulated across all industries. Unleashing the transformative power of ICT to bring a sustainable global boom could do for the world population what the post-war golden age did for Western democracies.

this moment in history, is thinking systematically about engineering a low-carbon transition, and is starting to reflect this objective clearly through its 5-year plans and other institutional mechanisms.

6. Concluding remarks and recommendations

This is a story about embracing and managing the next transformation of the world economy, in a way that both fosters growth and development, and reduces the risk of dangerous climate change by reducing greenhouse gas emissions.

Achieving this outcome will require policy and institutional reforms to tackle market failures, particularly around greenhouse gases and innovation, align expectations and drive a more efficient and productive economy.

In the past, countries that have overcome the barriers and political constraints to implement clear and credible structural reform policy have outperformed those that resisted or failed to embrace change. The framework presented here is in the economic interests of countries seeking to prosper over the coming decades.

The Commission accordingly makes the following recommendations:

- National, sub-national and city governments, businesses, investors, financial institutions and civil society organisations should integrate this framework for change and climate risk into their core economic strategies and decision-making processes. This includes decision-making tools and practices, such as economic and business models, policy and project assessment methods, performance indicators, and reporting requirements.
- Governments should design clear, credible and well-coordinated reform packages centred on fiscal reform, including carbon pricing and subsidy reform, to align expectations and send signals throughout the economy on the direction of change.

More specifically, the Commission recommends that countries:

  - Develop comprehensive plans for phasing out existing fossil fuel subsidies, essentially negative carbon prices. These should include enhanced transparency and communication and targeted support for poor people and affected workers. Developed countries could accelerate efforts to remove subsidies to fossil fuel exploration and production. Developing countries could explore innovative approaches with multilateral and national development banks on how to finance the up-front costs of reducing adverse effects on low-income households. Governments should build trust in the reforms by enhancing the delivery of services while subsidies are being phased out.

   - Apply a clear and credible carbon price signal across the economy.
   - Where political pressures for certain countries or sectors demand a lower price initially, ideally implement a predictable price escalator.
   - Revenues from carbon pricing should be recycled to productive uses, for example cutting distortionary or poorly structured taxes. A share of the revenues should be prioritised to offset impacts on low-income households.
   - Regulations, standards, "feebates", and other approaches should be used to complement carbon pricing. These can also help foster low-carbon change in countries for which even a low level of carbon pricing is politically or institutionally difficult, preferably with flexibility built in to facilitate the introduction of carbon pricing later.
- Governments should plan to put initial policies in place over the coming 5-10 years, and increase their ambition and efficiency as quickly as possible thereafter. The exact package of policies used in any country will need to reflect its specific realities and context.
- Major companies worldwide should apply a "shadow" carbon price to their investment decisions and look to cascade this shadow price through their supply chains.
- Countries should recognise and tackle the social and economic costs of the transition. Change on this scale will require policy to ease adjustment for vulnerable workers; in particular enhancing their ability to participate in faster-growing low-carbon sectors.
- Together with technical support from public international institutions such as the OECD, the World Bank and the IMF, national governments should accelerate the deployment of metrics and models that provide a more comprehensive, reliable analysis of potential climate risks to natural and societal capital, as well as the costs and benefits of climate action.

Endnotes

1 In this chapter short-term is defined as up to 5 years, medium-term as 5–15 years ahead, and long-term as beyond 15 years. (The terms -term and -run are used interchangeably).

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To build momentum and demonstrate broad support for carbon pricing at the UN Summit on Climate Change in New York in September 2014, the

World Bank has issued a call on those countries, regions, companies and organisations that are applying some form of carbon pricing or that support carbon pricing to sign a statement to this effect.

24 Each of these instruments has its own merits. A tax imposes a fixed price on greenhouse gas emissions and provides an incentive to reduce emissions to the point where the tax is equal to the marginal cost of emissions reductions. One advantage of a tax is that it provides price certainty, which can send a clear signal to markets. For emissions trading, an important advantage is certainty regarding a fixed cap on emissions. Such schemes allocate a fixed quantity of permits to participating firms, with one permit typically representing the right to emit one tonne of greenhouse gases. These permits can then be traded on a secondary market where the price of permits or emissions is determined by supply and demand. In practice, cap-and-trade systems can be designed to function more like taxes, for example with price stability provisions, such as a price cap or floor, and by auctioning allowances. These features provide more price certainty and raise auction revenues.

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Chapter 6

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Main points

- Maintaining or strengthening economic growth to 2030 will require a significant increase in investment, including an estimated cumulative US$89 trillion of investment in infrastructure. A shift to low-carbon infrastructure will have an additional impact, changing both the timing and mix of infrastructure investment. A low-carbon transition across the entire economy could be achieved with only 5% more upfront investment from 2015-2030.
- From a broader financial perspective, the global economy could create value from the transition to low-carbon energy. Low-carbon infrastructure has significantly lower operating expenses and a longer expected lifespan than fossil fuel assets. Low-carbon infrastructure also has the potential to achieve lower costs of capital.
- We estimate that the full investment impact of a low-carbon transition in the electricity sector would be a net financial benefit of up to US$1.8 trillion over the period 2015-2035. This accounts for all investment impacts including stranded asset costs, and refers to a transition to a 2°C scenario from "business as usual".
- A global low-carbon transition will lead to a decline in value of some fossil fuel assets, or "stranding". Clear policy signals can reduce this value destruction by discouraging new investment in fossil fuels that would be at risk of stranding.
- The potential stranding of investment in the coal sector is less than for oil and gas, because coal produces less economic value per tonne of CO_2 emitted, and there is comparatively less sunk investment in coal production, including coal-fired power plants. Over the next 20 years, reducing the use of coal can achieve 80% of the required energy-sector emissions reductions at only 12% of the total potential stranded asset cost, supporting a focus on coal in climate policy.
- There is sufficient capital available to finance a low-carbon transition. Accessing this capital will require the right long-term policies, however, including carbon pricing and regulation. Significant, near-term opportunities can reduce the costs of finance by up to 20% for low-carbon energy in all countries through a mix of financial innovation, greater use of national development banks and concessional debt, and increased development capital flows into low-income countries.

1. Introduction

Transitioning from a high-carbon to a low-carbon economy will require significant investment by all sectors of society. Industries, land owners and households will invest to improve efficiency. Energy producers will invest in low-carbon generation. Additionally, governments will invest in infrastructure to protect their nations against the long-term effects of climate change and to knit all of this new investment into a well-functioning, low-carbon economy.

Governments will play a dual role. First, they will invest directly in infrastructure to ensure an ordered transition to a well-functioning, low-carbon economy. Second, they will influence the direction of private finance through regulation, incentives and other policy measures. This chapter touches on both forms of government action, but focuses on the role of governments in shaping and motivating private finance.

Much of the needed investment in low-carbon infrastructure can be handled through existing structures and mechanisms, with the help of effective policy, regulation and market signals. Energy efficiency is an example where value is already created within the existing commercial environment for consumers and businesses, providing cash flows that can make these investments attractive.

Other investment requirements will need more intervention. In these cases, creating new, efficient finance structures and directing finance into these new industries becomes more challenging and may require dedicated policy to initiate and continue the transition. Energy supply is an important example, as the energy sector accounts for around two-thirds of global greenhouse gas emissions.A low-carbon transition in energy supply requires the highest near-term financing, and some of the most significant changes in financial and industry structures.

The good news is that between public and private sources, there is sufficient capital available globally to finance an energy transition. Many new industries and market structures are already emerging in both the developed and developing world. However, current industry and financial structures often allocate capital inefficiently, with risk, reward and geographic preferences that do not match well with an effective low-carbon energy transition. Some investors express concern that the transition will be unaffordable or will require capital that is not available. Others fear coal, oil and natural gas assets will suffer. The Commission has taken these concerns seriously and recognises that innovation in the financial sector will be as critical to the transition as innovation in the urban, land use and energy sectors.

This chapter focuses on financing in the energy sector, given risk-return characteristics which are likely to see the most significant changes over the next decade. It begins by presenting estimates of the overall need for infrastructure investment between 2015 and 2030. Next, it discusses how to develop financing instruments and models which significantly cut the cost of investing in low-carbon energy assets, separately for high-income, middle-income, and low-income countries. Then it presents the likely additional investment and financial costs of an overall system shift to a low-carbon model that reduces the risk of dangerous climate change. Finally, it outlines how governments and private investors can minimise the risk of destroying the economic value, or "stranding", of fossil assets during the transition.

The good news is that between public and private sources there is sufficient capital available globally to finance an energy transition.

The chapter should not be viewed in isolation from the rest of the report. The focus here is the transition to a low-carbon energy system, with particular emphasis on investment in renewable energy. There are many other aspects of the low-carbon financing agenda which are touched upon throughout the report as a whole. Chapter 2: Cities describes some of the key instruments that will be needed to strengthen capital mobilisation at the city level, for investment in smarter infrastructure. Chapter 3: Land Use describes the forms of finance that will be needed to support tropical forest protection in the context of measures to increase overall capital mobilisation in developing country agriculture. Chapter 4: Energy addresses the challenge of mobilising capital for the more than one billion people who lack access to modern energy services. Chapter 5: Economics of Change considers the institutional and policy frameworks for mobilising the necessary capital. Chapter 7: Innovation more specifically addresses the funding of research and development and the early-stage, low-carbon innovation pipeline.

2. Overall infrastructure financing requirements

2.1 Infrastructure investment and global growth

The global economy will require substantial investments in infrastructure as the population and the middle class grow. An estimated US$89 trillion of infrastructure investment will be required through 2030, based on data from the International Energy Agency (IEA), the Organisation for Economic Co-operation and Development (OECD), and analysis for the Commission (see Figure 1). This is chiefly investment in energy and cities. This estimate for the required investment is before accounting for actions to combat climate change.

A significant shift in the composition of these infrastructure investments will be needed to move to a pathway consistent with a good chance of keeping global average warming below 2°C. This includes increased investments in energy efficiency, and the deployment of low-carbon technologies. Improvement in efficiency of energy end-use sectors such as buildings, industry and transport could alone account for an additional US$8.8 trillion of incremental investment according to the analysis presented here (see Figure 1). Investment for the deployment of low-carbon technologies including renewables, nuclear and carbon capture and storage (CCS) could lead to an additional investment of US$4.7 trillion.

Overall, the net incremental infrastructure investment needs from a low-carbon transition could be just US$4.1 trillion, if these investments are done well.

At the same time, however, a low-carbon scenario could potentially also lead to savings in several components of infrastructure investment. Savings of US$2 trillion to 2030 are estimated from reduced investment in fossil fuel power plants in a low-carbon scenario. Reduced demand for fossil fuels could potentially also lead to further savings of US$3.7 trillion along the supply chain of fossil fuels. This includes reduced investment in the exploration and transport of fossil fuels.

Another source of savings could be from reduced investment in electricity transmission and distribution, by an estimated US$0.3 trillion, as a result of greater energy efficiency and thus less demand for energy. The IEA projects that the savings from energy efficiency will outweigh the additional investment in the electricity grid needed to integrate intermittent renewable energy sources. Finally, the construction of more compact, connected cities, in an effort to reduce emissions, pollution and congestion and to rejuvenate the urban core, has the potential to reduce the overall infrastructure requirement for roads, telecommunications, water and waste treatment. Our estimates suggest that these savings could be worth cumulatively up to US$3.4 trillion by 2030. Figure 1 understates the scale of the transition that would occur in such an economic transformation, as investments shift from higher- to lower -carbon.

Overall, the net incremental infrastructure investment needs from a low-carbon transition could be just US$4.1 trillion, if these investments are done well. In this case, the infrastructure capital spent in a low-carbon economy would be 5% higher compared to a business-as-usual scenario of high-carbon growth. Given the additional infrastructure investments that would likely be needed under business as usual, to adapt to the impacts of climate change which are not included here, it is possible that investments in infrastructure in a low-carbon economy may be about the same as those in a high-carbon one. Other studies have suggested that, if done well, investment in low-carbon infrastructure could be even lower, given some of the potential synergies in fuel and infrastructure savings, for example in cities, indicated above.[1]

Financial considerations other than upfront investment, such as lower operational expenditures from low-carbon energy, were not included in this comparison exercise. Including them would make the low-carbon scenario even more favourable in terms of overall costs, leading to net savings of US$1 trillion. Section 4 of this chapter provides an in-depth consideration of wider financial impacts of a low-carbon transition in the energy sector.

Including full, longer-term impacts on investment under a low-carbon transition make such an outcome even more favourable, leading to net savings of US$1 trillion.

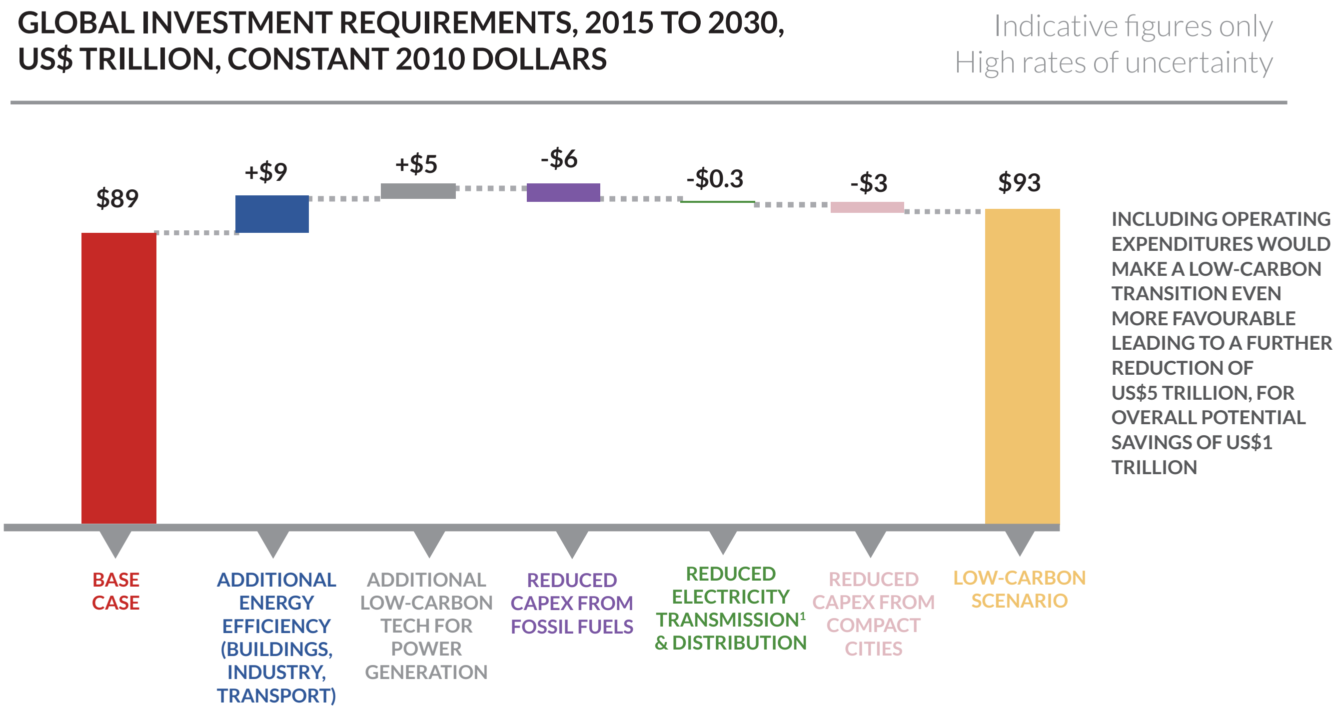
Given the uncertainties in projecting out to the future, these estimates are directional estimates, designed to provide orders of magnitude rather than precise figures. In addition, not all relevant infrastructure components and financial aspects were included in the comparison of the two scenarios. For example, the total investment needs for building infrastructure are not included in Figure 1, although the incremental costs of increased energy efficiency in buildings are reflected in the low-carbon scenario. Global construction spending on buildings in 2010 has been estimated to be on the order of US$5.4 trillion (in constant 2005 US$).[2]

2.2 Financing a low-carbon energy transition

The energy sector is the backbone of the global economy. Investment in energy and related infrastructure will be important to support economic growth, whether or not nations transition to low-carbon economies. From a climate change perspective, the sector acquires even more importance, because reducing greenhouse gas emissions from the energy sector is crucial to reducing the risk of dangerous climate change. Energy supply and consumption represent approximately two-thirds of global greenhouse gas emissions.[4]

Figure 1

Infrastructure capital spend is 1% lower in a low-carbon scenario



NOTE: For further details, see the New Climate Economy Technical Note, Infrastructure investment needs of a low-carbon scenario, to be available at: http://newclimateeconomy.report. [forthcoming].

Net electricity transmission and distribution costs are decreased due to higher energy efficiency lowering overall energy demand compared to base case. This efficiency effect outweighs the increased investment for renewables integration.

SOURCE: Climate Policy Institute and New Climate Economy analysis based on data from IEA, 2012, and OECD, 2006, 2012.

However, the transition to low carbon need not add substantially to the required energy investment. One way to illustrate the scale of the task to shift to a low-carbon energy economy is to measure investment as a proportion of fixed capital formation. The latter is a proxy for total investment across the economy.[5] IEA estimates of infrastructure investment suggest that a transition to a low-carbon economy would increase global energy investment from 9% to 12% of fixed capital formation.[6] Alternatively, this can be viewed as a shift in investment equivalent to less than 0.5% of gross domestic product (GDP), arguably a small shift given the scale of the risk and challenge at hand.

3. Financing the electricity sector over the next five to 10 years

3.1 Power generation infrastructure

Since the beginning of the 20th century, electricity financing has been characterised by the need to create scale and efficiency. Large-scale capital was provided by the public sector or through investors in regulated companies under a de facto government guarantee. As the industry grew, the quest for the lower costs that scale could deliver led to large, integrated, monopoly providers. These integrated utilities capitalised on lower costs achieved through scale across a network that connected generation, transmission, distribution and end users, relying on whatever was the cheapest energy source – fossil fuels or hydropower – available in their region.

A revolution in electricity system design began in the 1970s, '80s and '90s, as governments and regulators saw the benefits of scale begin to taper off, and sought to increase innovation and flexibility and reduce the inefficiencies of what had become a large and monolithic sector. In 1978, the US Public Utility Regulatory Policy Act (PURPA) sought to promote energy efficiency and bring in non-utility generators and cogeneration in response to the oil crisis.

Over the following years, many countries and regions developed independent power producers (IPPs), competitive short-term energy markets, privatisation, innovative regulatory systems and innovative risk sharing and financing schemes to enhance incentives for generators and utilities to improve efficiency and lower costs. New generators appeared, in some cases costs fell, and new investors entered the market and corporate structures shifted, sometimes beyond recognition. However, whether governments chose to introduce competition or remain mostly regulated, in most regions both the market and operating systems were, and are, still largely based around large-scale, mainly fossil fuel-powered, generation.

This can be viewed as a shift in investment equivalent to less than 0.5% of gross domestic product (GDP), arguably a small shift given the scale of the risk and challenge at hand.

Finance for low-carbon energy continues to evolve

Within the electricity system transition, more can be done in all countries to increase low-carbon investment. There are several areas with potentially large investment requirements, but in the near-term, each of these have very different policy and financing needs:

- **Energy efficiency:** Improving the efficiency of energy use and production is an important element of nearly every plan to achieve a low-carbon system. According to estimates outlined in Figure 1, achieving a 2°C pathway will require US$8.8 trillion in incremental investment in energy efficiency between 2015 and 2030, in areas like buildings, energy-intensive industry and transport. Financial incentives and loan programmes can be useful as a policy tool to accelerate investment in energy efficiency (see Box 3). However, the lack or high cost of finance are not the only impediments to most efficiency improvements. Demand for energy efficiency is constrained by other factors, including lack of information, transaction costs, agency problems, mispricing and a host of other barriers discussed in the energy efficiency literature. Energy efficiency investments also tend to be intimately wrapped into the operations of a business or household, and therefore are often difficult to finance independently of financing to the household or business in question.
- **Carbon capture and storage (CCS):** Removing the CO_2 from the exhaust gases of fossil fuel fired power plants can be an important strategy for reducing greenhouse gas emissions from the power sector. As discussed in Chapter 4: Energy, there were 21 large-scale CCS projects in operation or under construction around the world as of February 2014. However, since the technology is currently more expensive than other technologies examined here, the financing policy challenges are not explored in this chapter. For the purposes of the next 5–10 years, financing of CCS is likely to be dependent upon research and public support schemes and therefore more of an issue for innovation, energy and climate policy than financing policy.
- **Nuclear energy:** Like CCS, nuclear energy development will likely depend on public support mechanisms in many countries. In addition, however, nuclear energy could benefit substantially from many of the financing and industry structure arrangements to be discussed below with respect to renewable energy.
- **Transmission and distribution:** As natural monopolies, transmission and distribution is generally owned and operated by regulated or government-owned companies. While the specific assets requiring investment, and even the business models employed, may shift substantially in a low-carbon transition, total investment will be slightly less than under a business-as-usual scenario. For instance, increased investment to connect new renewable sources will be offset by the impact of energy efficiency and distributed generation in reducing demand for centrally generated electricity. Thus, with appropriate system policy and design, current financing arrangements could work adequately for the near-term transition.
- **Other associated infrastructure, including energy storage, information technology and advanced metering:** The transition will require continued innovation across several technology areas, particularly on the demand side. In the near term, these are areas for continued innovation, as briefly discussed in Chapter 7: Innovation.
- **Maintaining conventional generation during the transition:** In many countries, the transition will involve phasing out the building of new coal- and gas-fired generation, and could reduce life extensions for many existing plants. Nevertheless, conventional generation will be needed for many years to support the transition: to provide ongoing energy to meet

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the demands of the economy; balance variable renewable power; and reduce the overall economic cost of a transition. In developing economies, some new conventional generation will be needed alongside low-carbon generation to support continued rapid economic growth. Thus, while investment needs for fossil fuel generation will decline, there will still be a need to ensure that this generation is financially viable. In developed countries, new capacity markets can value the flexibility and support that conventional generation offers, making these assets viable even at reduced output levels.[7] Further consideration will need to be given to the integrated utilities that may lose value in the transition, and find it difficult to support the required growth in transmission or distribution businesses.

The main, near-term financing concern lies in the growth of renewable energy investment and, to a lesser extent, nuclear energy. While costs were relatively high and falling, it made sense to finance and operate renewable energy sources, such as wind and solar, through existing corporate and financial structures, minimising industry disruption while concentrating on cost reduction and initial deployment. Today in some markets, the average cost of energy from many renewable energy sources is approaching that of new conventional generation, when levelised over the life of a new energy project, as detailed in Chapter 4: Energy. In some cases, the cost of renewable energy is lower than for conventional generation. With lower costs, a faster, larger scale roll out is more feasible and attractive, but the arrangements that helped when deployment was relatively small are inefficient at a larger scale.

Extending the duration of a PPA by 10 years could reduce the average electricity generation costs over the lifetime of typical wind and solar projects by 11-15%, while employing a FiT rather than a premium to wholesale prices can reduce costs by 4-11%.

The principal challenge many countries now face in financing low-carbon energy is therefore to reduce the cost of investment in low-carbon energy assets, and to identify mismatches between investor and finance needs. Solutions to these challenges are discussed in the following section.

3.2 New finance approaches for high-income countries

The utility companies and independent power producers that currently build and finance most power plants in high-income countries have developed their corporate and finance structures around fossil fuel generation. These structures are inappropriate for renewable energy for a number of reasons:

- Renewable energy has no intrinsic fuel price risk as fossil fuels do. In current markets wholesale electricity prices fluctuate with fossil fuel prices. This imposes fossil fuel price risk on renewable energy either directly through wholesale power markets, or more often through the investment return requirements of regulated or unregulated power producers whose business models are built on earning a premium to manage these risks. Fossil fuel price uncertainty thus raises risk, uncertainty and finance costs;
- Variable renewable energy such as wind power is not dispatchable (its quantity and timing cannot be easily controlled), but utilities must ensure reliability of the electric grid, and in competitive electricity markets will expect a premium to manage this variability. Such a premium translates into higher costs associated with renewable energy generation;
- The initial investment is a higher proportion of total costs for renewable energy than fossil fuel energy, making the finance costs that spread these initial costs over the life of the renewable energy plant much more important.

Many of these differences can be, and are, handled through policy. Feed-in tariffs (FiTs) or fixed price power purchase agreements (PPAs) can eliminate the price risk that would be experienced by a renewable provider attempting to sell renewable generation on wholesale electricity markets. Where these PPAs offer longer-term price guarantees – often up to 15 to 20 years or more – renewable energy projects can attract longer-term debt finance, which reduces the expected lifetime average finance costs for a project. Under current financing arrangements, extending the duration of a PPA by 10 years (say from 10 to 20 years) alone could reduce the average electricity generation costs over the lifetime of typical wind and solar projects by 11–15%, while employing a FiT rather than a premium to wholesale prices can reduce costs by 4-11%.[8] As the cost of renewable energy approaches that of market prices, the benefits of these policies will fall slightly, but the benefits in reducing risks remain.

There is, however, another impact of policy on financing. Uncertain or changing policy can raise risk perceptions and increase borrowing costs or even make it impossible to borrow against a project without some sort of explicit or de facto government guarantee. Without debt, the cost of finance can increase markedly.

New business models can attract long-term investors, reducing renewable energy costs by up to 20%.

The following analysis of the impact of policy on financing costs assumes that projects are financed with the current industry structure and common project development arrangements. Typically, these projects are developed and owned by independent power producers and investor-owned utilities, and often use project finance to enhance returns to levels consistent with their business models. Investors in utility company shares expect certain levels of returns from their equity investments. Under current business and investment models, renewable energy returns have to rise to these expectations to make these investments attractive to utilities and to make utility shares attractive to the financial markets.

However, the key to optimising finance for any investment is to match the investment and the related regulatory and corporate structure with the investment pool that is most closely aligned with the financial characteristics of the investment. From this perspective, renewable energy is more similar to long-term infrastructure investments than fossil fuel investments, making renewable energy, if properly structured, particularly well-suited to three sets of investors:

- **Institutional investors**, like pension funds, seeking to match defined cash flow needs over a long period of time to service liabilities such as pensions and life insurance policies;
- **Municipalities** and other local and regional agencies, seeking to provide long-term infrastructure for themselves and their residents and companies;
- **Energy users** seeking long-term price certainty for energy, or a hedge against volatile energy costs.

As shown in Figure 2, solutions tailored to the investment needs of these types of investors could reduce the cost of renewable energy by up to 20%.

Once development and construction is finished, renewable energy projects are relatively simple investments. There are no fuel costs to manage, operating costs are relatively low, output is fixed by wind or solar conditions, and revenues are also fixed, assuming a fixed, long-term price contract or feed-in tariff. As simple investments, these projects remain attractive investments even when returns are low, and with the right structural changes they can remain attractive at lower returns still.

Utilities and IPPs have used project finance – where a stand-alone project company is formed that owns only the renewable energy project – to increase returns to levels more in line with what their shareholders expect from utility investments. Project finance increases returns by allowing the owner to borrow more money directly against the asset, without otherwise affecting the company's finances. By borrowing more, project owners get their cash back earlier and thus enhance their returns. However, project finance can be expensive to arrange and banks charge higher interest on loans to project companies, thus increasing the cost of finance.

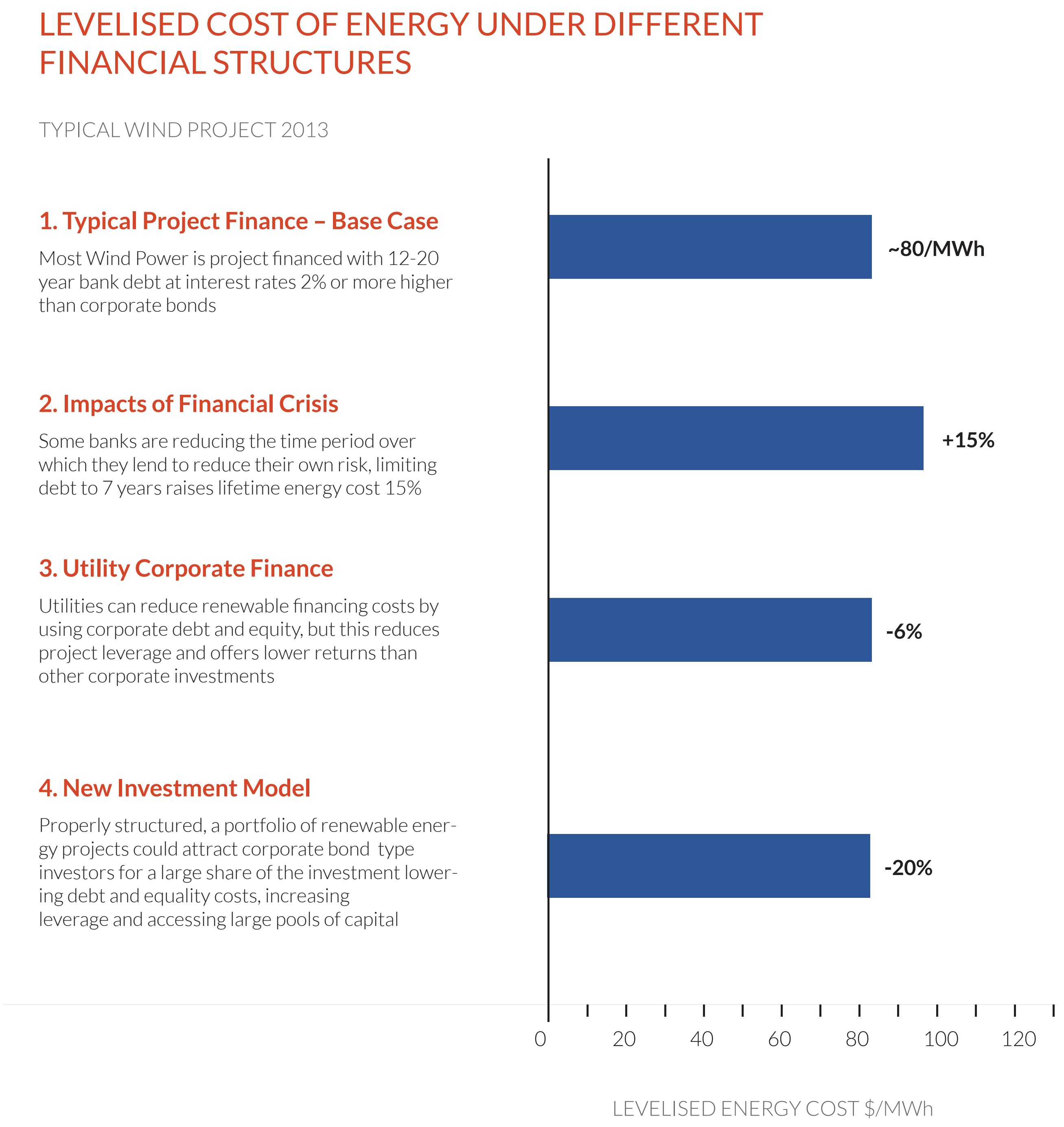
Policies can encourage the use of project finance despite its lower efficiency. For example, in the United States, tax credits used to incentivise renewable energy are often worth more with project finance, because they are realised earlier. Project finance can be used to transfer these credits to banks or other companies with immediate tax obligations to offset, thereby shortening the period over which tax credits are received by as much as several years. However, arranging the project finance and providing an incentive for the investor with the "tax appetite" can be costly and inefficient. As a result, the use of tax credits can end up costing the government more than other types of policies.[9]

If the market for longer-tenor debt were to dry up completely, the cost of renewable energy could increase by 16% or more.

The financial crisis has made project finance less attractive. Longer-term loans are riskier for banks in general, and one response to the financial crisis has been to shorten the tenor of loans that they offer – that is, how long the loan lasts – in order to manage their own risks, and in anticipation of regulatory requirements under Basel III and Capital Requirements Directive (CRD IV). With shorter-term loans, project owners need to set aside more cash each year to pay the debt principal. The result is that the average debt over the project life goes down, and higher tariffs are needed to make projects attractive to developers. If the market for longer-tenor debt were to dry up completely, the cost of renewable energy could increase by 16% or more.[10]

Some utilities have responded by financing renewable energy on their balance sheets – that is, by borrowing against the entire company rather than just a specific project. Companies have lower debt costs than projects, since lenders have more assets to recover in case of default, and thus face lower risks. The lower debt cost would reduce the renewable energy costs by 6% for a well-financed utility. For many utilities, however, large renewable energy portfolios still offer lower returns than other investments, consume investment capital while producing little growth, and thus make the companies less attractive to investors. That is notwithstanding the fact that the very best renewable energy projects, including many wind projects in Texas and Midwestern US, have very good wind conditions that can make projects

Figure 2
New finance models could reduce renewable energy costs by up to 20%



Source: Climate Policy Initiative modelling, based on interviews with developers and investors and Standard & Poor's; company reports.

competitive over their lifetime. An additional, emerging problem with utility financing in Europe is that these companies are seeing falling revenues and profits, and many can no longer support additional debt.

The essential problem is that renewable energy investments have financial characteristics that are more akin to corporate bonds than the typical utility investment. A utility would make no money borrowing at a bond rate just to invest in another bond with the same return. Packaged appropriately, in structures that look like bonds rather than utility company shares, and then selling the assets directly to bond investors could significantly reduce the cost of financing renewable energy.

Another issue is that many current renewable projects investments are relatively "illiquid". That is, investors tie up their money in the investment and cannot easily sell the assets if their circumstances, or those of the market, change, or can only do so with substantial transaction costs or loss of value. Illiquidity imposes a significant cost on institutional investors, if it makes them unable to react to new investment opportunities that may arise in the market. They may have to retain extra investment in secure, very liquid, but low-return investments such as government treasury bonds.

Appropriate structures that provide both direct access to the bond-like risk reward profiles of renewable energy projects and some liquidity are already beginning to emerge, including "YieldCos" (described in Box 2). These new investment vehicles are tailored to the investment needs of long-term, institutional investors, such as pension funds and insurance companies. They focus exclusively on owning and operating portfolios of renewable assets that are largely free of fuel, market, and technology risks, providing investors with steady, predictable revenues over 15 to 20 years, while creating an opportunity to sell the investment should the need arise. Based on interviews with long-term investors and rating agencies, the analysis for the Commission suggests that such low-risk structures could attract equity investment at costs 2% per year lower than traditional utilities, and could support more debt on their balance sheets. Alternatively, institutional investors could buy the YieldCos without debt as direct replacements for corporate bonds, essentially earning corporate bond rates for the entire investment. Renewable energy investments are more capital-intensive than fossil fuel power generation, and so are highly sensitive to the cost of capital. Financial modelling of typical wind and solar projects in the US and Europe shows that renewable energy-specific business models could reduce the cost of renewable energy by up to 20%.[11]

The Climate Bonds Initiative and HSBC reported US$11 billion in green bonds were issued in 2013 — a marginal portion of the total global bond market, but one that is growing rapidly.

Other approaches such as securitisation of loans to renewable energy and covered bonds rely on standardisation and pooling for diversification and aggregation. These can also be appealing to institutional investors, which require large transactions and low transaction fees, high credit ratings, sufficient transaction data to assess risk and return, liquidity, benchmarks, and a defined asset category in which to invest. Institutional investors are also primarily interested in providing long-term debt investments that match their liabilities.

Green bonds (described in Box 2) could be a promising vehicle for institutional investors if renewable energy projects can be standardised and securitised. The Climate Bonds Initiative and HSBC reported US$11 billion in green bonds were issued in 2013 – a marginal portion of the total global bond market, but one that is growing rapidly.[12] Institutional investors are very comfortable with bond investments. If green bonds can be used to finance renewable energy projects in a manner that delivers liquidity and high credit ratings (e.g. through pooling, credit enhancement and securitisation) this may be a promising path for increased institutional investment in renewable energy.

Creating national infrastructure banks

Although the sophisticated financial systems of developed economies can cultivate innovative solutions to financing problems, they need an investment case to do so. The unfamiliarity and risks of new financial products can prevent their development, but, once the market is established, risks fall and financial actors join the market. In this context, national infrastructure banks can develop credible markets that will eventually bring in private capital.

For renewable energy and energy efficiency, there are a number of markets that a government infrastructure bank could help develop. These include:

- **Creating appropriately designed YieldCos:** Although YieldCos, as discussed above, are gradually entering the market, their design is not perfectly aligned with institutional investor needs. A government infrastructure bank could take on this role and develop the new, appropriately designed, asset class.
- **Lending to small-scale distributed generation and energy efficiency projects:** Infrastructure banks could extend loans to de-centralised, customer-generated electricity and energy efficiency projects with marginal credit risks, creating business opportunities both for the private sector and low-carbon investment. Examples of these programmes are discussed in Box 3.
- **Financing infrastructure that needs scale for rollout:** As an example, an infrastructure bank could lead investment in electric vehicle (EV) charging infrastructure, an investment that is difficult for individual actors to make due to scale up and timing issues, but one with significant public benefits. The timing issue refers to a "chicken and egg situation" where widespread EV adoption requires a charging infrastructure in place, but without EV users charging infrastructure will fail to generate revenues.

Box 1
How business models and financial regulations create barriers to scaling up low-carbon infrastructure

Current investor business models, accounting rules and investment restrictions established by financial supervisory bodies, may discourage institutional investors from investing in infrastructure and other "illiquid" asset classes. The motive of such rules is to ensure financial solvency of investors by not locking them into long-term investments that may be hard to exit from at short notice or at acceptable prices.[13]

Despite their long time horizon, institutional investors tend to invest overwhelmingly in liquid assets, so that they can maintain diverse portfolios and manage risks in a changing investment landscape. Large-scale funds are better positioned to increase investment in green infrastructure and other illiquid assets, because they can develop specialised knowledge on the risks and returns to these assets, increasing their confidence in the investment and reducing the need for liquidity.[14] For example, the largest of these funds, the Norwegian Bank for Investment Management, may be able to manage the risks of more investment in illiquid assets and emerging markets, consistent with its mission of investing for the benefit of future generations.[15] However, investors overall continue to favour shorter-term investment. The OECD has identified several reasons for this:[16]

1. Financial markets tend to reward short-term over longer-term investment. Although they are long-term investors in theory, institutional investors often face short-term performance pressures which can prevent them from investing in long-term assets.[17] Investment holding periods are declining among institutional investors, and allocations to less liquid, long-term assets such as infrastructure and venture capital are generally very low.

2. As part of the liberalisation of gas and electricity markets, "unbundling" regulations have been set up to prevent investors from owning a controlling stake in both transmission and generation. This applies to renewable energy as well, and the OECD notes that given the attractiveness of transmission and pipeline-type infrastructure assets, "unbundling" regulations "may unintentionally force investors to choose between majority ownership in transmission and generation/production". Similarly, the use of tax incentives may discourage investment by institutions that are already tax-exempt (such as pension funds in many countries), and instead can create a new class of "tax investor", the OECD notes, "whose purpose is to accelerate the use of, and improve the value of tax credits, but whose presence can crowd out institutions".

3. "Capital adequacy" rules designed to increase banks' levels of capital and reduce their exposure to long-term debts can also discourage long-term investments, including green infrastructure investments. (Examples include Basel III for banks around the globe, and Solvency II for insurance companies in Europe.) In addition, the OECD notes, certain accounting rules that are meant to increase transparency and consistency in financial statements – such as fair value or mark-to-market accounting – can be hard to apply to illiquid investments with long holding periods.

There are policy initiatives underway to attempt to re-orient the financial sector toward longer-term, lower-carbon investments, including the United Nations Environment Programme (UNEP) Inquiry on the Design of a Sustainable Financial System.[18] A number of banks have made statements on the value to investors of taking a longer-term perspective or considering social and environmental risks. However, implementation of these principles has been sparse to date.

- **Providing early-stage deployment support**: An infrastructure bank could take on some early-stage risk to accelerate deployment of newly emerging technologies that drive infrastructure productivity.

- **Supporting local municipal governments and aggregating small-scale projects to attract cheaper capital**: Securities backed by pools of diversified small-scale clean energy loans can attain much greater cash flow certainty than individual projects, making them attractive to institutional investors. Building such projects portfolios have to acquire a certain scale, however, where a government infrastructure bank can provide initial support for example through first-debt loss guarantees.

Table 1 lists several examples of public green infrastructure banks in in OECD countries.[19] These types of banks and other public finance institutions, the OECD notes, are currently being used to leverage private capital and support investment in low-carbon infrastructure, including from institutional investors.[20] There are also green investment banks (GIBs) or similar institutions in developing and emerging economies, such as South Africa (Green Fund), Malaysia (Malaysian Green Technology Corporation), and United Arab Emirates (Masdar).[21]

Green investment banks have been established at both the national and sub-national levels.[22] Many have leveraged private capital, and engaged with institutional investors in a number of ways including: taking cornerstone stakes in funds or vehicles that attract pension and insurance

Box 2
Green bonds, infrastructure bonds, YieldCos and municipal bonds

Financing costs are crucially important in keeping down the cost of infrastructure, given the high upfront investment. As discussed in Box 1, there are presently financial market barriers that restrict or raise the cost of finance to infrastructure.

A number of different financial instruments address this challenge, by attracting institutional investors.

Infrastructure bonds are primarily used in the project finance of infrastructure assets. Through these bonds, institutional investors can gain direct access to long-term, steady, low-risk investments. Bank deleveraging and Basel III capital restrictions have limited new investment from banks. Infrastructure bonds and other vehicles below here have the potential to fill the void by attracting institutional investment.

Green bonds are a type of infrastructure bond that provides debt to a project or a portfolio of projects that are certified as being environmental or "green". The green character is the key enhancement over infrastructure bonds. By being green, these bonds may be able to access investors who prefer green investments or have restrictions or limitations to non-green investments when debt is scarce. By creating a distinct market and through competitive forces, green bonds could lower the cost of environmental infrastructure projects. Corporations and governments have also issued green bonds to back low-carbon projects, using their institutional creditworthiness to bring down financing costs for the projects.

YieldCos, which own portfolios of low-risk, long-term projects are equity vehicles that can go a step further than infrastructure bonds by effectively bundling equity and debt together in one package. By bundling projects together, the project finance premium for single projects can be avoided. Moreover, for a portfolio of projects with risks comparable to corporate bonds, the result for investors can be a higher-yielding, bond-like instrument that nevertheless reduces the overall financing cost for the projects in question.

Municipal bonds can serve the same purpose for renewable energy as YieldCos – that is, using high leverage for a project while keeping debt and equity costs down – if a municipal government is willing to bear the equity risk and role of investor itself.

capital; providing debt financing; issuing green bonds; or designing products that have stable long-term cash flows which will be attractive to long-term institutional investors. Some green investment banks have a particular focus on financial sustainability and demonstrating that low-carbon investments can be profitable. The UK Green Investment Bank expects to earn taxpayers an average return of 8% per year, with every investment on track to make a profits.[23]

At the national level, green investment banks can be effective tools to mobilise domestic private finance and investment in low-carbon infrastructure when existing institutions are not already fulfilling this role. Some Public Finance Institutions (PFIs), such as Germany's KfW, already have an explicit mandate and authority to invest in green infrastructure – often with established guidelines on which technologies or markets to address. "Greening" existing PFIs, where there is the necessary institutional and political support, might be preferable to creating new institutions.

Currently, these banks are a small portion of the financing landscape, but through their investments they may be able to kick-start liquidity in these assets, creating a virtuous circle whereby more investors are able to participate in financing low-carbon assets. As these begin to replace high-carbon assets, they shift the landscape of infrastructure investment needs. For example, energy efficiency investments bring down the need for renewal and expansion of the power generation, transport networks and building stocks.[24]

Apart from their role in funding and directing national infrastructure banks, governments also invest in low-carbon infrastructure themselves, both via direct investment and via companies that are fully or partially owned by the government.

3.3 Development banks and low-carbon investment in middle-income countries

Renewable energy can play a slightly different role in rapidly developing, middle-income countries. First, rapid growth creates a thirst for new energy sources to meet growing demand. Thus, competition for renewable energy comes from new plants that are yet to be built, rather than already existing facilities, as may be the case in developed markets. With good renewable resources, renewable energy could already be competitive, and in some cases, renewable energy might even have an advantage given the infrastructure that may be needed to support large-scale, centralised coal-fired generation. Second, the potential role of renewable energy is especially important in boosting energy security and improving balance of payments compared with importing coal, oil or gas. Third, some developing markets have viewed the manufacture of renewable energy equipment as a potential national strategic objective.

To meet these goals, many middle-income countries have adopted policies and incentive schemes also used in developed markets, such as feed-in tariffs, power purchase

Table 1
Examples of public green infrastructure banks in the OECD

Bank Name & Location	Capitalisation	Source of Capitalisation	Year of creation	Target rate of return	Scope	Instruments used
Australia – Clean Energy Finance Corporation	**AU$10** billion	Government budget appropriation	2013	Commercial-level returns	Renewable energy, energy efficiency	Direct debt/equity investment and indirect (pooled) investment
UK Green Investment Bank	**GBP3.8** billion	Government appropriation	2012	Sufficient to offset losses, and create profit	Offshore wind, waste, non-domestic energy efficiency, with goal of market transformation	Direct debt and equity investment; indirect, fund-led investment
Korea Export - Import Bank (Kexim) Green Bonds	**US$500** million	Bond issuance	2014	None provided	Low carbon and climate resilient growth, including clean energy, energy efficiency, emissions reduction, and waste filtering.	Direct debt investment
Canada – Ontario Financing Authority Green Bonds	**<C$500** million, planned	Bond issuance	2014 – 2015 planned	None provided	Environmentally friendly infrastructure including transit	Not specified
Canada Export Development Corp. Green Bonds	**C$300** million	Bond issuance	2014 – 2015 planned	Sufficient to generate "modest profit to finance growth"	EProjects "aimed at the preservation, protection or remediation of air, water or soil or the mitigation of climate change."	Direct debt investment
USA – New York State Green Bank	**US$218.5** million	Utility bill surcharge, auction proceeds.	2013	Sufficient to offset losses	Commercially proven clean energy and energy efficiency	Credit enhancements, joint or pooled debt investment, loan warehousing
USA - Green Energy Market Securitization (GEMS)	**US$100** million anticipated	Bond issuance	2014 planned	Not a key concern	Distributed solar, energy efficiency	On-bill financing, securitisation (proposed)

Source: Berlin et al., 2012; Booz&co, 2013; Clean Energy Finance Corporation, n.d.; Critchley, 2014; Export Development Canada, n.d.; Gutscher, 2014; Hawaii State Energy Office, n.d.; Kidney, 2014; Moore and Morrow, 2013; New York Green Bank, n.d.; Parliament of Canada, n.d.; UK Green Investment Bank, 2014; Wee, 2013.[25]

Box 3
Challenges and innovative policies for financing energy efficiency

The priority

Increasing energy efficiency is a key part of developing better energy systems. Improving energy efficiency in buildings and energy-intensive industries accounts for US$5.3 trillion of the US$8.8 trillion of incremental investment in energy efficiency from 2015 to 2030, laid out under the low-carbon transition scenario in Figure 1. Efficiency is particularly important for those countries whose growth is constrained by unmet energy demand.

The challenge

Energy efficiency poses specific financing challenges. Achieving investment at the scale needed will require new policy and financing vehicles.

While many energy efficiency investments generate substantial savings relative to the initial investment, few projects are large enough to attract the attention of financiers. Energy efficiency projects generally offer poor collateral, for example improvements to a building's shell have little value if removed and resold. Credit risk is the principal driver of financing costs for most energy efficiency projects, and that risk – being uncollateralised – is substantial enough that interest rates for small commercial and residential consumers are relatively high. In developing countries, where credit-based lending is rare, energy efficiency financing is often not available for small-scale borrowers. Even lending to large industrial actors with collateral is restricted to five years or less. Moreover, it may depend on targeted lines of credit financed by international institutions, such as the International Finance Corporation (IFC) and the European Bank for Reconstruction and Development (EBRD), both of which have prioritised funding for private-sector energy efficiency investment.

New business models are emerging to deliver financing

Despite these difficulties, private-sector interest in energy efficiency financing is growing, with new business models emerging that shift risks in helpful ways. Public programmes that add security to investments by tying them to utility bills, mortgages, or property tax assessments may lower rates from financiers. Sales of securities backed by energy efficiency loans have begun to emerge, potentially making energy efficiency lending more liquid and attracting cheaper capital.

Innovative policies are generating results

The HERO programme started in Riverside County, California demonstrates the potential benefits. With repayments secured on property tax bills (and therefore senior in obligation to mortgages), private lenders have provided more than US$200 million in capital for efficiency and distributed renewables in residential and commercial buildings. One capital provider has securitised and sold bonds backed by the loans to raise additional capital. Demand has been strong and over 100 California municipalities have now joined the programme.

The German development bank KfW runs a residential energy efficiency programme that provides increasing amounts of principal reduction for projects with higher energy savings, and buys down local banks' interest rates to low (1%) levels. Almost 1% of German households participate annually – a considerably larger participation rate than most whole-home programmes of its kind achieve.[26]

Through its Sustainable Energy Financing Facilities (SEFFs), EBRD has offered credit lines and technical assistance to support development of energy efficiency financing among banks in Eastern Europe and Central Asia. Since 2006, the bank has provided over €2 billion in financing to local banks to establish new markets for lending for energy efficiency and small-scale renewable energy projects.[27]

In the developing world, risk-sharing programmes run by multilateral development banks have encouraged energy efficiency lending at more attractive terms. For example, under the China Utility-Based Energy Efficiency Finance Program (CHUEE), the IFC provided a loss reserve to participating banks, thereby inducing them to extend loan tenors and offer loans to smaller enterprises. Participating banks have lent over US$500 million under the programme, and as of 2010 the programme had not experienced a single loan default.[28]

Most financial programmes, even those that offer substantial concessions, have struggled to motivate customers. The extent to which improved financing drives project uptake has not been well studied, and may vary substantially in different markets. That said, the approach clearly offers potential.

agreements, auctions and green certificate markets. A distinguishing feature of some middle-income countries which can alter the effectiveness of these types of policies is their greater cost of debt.

Low-cost debt can reduce the cost of renewable energy

Middle-income countries tend to grow faster than high-income ones. Growth creates competing investment needs, particularly for infrastructure, and it can also lead to inflation. The result is usually higher interest rate environments than in slower-growing developed countries. Additionally, generally younger populations and less well-developed pension and insurance industries limit the pool of long-term, relatively low-cost investment available for infrastructure.

Thus, in middle-income countries low-carbon energy may suffer in two ways. First, since low-carbon generation is often more capital-intensive than fossil fuel generation, higher interest rates and low debt availability have a greater impact. Second, since fossil fuel generation is often priced in dollars and has access to global markets, it can be financed on international rather than domestic markets. Yet for the developing country itself, renewable energy is often a direct substitute for the fossil fuel, replacing imported coal, gas or oil, and reducing foreign exchange requirements that go along with fossil fuel imports.

For developing countries there are a number of financial mechanisms that can bridge the difference between the high cost of financing in local currency and the benefits that should be priced in hard currency.

Countries such as China and Brazil effectively use subsidised, low-cost debt to finance renewable energy. National development banks, national sovereign wealth funds and investments made from national budgets or state-owned enterprises (SOEs) under administrative direction fund substantial percentages of the world's low-carbon investment, overwhelmingly in their own domestic markets.

The China Development Bank, for instance, is the largest development bank in the world and has supplied over US$80 billion to renewable energy projects.[29] In China, as of June 2012, 87% of wind projects and 68% of solar projects were built and owned by SOEs and their subsidiaries.[30] As such, they have access to capital at low, administered interest rates. In Brazil, the national development bank, Brazilian Development Bank (BNDES), sets a separate long-term interest rate that it uses as a basis on which to make loans to infrastructure projects. Nearly every major power project in Brazil has had access to BNDES funding, with around US$50 billion committed so far into low-carbon energy.[31] The result is that renewable energy projects in these countries have access to low-cost financing that reduces the cost disadvantage compared with fossil fuel alternatives. Recent auctions in Brazil, for instance, achieved average prices for energy from wind projects at the comparatively low price of US$58/MWh.[32]

The China Development Bank, for instance, is the largest development bank in the world and has supplied over US$80 billion to renewable energy projects.

The accomplishment of state banks in funding low-carbon energy at tolerable debt rates is substantial. In China, it may be that the combination of China Development Bank debt, SOE equity funded by retained earnings, and secure power purchasing agreements in administered markets creates the functional equivalence of municipal finance, energy user finance or YieldCos in high-income country, market-based finance systems. However, it is important to note that there are active reform movements in China, Brazil and other middle-income countries with strong development banks that would liberalise the existing financial system, changing the supply of low-carbon debt financing.

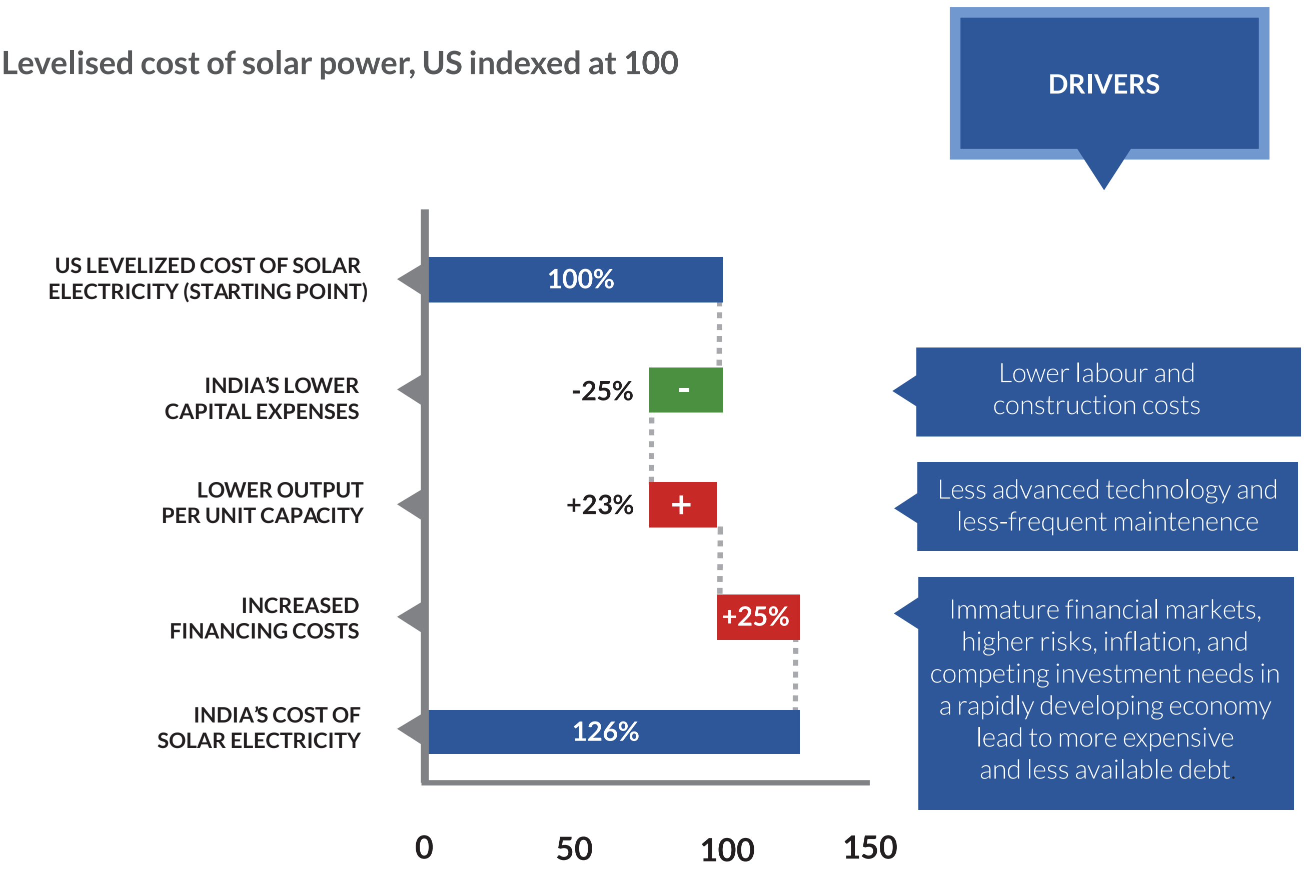
Middle-income countries such as India, Mexico, South Africa and Morocco use a variety of national niche and multilateral solutions to finance low-carbon projects, but are constrained by an absence of low-cost debt necessary for such capital-intensive investments. In this analysis, those countries are labelled as MIC2, in contrast to middle-income countries with access to low-cost debt through development banks, such as Brazil and China (MIC1).

MIC2 countries often pay as much for renewable energy as the US and Europe, and sometimes much more, despite potential labour, land and construction cost advantages. Figure 3 shows how increased financing costs could impact a typical Indian solar project. Lower initial capital expenditures for this plant were almost 25% lower than a US counterpart. Less advanced equipment, lower solar radiation and dust were expected to decrease its output, but even then, costs were slightly lower than in the United States. However, financing costs due in large part to wider capital market factors in India, pushed lifetime cost per unit of energy well above the US counterpart.

More specifically, the difference is the cost and terms of debt. In India, our modelling of a range of projects shows that the cost and terms of debt alone can add 24–32% to the cost of utility-scale wind and solar photovoltaic (PV) projects.[34]

The high cost of debt creates other problems. Policy solutions such as stable long-term contracts or reliable feed-in tariffs can reduce the cost of renewable energy in other countries by allowing a larger share of a project to be financed with debt, which carries lower financing costs than equity. But in many rapidly developing countries, the cost of debt is so high that there are virtually no savings to be gained by growing the share of debt in a project. As a result, those same policy solutions are much less effective at bringing down renewable energy costs and driving deployment.[35] More expensive debt can limit the availability of upfront equity capital, given uncertainty over the cost of refinancing the completed project. Developers may not be willing or able to refinance completed projects with debt. Discussions with stakeholders in India reveal that the difficulty in securing

Figure 3
Financing costs for solar power eliminate natural cost advantages in India



Source: Climate Policy Initiative, 2012.[33]

debt may already be causing developers to run out of equity to invest in the next set of projects.

High debt costs are not unique to renewable energy. Rather, they reflect the high interest rate environment, which itself reflects the higher inflation, large infrastructure needs, heavy government borrowing, and a less developed financial system typical of rapidly growing economies.

In India, our modelling of a range of projects shows that the cost and terms of debt alone can add 24-32% to the cost.

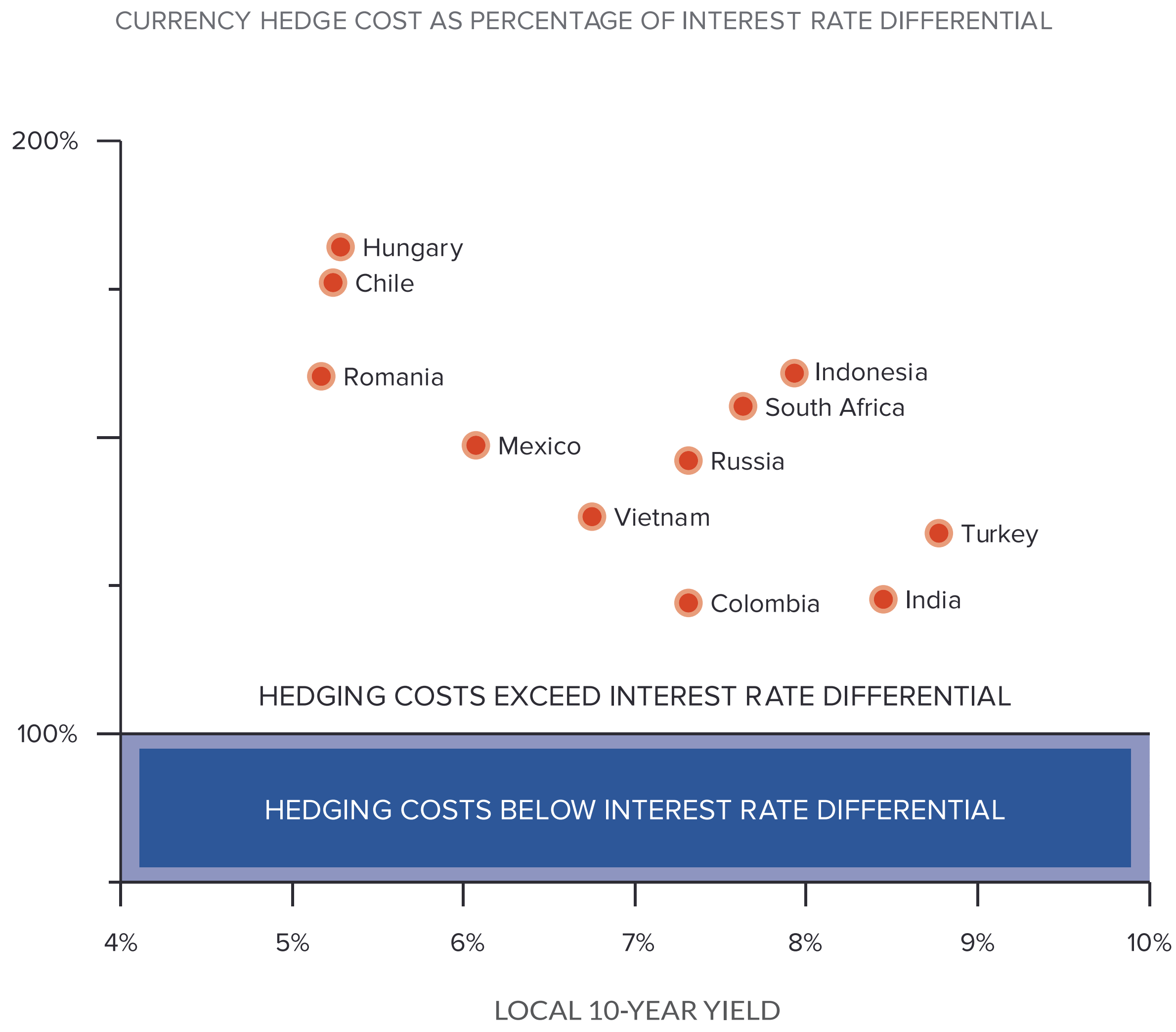
Cheaper foreign debt is not an easy solution for middle-income countries because of exchange rate risk

One option would seemingly be to use lower-cost debt from developed markets. The first question is, then, whether the loan should be denominated in, say, US dollars, or in the local currency. If it is denominated in US dollars, then the borrower must take the risk that the local currency falls and the debt becomes much more expensive. The lender will likely refuse to make this loan because the default risk associated with unfavourable currency movements will be too high. Alternatively, the loan could be priced in local currency, but then the lenders need much higher interest rates to compensate them for the currency risk.

As a result, most loans require currency hedges that convert one currency to another over the life of the loan. In fact, unless they have offsetting liabilities, most dollar investors require hedges for euro investments and vice versa. Hedges cover relative currency movement risk that results from differences in inflation, economic growth, government policy, and so forth. The cost of these hedges depend on market conditions, trade flows and relative country risks, but often they can take up all of the difference in interest rates between dollar-based loans and local currency loans. In fact, Figure 4 shows that as of January 2014 the cost of hedging for a number of developing countries was 20–80% higher than the

Figure 4

The cost of hedging more than eliminates the advantage of lower foreign interest rates



Source: Adapted from CPI, 2014.[36]

difference between base interest rates in each country. In other words, foreign debt that was fully hedged against currency risk would have been more expensive than local debt, meaning that foreign debt is not a viable option for renewable energy project in these economies.

One solution for MIC2 that does have promise for increasing scale is national or local debt subsidies, which can reduce the total cost of subsidising renewable energy. Analysis for this report shows that if debt were available at terms and interest rates similar to those found in developed countries, the cost of renewable energy would be as much as 22% lower.[37] Debt subsidies can be used alongside feed-in tariffs or power purchase agreements, partially or wholly replacing the subsidy element within these mechanisms. Modelling conducted for the Commission shows that this switch could reduce the total cost to government and energy consumers of subsidising renewable energy, including the cost of the debt subsidy, by up to 30% for the same amount of renewable energy.

Lowering debt costs can allow the government to support greater renewable energy deployment with scarce subsidy resources, compared to providing the same rate of subsidy through higher guaranteed revenues.

A key challenge for incentivising renewable energy through concessional debt will be the administration of the debt and selection of projects. These arrangements must allow project developers to receive adequate incentives while ensuring that the value of the lower-cost debt flows through into lower energy prices. Project selection mechanisms must also target the most economic projects, to minimise inefficiencies through poor project selection including failed projects.

Many countries already have institutions which can perform part of the task, such as renewable agencies, energy ministries, treasuries or development banks. But careful design will be needed to ensure efficient project selection and development in coordination with national

Box 4
The finance challenge for cities

As discussed in Chapter 2: Cities, cities are likely to play a central role as drivers of low-carbon economies and low-carbon growth. Municipal financing is a common instrument to finance public transportation and efficient city infrastructure, and analysis in this chapter suggests it is also a useful vehicle for investment in renewable energy and energy efficiency. But in many countries, cities have limited authority to make decisions on major infrastructure investments. They also have limited financial resources and may not be able to provide sufficient collateral to finance investments themselves.

In order for cities to be able to deliver on the recommendations in this report, it will be necessary to resolve these issues of authority and financial resources. Further work is needed to better understand these challenges in each nation, and to develop financing vehicles that provide security for investors while helping low-carbon cities grow.

energy policy. In some cases, multilateral development banks may be able to help build the necessary institutions. In other cases, existing institutions may serve as a conduit for multilateral financing. Once these arrangements are in place, projects that receive concessional debt in lieu of subsidies should remain just as attractive to developers, while costing 30% less in terms of subsidies from governments or higher tariffs from consumers.

Other creative financing solutions for middle-income countries need to be scaled up

Rapidly developing, middle-income countries are in the process of quickly expanding their energy supply systems, and niche solutions for MIC2 countries abound, but need scaling up.

Examples of such creative niche solutions include private wind parks to supply off-grid power to high value firms in Mexico and India, which are willing to pay extra for a more secure electricity supply and can finance the project off their own balance sheets. Another is the case of large conglomerates which can access low-cost debt from commercial banks with which they have long-term relationships. A third is concessional financing from multilateral trust funds like the World Bank's Clean Technology Fund for early vintage concentrated solar plants in India, South Africa and Morocco and geothermal plants in Indonesia. Still, these solutions are, at the moment, limited in scale and do not compare to levels of low-carbon investment financed in high-income countries and MIC1 nations.

3.4 The role of development finance institutions

Development finance institutions (DFIs) have a significant role to play in the expansion of energy efficiency and renewable energy in both MIC2 nations and in low-income countries (LICs). These include global and regional multilateral banks such as the World Bank Group, national development banks with international portfolios, and bilateral development agencies. They can provide support through equity investments, loans (concessional and non-concessional), guarantees and insurance products, principally to MIC2 recipients.[37]

DFIs can provide a layer of risk protection and capital cost reductions beyond what can be provided by host governments. Historically, international concessional financing has formed a substantial share of financing in low-income countries. Official development assistance in low-income countries averaged 54.9% of gross capital formation in 2012,[39] and those with lower GDPs had even larger shares of foreign assistance.

Concessional loans are known to be an effective tool to support governments in the development of large projects that might not garner private sector participation, such as large hydropower plants or binational/regional high voltage transmission lines to transport electricity from renewable sources.

Projects that receive concessional debt in lieu of subsidies should remain just as attractive to developers, while costing 30% less in terms of subsidies from governments or higher tariffs from consumers.

Equity and non-concessional loans can attract the private sector to invest equity and debt in utility-scale renewable power generation plants. The return on equity and the financing cost of the loans of DFIs are similar to private-sector investors and so do not directly reduce financing costs. However, the participation of DFIs as co-lenders or equity partners is regarded as positive with respect to reducing regulatory and other risks, and so still attracts private investors.

Recent OECD analysis shows that both bilateral and multilateral external development finance has a positive and significant effect in mobilising private finance flows to developing countries, with a more pronounced effect in attracting domestic over international financial flows. These results are robust across different models and estimation approaches. Interestingly, the results suggest that the effect of multilateral public finance is greater on the decision over whether to invest at all, than on the volume of investment once the decision to invest is taken.[40]

The same analysis shows that raising the ambition of domestic policies in developing countries to incentivise renewable energy investment, such as through feed-in tariffs and renewable energy quotas, is vital to attracting private investment at scale. Evidence shows that external official development finance operates on at least two levels to support green investment: first, to directly attract private co-financing and investment for green infrastructure; and second, to work with MIC governments to support policy reform processes and build local capacity and conditions so as to make green investment viable in the longer term.[41] Delivered through bilateral or multilateral development cooperation channels, external official development finance often has a catalytic role in shifting and scaling up green investment.

In addition to direct equity and debt investments in infrastructure projects, DFIs offer risk-bearing instruments for investors in MIC2 and low-income countries, such as insurance protection and guarantees. With additional improvements and innovation, these instruments, could help address finance needs for low-carbon assets at larger scale.

Some institutions offer political risk insurance that can partially cover the impact of policy change, provided that the change qualifies as an expropriatory breach of investor's rights. For example, the Multilateral Investment Guarantee Agency (MIGA), a World Bank Group agency established in 1988 to offer political risk insurance to investors in developing countries, can cover a tariff reduction for the equity and debt provider. Similarly, the Overseas Private Investment Corporation (OPIC) provides policy risk coverage to US investors when the policy change causes a breach of the power purchase agreement (PPA) and constitutes an expropriation of investors' rights (or regulatory taking) originating from the contract.[42]

While these are useful steps forward, there are still significant gaps in the supply of instruments to address these risks. Existing instruments (such as those offered by MIGA and OPIC) have costly compliance requirements, which limit their application to large and well-resourced projects only. They may also not be fully visible under international official development assistance accounting rules, which measure assistance on a cash flow basis.

Because these instruments are largely unaffordable for smaller projects and programmes covering widespread, small-scale installations,[43] due to high costs as a result of complex negotiating and drafting processes, other dedicated programmes are needed to seek justice locally and keep investments solvent before compensation is paid.

A number of factors have limited a more widespread adoption of partial risk guarantees, which have only been issued 23 times since their inception and eight times for renewable energy projects.[44] The World Bank has in the past promoted the use of partial risk guarantees mainly for large and complex projects, such as large hydro investments and cross-border projects, and required an indemnity agreement from the host government. This has increased a market perception of product complexity, lengthy procedures and high transaction costs. Furthermore, partial risk guarantees directly cover only debt holders, while tariff reductions usually affect many other parties including equity owners, providers of operations and maintenance services. This last issue can be addressed by complementing the instrument with other insurance tools and guarantees, such as MIGA insurance, albeit at increased complexity and transaction costs.

MIGA aims to provide compensation within six to 14 months following the date of loss.[45] Historical evidence made available by the Agency[46] shows that so far claims have been paid after two to three years from the event date, and no later than one year from the date of claim's submission.

Delivered through bilateral or multilateral development cooperation channels, external official development finance has often a catalytic role in shifting and scaling up green investment.

OPIC data based on 13 available observations, from a total of about 70 projects determined under total expropriation clause, show that claims are resolved on average 3.5 years after the event date and 1.5 years from the submission of the claim. Timing of the reimbursement process is uncertain and varies significantly from case to case. These delays and uncertainty have a large impact on the viability, and the perception of viability by investors, of these schemes.

Guarantees are another financial instrument offered to reduce and mitigate investment risks. They are mostly offered by the World Bank and have proven to be an effective tool to attract private investment to the energy sector. Guarantees are particularly well suited for use in MIC2 and low-income countries, as they are focused on reducing the risk associated with payments due from governments or state-owned enterprises to investors (equity or debt) under contractual or regulatory commitments. These payments can be of a diverse nature such as those due monthly under a power purchase agreement, payments due as compensation resulting from a change in law, or payments due from SOEs under loan agreements with commercial banks. The World Bank has approved 19 guarantees in the past three years for an aggregate amount of US$2.9 billion.[47] These guarantees have enabled US$11 billion of investment, mostly in the energy sector, in highly challenging markets such as Cameroon, Ivory Coast, Kenya, Mali, Mauritania, Nigeria, Pakistan, Senegal and Uganda.

3.5 Addressing the energy financing challenge of low-income countries

Across low-income countries (LIC), even those now exporting oil and other natural resources, the challenge of capital mobilisation for investment in energy assets, whether low or high-carbon, is still very severe. Infrastructure investments typically depend on government involvement in the form of partial ownership, subsidies or credit guarantees, or contracts with a government-owned utility. As in all countries, a stable regulatory system and enforceable, long-term power purchasing contracts is a major component of an investment case. However, lack of government credibility and/or financial capacity is a potential barrier for investment in infrastructure assets.

Given the lack of long-term domestic or international private capital for these classes of investment, multilateral banks and development finance institutions, including the Global Environmental Facility, the Green Climate Fund, and the United Nations Framework Convention on Climate Change (UNFCCC) Adaptation Fund, continue to play a central role in financing infrastructure in low-income countries.

The extra up-front capital costs of low-carbon energy present a challenge to the multilateral banks, given many other demands on their balance sheet capacity. Fortunately, new initiatives, funding vehicles and programmes, special purpose funds and institutions with particular dedication to low-income countries energy provision are expanding.

Examples include innovative distributed, off-grid energy solutions such as community-inclusive local area networks, anchored on an agricultural or mining producer with substantial base demand, or small-scale mechanisms such as prepayment cards as used in mobile telephones or securitised microfinance. Multilateral platforms such as the Green Climate Fund, Sustainable Energy for All, and the Climate Finance Innovation Lab assign leading emphasis to the particular demands of low-income countries, including funding adaptation and the design and implementation of specific equity funds, project development facilities and the private refinancing of multilateral banks' energy development budgets. Finally, it is worth noting the growing significance of funding of energy infrastructure in low-income countries by Chinese development banks (see Box 5).

4. Financing energy system transformation

While the emerging strategies described in the previous section can reduce the cost of capital and increase the availability of finance for a low-carbon energy transition, these measures by themselves would not achieve the full investment necessary to reach an ambitious climate goal, often benchmarked at a 2°C rise in global average temperatures. The Commission therefore decided to explore just how much additional capital might be required to achieve this goal and what impact that those additional capital needs could have on global finance.

The headline financial impact of the low-carbon transition is the incremental investment required. Incremental investment is important because it can describe how much of the available global investment capital would need to be "crowded out" and shifted to the low-carbon energy investments. If, for example, a doubling of investment into the power sector were required (relative to a "business as usual" scenario), it would be hard to reconcile this with the imperative to grow global energy supplies in an affordable way. But incremental investment tells only a part of the story.

These guarantees have enabled US$11 billion of investment, mostly in the energy sector, in highly challenging markets such as Cameroon, Ivory Coast, Kenya, Mali, Mauritania, Nigeria, Pakistan, Senegal and Uganda.

First of all, the mix of assets will change beyond just incremental investment, since there would be a reduction of investment in fossil fuel assets like coal mines, oil production facilities and coal-fired power stations. Furthermore, incremental investment does not adequately capture the effect that this shift in investment will have on other costs that then feed back into financial markets, for investment in an energy transition can create or destroy value in a number of ways, in so doing freeing up (or consuming) additional cash to the economy that could then be recycled into other investments in the future. Four adjustments must be made to incremental capital investments to understand the true impact on the economy and financial markets:

Box 5
The emergence of new international financial institutions

Infrastructure in developing and emerging countries will require a step-change in investment levels over the next decade, even before accounting for climate action. Estimates indicate that investment in developing and emerging markets, in order to sustain projected growth paths, will need to more than double from the current US$1 trillion a year invested in electricity supply, transport, telecoms and water.[48]

At the moment, the majority of investment in infrastructure in developing and emerging markets is provided by the public sector. Given the budget constraints faced by these countries, and the projected needs, the private sector will need to participate more strongly in the future. Private-sector money is not flowing to developing and emerging countries at the pace and scale required. Political risk, macroeconomic instability, lack of well-developed projects all contribute to the reluctance of the private sector to invest.

A number of new public funds and banks are being created or strengthened in developing countries to respond to the new government demand. The latest two are the Asian Infrastructure Investment Bank (AIIB) and the BRICS (Brazil, Russia. India, China and South Africa) Bank. The AIIB was proposed last October by Chinese President Xi Jinping during the Asia-Pacific Economic Cooperation Summit in Bali. It is expected to be established within the year with an operating capital of US$50 billion to start with, and the perspective to grow quickly to US$100 billion. To date, China has invited Japan, South Korea and other countries to join. The BRICS Bank, an initiative of Brazil, Russia, India, China and South Africa, was proposed at the BRICS summit in Delhi in 2012, and was formally launched at the BRICS Summit in July 2014. The bank would begin with a subscribed capital of US$50 billion, divided equally between its five partners, with an initial total of US$10 billion in cash and US$40 billion in guarantees.[49]

While the total subscribed capital of these institutions is not insignificant, it is still fairly limited in comparison with the International Bank for Reconstruction and Development (IBRD), at about US$200 billion, or the Asian Development Bank, at about US$160 billion.

The real potential of these institutions derives from their shareholding, formed by key emerging and developing countries, and their focus on infrastructure. This puts these new institutions in a strong position to leverage and blend their finance with national development banks and funds, such as the China Development Bank or the Brazilian National Development Bank (BNDES), both able to mobilise substantial investments.

Some smaller regional development funds, such as the Development Bank of Latin America (CAF), are also increasingly influential. With one of the highest credit rating of debt issuers in Latin America (AA-), the CAF is now lending more than the World Bank and the Inter-American Development Bank together in the Latin American region. As developing and emerging countries' domestic financial markets deepen and savings are increasingly recycled through their domestic banking system, these new banks and funds will be in a strong position to blend their finance with private sector funds.

An important question is to what extent these institutions will recognise the opportunity to invest in infrastructure that lays the foundations for a more sustainable, low-carbon future, particularly when investing in energy infrastructure. The nascent Green Climate Fund, which is meant to provide global climate change finance in the context of delivering on the commitment of mobilising US$100 billion a year by 2020 to support emerging and developing countries on adaptation and mitigation options, can play an important role in blending its finance with other infrastructure funds. While US$100 billion is a small part of the total financing needs for sustainable infrastructure, and can be raised in rich countries through current and future fiscal instruments, used wisely these funds can be a catalyst for further public and private funds.

Using innovative financial instruments to address multiple issues including policy risk and affordability of infrastructure in poorer countries, will be key for these institutions to invest at scale in sustainable infrastructure. BRICS countries have explored how their new bank could support sustainable infrastructure, but the outcome will only be clear once the bank starts lending at scale.

- **Operating expenses**: Capital investment will replace some operating expenses freeing up cash for further investment. For example, wind turbine investment reduces the cost of transporting coal from mine to power station. The money saved in transportation would then be available for investment elsewhere in the economy.
- **Asset life:** Both high- and low-carbon energy systems have a mix of long and short-term assets. In general, the average life of the assets of a low-carbon system is slightly longer, particularly when considering the short amortisation periods of some upstream fossil fuel assets. Longer-life low-carbon infrastructure may require more initial investment, but will delay future investment to replace capacity. For example, an investment made in 2025 with a 20-year life will still have half of its production remaining in 2035.
- **Risk and required return:** Lower-risk assets require smaller incentives to meet a given return. Investors in a project could require double or more incentive – that is return - to invest in a riskier project. Reducing risks in the

energy portfolio could free risk capital to invest in risky, value producing, ventures elsewhere in the economy.

- **Stranded assets:** On the other side, a low-carbon transition can create "stranded" fossil fuel assets which lose value when they are no longer needed. Valuable assets can be used as security for future investments, so such a loss of asset value can take value directly out of the potential investment pool.

The next section analyses the required incremental investment in a low-carbon transition, with an initial estimate that is then adjusted according to the wider influencing factors described above.

4.1 Investment needs are large and well investigated, but will depend on policy ambition and choice

The IEA uses a number of models and analyses to estimate future energy investment needs. Included in these estimates are scenarios that reflect current perspectives on "business-as-usual case" investment needs and scenarios with substantial carbon abatement, including the IEA's 2°C scenario, or "2DS."

Both scenarios define the investment requirements for: power generation (fossil fuel and low-carbon power generation, plus transmission and distribution), building energy efficiency, industry (energy efficiency and other measures), and transportation (vehicles and mass transportation). They exclude the upstream energy investment requirements in oil, gas, and coal and non-energy infrastructure investments (roads, railways, bridges, agriculture, etc.).

The difference between these two scenarios is an estimate of the *incremental* investment required to achieve substantial carbon abatement. It is only an estimate, since there are multiple possible scenarios, with very different investment implications. Nonetheless, the IEA investment figures provide a credible starting point from which to evaluate the impact of a transition on financing and financial markets. Analyses that specify less ambitious climate goals, for example to stabilise atmospheric greenhouse gases at 500 or 550 parts per million, could reduce substantially the incremental costs incurred by low-carbon systems and associated value stranding. However, the analysis of what such less ambitious transitions would mean for the average cost of capital, how these costs were distributed, and what political reactions might be expected would be logically similar.

The IEA estimates that about US$36 trillion of investment will be needed in 2015–2030 in the energy sector, as well as in energy end-use sectors such as buildings, industry and transport, regardless of climate goals. A 2°C scenario, the IEA estimates, could require about US$12 trillion of incremental investment over the same time period in comparison with a scenario with zero climate action, leading to up to 6°C of warming.[50] This is mainly because additional investments to improve energy efficiency and for the deployment of low-carbon technologies are only partially offset by reduced investment in fossil fuel power generation and in electricity transmission and distribution. (Note that savings from compact cities and reduced investment in fossil fuel exploration and transport, included in Figure 1, were not considered here.)

During that time, however, the world economy will grow substantially, and investments will be made in a variety of forms of capital capital stock. Analysis for the Commission shows that roughly US$400 trillion of new investments will be made into fixed capital (that is, total global investment in the economy) over the same time period. This is based on World Bank data on the historic ratio of Fixed Capital Formation to GDP, and OECD projections of GDP growth.

In comparison, the above IEA estimates imply that the total investment needs for energy are 9% of fixed capital formation without taking any climate action, and 12% including the extra costs of low-carbon investments. While these are significant additional capital requirements, our assessment is that 3 percentage points additional investment in energy, as proportion of total investment, is modest relative to the overall scale of capital formation likely to occur over the next 15 years. The challenge will be to generate the required quantity of attractive investments, through technology improvements and supporting policy, and to direct available sources of capital into such investments.

Table 2 breaks down incremental cost for a 2°C scenario for high-, middle-, and low-income countries.

4.2 Lower-risk, low-carbon energy investments

Earlier we outlined how incremental investment needs to be adjusted for operating expenses, asset life, risk and stranded asset to assess the full financial impact of an energy transition. Figure 5 makes this adjustment for one of the key components of the transition, the transition in electricity to move to low-carbon energy to replace fossil fuel-fired generation.

This analysis is based on a comparison of the IEA's business-as-usual and 2°C (2DS) scenarios, as well as additional market and financial analysis undertaken by the Commission. As such, it represents just one example of how low-carbon investment needs would translate into an actual financial impact on the economy. Many different paths could be taken to a

Table 2

Energy investment needs as a proportion of total fixed capital formation, under a 2°C scenario

		OECD	Middle-income				Low-income	Total
			China	India	Transition economies	Other		
2015-2030 Fixed Capital Formation (trillion US$)	Households	41.3	n/a	n/a	n/a	n/a	n/a	41.3
	Government	24.4	51.8	7.1	1.2	65.7	0.6	150.9
	Private	84.8	54.8	24.8	7.3	17.6	1.3	190.6
2015-2030 Investment needs in energy (trillion US$)	Baseline investment	14.1	8.5	2.5	2.6	4.8	1.4	33.8
	Incremental investment	5.4	2.1	0.6	1.1	1.8	0.2	11.2
Ratio of investment needs to fixed capital formation	Baseline % of fixed capital formation	9%	8%	8%	31%	6%	72%	9%
	Incremental % of fixed capital formation	3.6%	2.0%	2.0%	12.5%	2.1%	11.8%	2.93%

low-carbon future, and the Commission believes that policy-makers will follow this type of analysis in evaluating policy paths for a low-carbon transition.

Amortisation and operating expenses

As shown in Figure 5 ("Increased Low-Carbon Expense"), our analysis shows that US$2.8 trillion[52] of additional capital will be used, or amortised, between 2015 and 2035 for renewable energy, nuclear energy, carbon capture and sequestration and transmission under the IEA's 2DS scenario compared to business as usual. Our analysis also indicates that by the end of 2035, an additional incremental US$4 trillion of low-carbon assets (not pictured) would have been invested and be on the books and available for continued production after 2035. Thus, although US$6.8 trillion of capital is invested, only US$2.8 trillion of this capital is amortised during this period. Amortisation is lower than total capital investment during this period because a mortisation is spread out over the entire lifetime of the asset.

The incremental costs of operating the additional plants, including nuclear fuel, will consume an addition US$1 trillion between 2015 and 2035. These estimates are based on the IEA investment paths, and on Commission modelling for upstream gas, oil and coal, based on commercial databases, including the Rystad oil and gas production economics database and a variety of industry and government data sources (see the discussion on stranded assets for further detail). Table 3 shows an application of various return and amortisation assumptions to different types of investment, based on industry and company analysis.

Coal mining is less investment-intensive than low-carbon energy, but it requires substantial operating costs to mine the coal and transport it to the power station where it will be used. Coal-fired power stations themselves also have higher operating expenses than comparable renewable energy generators. Our analysis shows that reducing coal and gas consumption in power plants will avoid about US$1.7 trillion of capital investment from 2015-2035 (and avoid a further US$2.8 trillion on the books in 2035). Meanwhile, operating expenses – excluding fuel use in power plants which is already accounted for in the fuel production expenses – will fall by US$5.5 trillion.

Thus, while the transition will consume US$1.1 trillion more capital during the period, total costs, after including amortisation and operating expenses, actually fall by US$3.5 trillion.

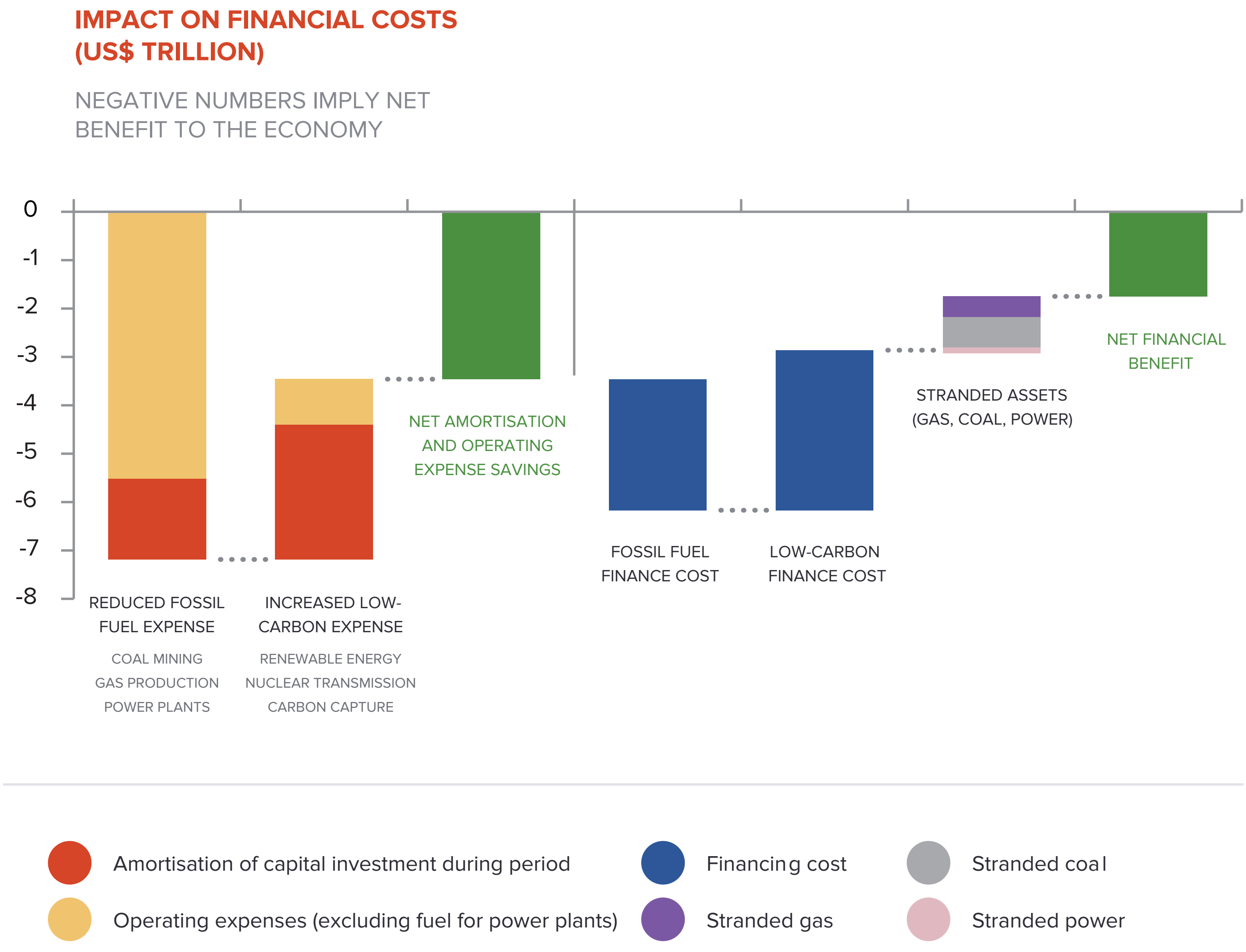
Financing costs

However, the story does not end there, for assets require investment returns — that is, they incur financing costs

Figure 5

Increased investment in low-carbon technology is offset by avoided operating and financing costs

Financial Impact of a Coal to Renewable Energy Transition (2015-2035)



Source: Climate Policy Initiative analysis, using data from IEA, 2012; IEA, 2014; Platts, and Rystad.[51]

— based on the entire value of the investment, not just the portion that is used (amortised) during a given period. The total amount of investment will be much larger for the low-carbon asset group, and therefore financing costs are higher as well. Nevertheless, the differences in returns required are not as large as the differences in total investment because the low-carbon assets are generally lower-risk than the high-carbon assets they replace.

While fossil fuel generation technologies are well-established, fossil fuel investment must still manage substantial risks across the supply chain, including exploration and transportation of the fuel. The riskiness of fossil fuels can be observed in their historically volatile prices. Fossil fuel power-generating assets are exposed to this risk, as fossil fuels have to be purchased as inputs. This is particularly true when the fossil fuel generator is participating in a competitive electricity market and is not guaranteed a fixed return for the power it sells.

Renewable energy investments, by contrast, are not exposed to volatile inputs, and deliver electricity over the life of the investment at low operating costs (up to 90% of the total cost of a wind or solar plant is in the initial investment) and with a high degree of predictability. Thus, renewable energy sources can supply electricity at lower risk, if not at lower cost, than fossil fuel generators.

Whether the inherent low risk of renewable energy translates to a low cost of capital depends on the policy and market structures in place. If renewable energy generators participate alongside fossil fuel generators in a competitive market, they will receive a market price based on fossil fuel costs — and will still be exposed to fossil fuel price risk. However, if renewable energy generators can sign long-term contracts to provide power to a credible off-taker, they are not exposed to fuel price risks.

Table 3
Return requirements and amortisation periods for different categories of high- and low-carbon assets

	Average investment life in years (Amortisation)	Return on investment (weighted average cost of capital)
Coal mining – internationally traded coal, or domestic markets in countries with lower financing costs	15	9%
Coal mining – domestic markets in countries with high financing costs	15	12%
Gas upstream investment	10	12%
Gas transport investment – global markets	25	6%
Fossil fuel generation – countries with low interest rates	25	10%
Nuclear generation	30	6%
Transmission	25	6%
Carbon capture and storage	20	10%
Renewable energy – countries with low interest rates	20	6%
Renewable energy and fossil fuel generation – countries with high interest rates	20	10%

The lower risk of renewable energy sources could lead to lower overall financing costs as equity investors require a lower rate of return, and more of the total investment can be financed through debt. The lower financing costs reduce energy prices and free capital for savings and investment. From the investor side, relatively risk-tolerant capital is then freed to invest in new businesses elsewhere in the economy.

Once the incremental cost and relative risk of investments is considered, modelling for the Commission suggests that the transition will require US$600 billion of additional investment return to investors over the twenty year period.

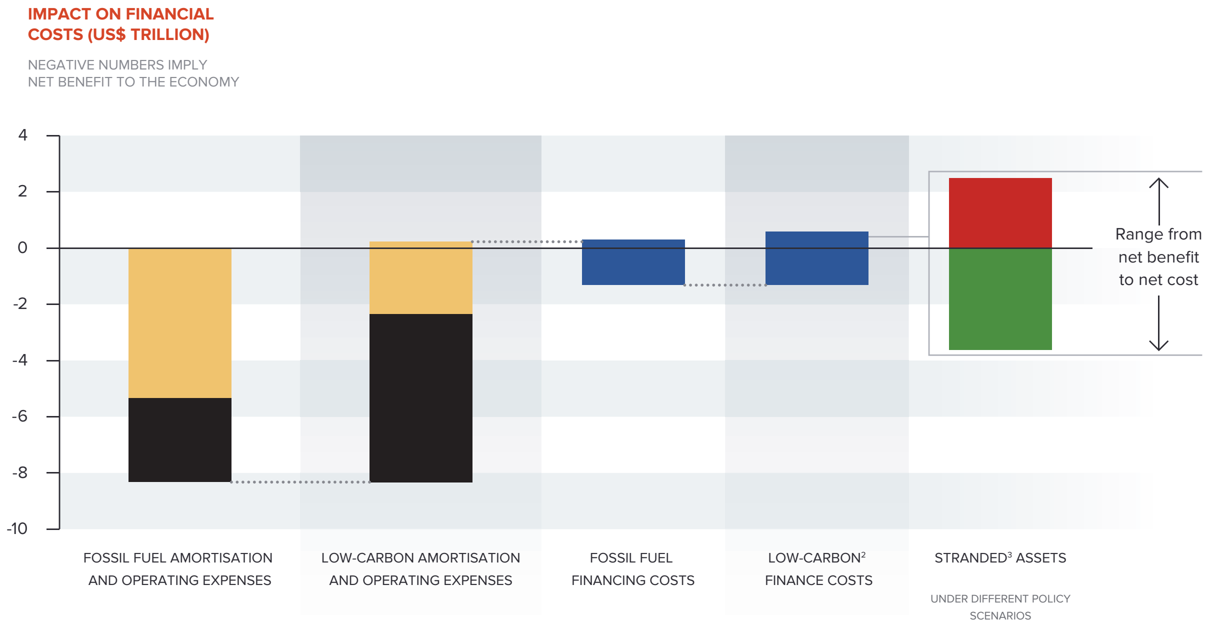
Stranded assets

Stranded assets are the final piece. Owners of fossil fuel assets would find that the value of their assets might fall in a transition. Valuable assets and the cash flows that they generate are used to underpin future investments. Reducing the value of these assets removes investment potential from the economy. Unlike capital and operating expenses, declining asset value does not represent a cost, but a one-time hit to the financial system. Therefore, this investment loss to 2015 was discounted to reflect the impact on the system.[53] For the power transition, asset stranding – or the decline in asset value which reflects potential reduced prices for ongoing production, as well

Box 6

The financial consequences of another transition – reducing oil use in transport and the central role of policys

FINANCIAL IMPACT OF REDUCING OIL IN TRANSPORT (2015 – 2035)[1]



- Capital expenses
- Operating expenses
- Fiinancing Costs
- Net cost (range)
- Net benefit (range)

1: Based on transition from IEA World Energy Outlook BAU Scenario to 2DS Scenario

2: Although low carbon sources would face a lower cost of capital due to their low risk, the larger capital base is reflected in higher total financing costs

3; Oil supply and demand curve modelling and analysis demonstrates the impact of policy on asset stranding - a purely tax or cost based policy would cost the economy $1.7 trillion over 20 years due to reduced consumption, while pure innovation policy would save $3.6 trillion through lower transport costs.

Source: Climate Policy Initiative, using data from IEA, 2012; IEA, 2014; Platts, and Rystad.[54]

The electricity transition is not the only one that involves a trade-off between higher capital expense, lower risk and lower operating costs. The same story plays out in an oil transition to higher electric vehicle penetration, fuel substitution, more mass transit and higher efficiency.

In this case, the analysis again used a combination of the IEA 2DS and business-as-usual scenarios with modelling for the Commission. It was found that a combination of lower operating costs, savings from reduced oil production, refining, transport and fossil fuel powertrains, and lower price risk almost entirely offset the higher capital investment, compared with the business-as-usual scenario. In total, before considering stranded assets, the global transition would cost around US$750 billion cumulatively for 2015–2035.

Regarding asset stranding, oil supply and demand curve modelling and analysis were used to demonstrate the impact of different policies. The impact of the transition on consumers as well as producers and the government was explored. The impact that lower demand would have on benchmark, wholesale oil prices is far more important to producers as a group than lost production. But when prices fall, consumers benefit. The net cost or benefit to the economy is the net of costs or benefits to producers, consumers and government tax receipts.

The result depends on the chosen policy. If customers lose value through reduced consumption or from being forced to switch transport due to costs – for instance through higher consumption taxes – the economy loses out because of consumers' loss of value. However, if innovative new and lower-cost transport options – perhaps developed through innovation policy – attract consumers away from oil-based transport, the economy wins. Including all of the cost elements, a purely tax or cost-based policy would cost the economy US$2.5 trillion over 20 years while pure innovation would save US$3.5 trillion. In practical terms, a mix of policies will be needed as higher prices are a major spur to innovation and tax receipts can be used to invest in innovation. Meanwhile, the more successful innovation is, the lower taxes will be needed to reach a low-carbon trajectory.

as delayed or curtailed production resulting from the transition – is estimated at approximately US$1.1 trillion.

Coal mining investments comprise the majority of lost value, with gas production assets accounting for a smaller part of the impact. The impact on power plants is relatively small, as there are available policies to manage coal plant stranding risk. The US$1.1 trillion estimate is likely to significantly overstate the impact on financial markets as valuations currently seem likely to reflect some action towards reduced fossil fuel use, as discussed in Box 6.

Summing the above calculations, after accounting for the cost of finance and the one-time cost of asset stranding, the analysis shows that the transition would have a net financial benefit of about US$1.8 trillion. However it should be noted that this is based on just one scenario, and that the IEA scenarios assume a significant increase in energy efficiency in the 2DS. The analysis has not attempted to value either the investment or operating costs of energy efficiency, except to note that much energy efficiency, if it can be achieved, has a net financial benefit, some, but not all, of which is reflected in the US$1.8 trillion figure.

5. Addressing stranded asset risk and the cost to fossil fuel asset owners

5.1 Stranded assets and the capacity finance growth and investment

While capital expenses, operating expenses and even financial expenses have easily visible, tangible impacts on the flows of money within an economy, the effect of the final element of our impact analysis – stranded assets – can seem less obvious. The term "stranded assets" comes from the regulatory and economic concept where a change to technology, regulation or markets can leave assets "stranded", reducing their usefulness and reducing or even eliminating their economic value.[55]

When the value of an existing asset falls, there is no obvious immediate cash impact on the economy. However, there is still an important impact on the ability of an economy to finance its growth and investment needs. Take the example of a homeowner whose house value falls 50%. After the price drop, the owner may no longer be able to borrow against the house to finance home improvements or even buy additional properties, and in the worst case, may no longer be able to pay off the debt. For the energy industries, stranded assets related to the transition could be particularly important if the very companies that are expected to finance the transition, such as electric utilities, are the ones who no longer have the financial firepower to make new investments.

For the purposes of evaluating the impact of stranded assets on the financing of a transition, several concepts should be highlighted:

- **Value rather than output:** The financial impact of stranded assets is not about lost production, but lost value. For example, under our evaluation scenario, even oil producers whose output is unaffected by the transition could see the value of their oil production fall by up to 60% due to falling wholesale oil prices that result when demand declines.
- **A loss in wealth, not an ongoing cost:** Stranded assets are a one-time hit to expected or perceived wealth rather than an ongoing drain in expenses. It is this loss in wealth that could make it more difficult to finance the transition. The impact on the ability to finance the transition is thus roughly the same as a one-time, unexpected cash cost.
- **Expectations matter:** Since stranded assets affect markets through declines in expected wealth against which financing can be secured, expectations matter. If the market already expected the policy changes that would lead to a full transition, and further had included the impact of these changes in asset valuations, there would be no asset stranding impact on financial markets.

5.2 Economic modelling and scenario analysis to inform better policies

The impact of a low-carbon transition on asset stranding will depend on the starting point, the end point, and the process and trajectory of getting there. Thus, current market expectations, the ultimate shape of the transformed economy, and the policy, technology and economic paths followed during the transition determine the stranded asset impact, for it is these three elements that will define the surprise or adjustment that investors will need to make.

Describing these three more fully, it is possible to guess, but never fully know, what market participants are thinking based on interviews, asset prices and analysis. The set of assets and industries that comprise a future low-carbon economy can be envisaged, but many versions of that economy are possible, and new possibilities will continue to develop over time as new technologies develop and unforeseen advances and costs reductions are made. As for policy change and the shape of the transition, the Commission sees the evaluation of potential policy paths, including their impact and consequences, as one of the critical responsibilities of policy-makers worldwide.

To begin this process of evaluation and quantification of stranded assets and their impact, two scenarios are used as starting points. The first scenario is based on business-as-usual, where no additional climate relevant policy action is taken. The second is based on the IEA's following – broadly consistent – low-carbon scenarios; the 2°C scenario (2DS) from the Energy Technology Perspectives 2012 modelling,[56] the 450 ppm scenario from the World Energy Outlook 2013,[57] and the 450 ppm scenario from the 2014 World Energy Investment Outlook.[58] The term 450 ppm refers to the level of greenhouse gases, in parts per million of carbon dioxide equivalent in the atmosphere, consistent with avoiding more dangerous climate change. Both of our scenarios are likely to overstate the impact of stranded assets:

- **The business-as-usual scenarios** are likely to imply higher asset valuations than current market expectations, as investors assume at least some policy action to curb greenhouse gas emissions. For example, major oil companies such as Exxon and Shell typically use reasonably high carbon prices in their investment evaluation process.[59] Furthermore, metrics that investors typically use to value companies, including price-to-earnings[60] (forward PE) and five-year growth expectations, show that markets expect industries like integrated oil and gas companies and electric utilities to grow more slowly than the market in general.
- **The scenarios based on IEA 2DS and 450 ppm** reflect a feasible path to a low-carbon economy based on current technologies. However, as technology and the economy evolve, new, low-cost carbon-reducing opportunities are likely to emerge, while existing ones will become cheaper. By reacting and selecting the set with the lowest cost, even the path all the way to 2DS is likely to become less costly, with different sets of asset stranding. For example, the rapid decline in solar PV pricing has exceeded expectations from just two years ago.

Thus, the business-as-usual and 2°C/450 ppm scenarios are not used as definitive numbers. They are used as guides with the following aims: to help quantify the potential impact of stranded assets; understand how asset stranding costs could be distributed; and identify the potential impact of policy on stranding and implications for policy-makers. For example, the results would be quantitatively but not directionally different had we modelled scenarios more consistent with 2.5°C or 3°C of global warming (i.e. 550 ppm rather than 450 ppm stabilisation levels).

5.3 Governments bear the biggest risk of value loss due to an energy transition

Stranded assets are often viewed solely from the perspective of investors and investor-owned companies. It is these investors, after all, who may not be able to invest in new assets once they find their balance sheets weakened by declining asset values.

However, when assessing the impact on the global economy, governments and even consumers have an important part to play. A government that could no longer rely on oil exports earnings might find it harder to borrow money or invest in infrastructure. Thus, when examining stranded assets, producers, both investor- and government-owned, are considered first, and then in the case of oil, the analysis is extended further to consumers. After all, falling prices may impact an oil producer, but depending on how these flow through to retail prices they could benefit a consumer. A consumer with more cash in their pocket could spend or invest the money that could then flow back into more investment.

Beginning with producers, governments and government-owned companies own well over half of global fossil fuel assets by output and reserves. Even for those assets produced by commercial enterprises and owned by investors, governments typically extract significant value through royalties or taxes. Therefore, it is hardly surprising that governments, rather than investors, face the greatest risk of stranding, as shown in Figure 6.

Summing the above calculations, after accounting for the cost of finance and the one-time cost of asset stranding, the analysis shows that the transition would have a net financial benefit of about US$1.8 trillion.

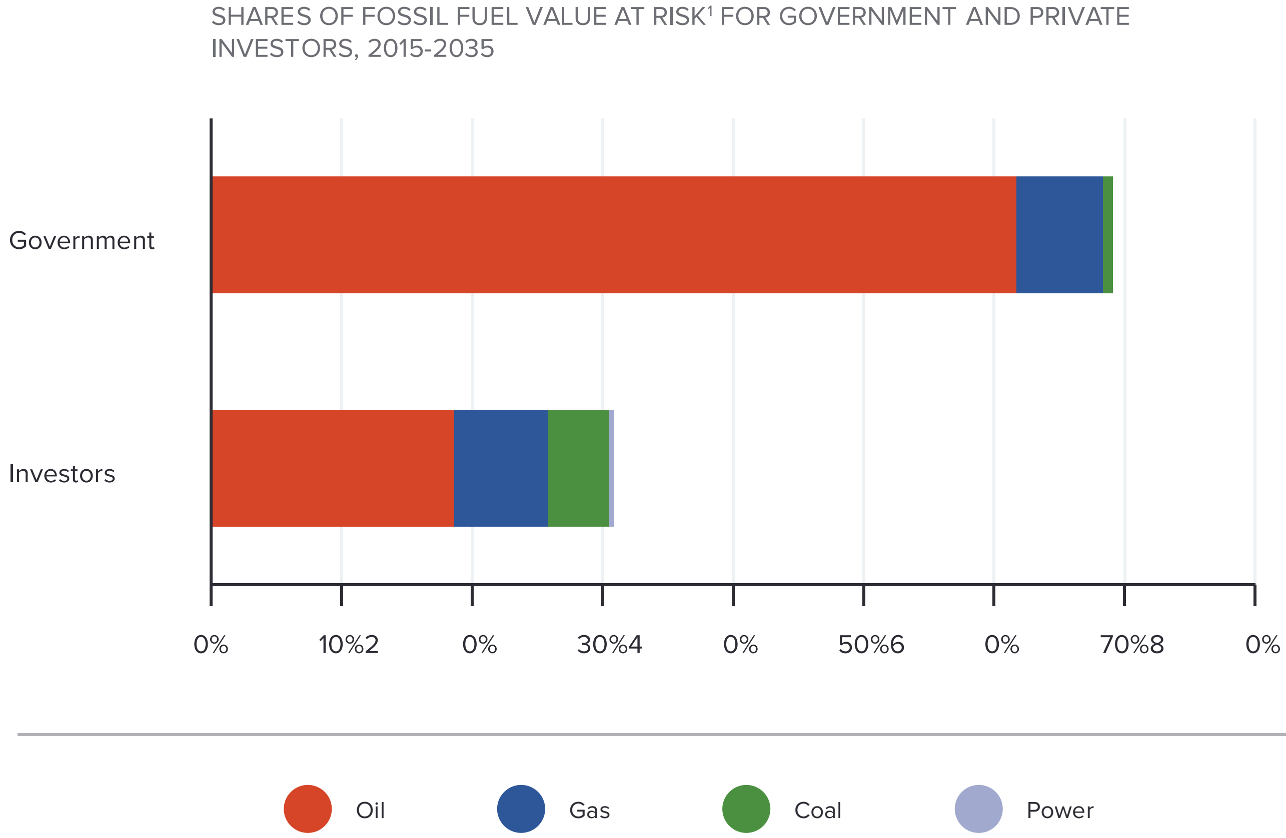
These figures only include the value that governments receive from exports and the taxes and royalties they garner from commercial enterprises operating in their own country. These numbers do not include the profits that governments make on their own consumers, as this is, essentially, just another form of taxation that could be replaced with other taxes with the same economic effect. In fact, many countries choose not to collect all of this profit, instead subsidising their consumers (by comparison with the world price). While they face 70% of the risk as measured by the difference in value between a business-as-usual scenario and a 2DS scenario, if the value that governments could make on their own consumers were to be included, the figure would be well above 80%.

5.4 Stranding of coal: more carbon reduction for lower stranding risks

- Based on the stranded assets modelling conducted for the Commission, nearly 80% of the fossil fuel-related CO_2 emissions reductions in low-carbon scenarios come from the reduction in coal production and use.

Figure 6

Governments lose more than private investors if fossil fuel consumption is reduced



Source: Climate Policy Initiative modelling, based on data from Rystad and Platts.

This refers to the reduction in carbon emissions required to stay on a 2°C pathway. At the same time, coal only represents approximately 12% of the potential stranded asset cost. Therefore, if asset stranding is a major concern, then focusing on reducing coal use makes economic sense. Furthermore, approximately 70% of coal consumption is in the power sector. As outlined above, a low-carbon transition in the power generation sector could yield a net benefit to the global economy.

5.5 Coal-fired power plant risks compared with oil, gas or coal

Regarding the coal sector, coal-fired power plants may be stranded in addition to coal reserves. Here, asset stranding costs to meet the IEA low-carbon scenarios are comparatively even smaller, at just over US$32 billion. All of this risk is in the developed world, as the IEA low-carbon scenarios include a modest amount of growth in coal-fired power plants in developing countries. The risk for power plants is small for a number of reasons:

- Unlike coal, gas or oil there are no reserves to strand, only production assets.
- In the developed economies, recent air pollution legislation, such as the Large Combustion Plant Directive (LCPD) in Europe and the Mercury and Air Toxic Standards (MATS) in the US, has led to the retirement, or pending retirement, of coal-fired power plants. In these cases of retirement, the plant owners decided to close plants rather than invest in upgrades to reduce pollutants like SOx, NOx or particulates. This impact is shown in Figure 7.
- Some of the remaining plants in developed countries are old and without investing in life extension could be nearing retirement. It is assumed that all plants that have pollution control retire "early" at 60 years, while those that do not retire at 40 years. Based on the prevalent market prices for power, coal and other costs, it is calculated that the value that these plants forgo by not operating an additional 20 years, once life extension and maintenance costs are considered. In Europe, the additional value of these plants is particularly small, since we assume that the market

Box 7
Evaluating stranded asset risk for fossil fuel assets

Five data sources influence the calculation of the potential value at risk in any given sector: price, quantity, production cost, ownership and taxes. Below is a description of how the data were sourced for the analysis:

- Production cost, ownership and taxes are allocated based on commercially available data sources, such as the Rystad database of 66,000 global oil and gas fields and various other cost and ownership data sources.
- For the price and quantity of coal, gas and oil production, supply and demand modelling was developed to forecast which production would be curtailed because it is too expensive to operate under different scenarios and how prices in commodity markets would react to falling demand under a transition.
  - These supply models are based on aggregations of cash costs and investment costs from the same data sources, adjusted to account for the impact of sunk costs, transport costs, investment returns and in the case of gas, the interrelationship between oil and gas supplies.
  - The oil demand model is based on International Monetary Fund forecasts for country-by-country GDP growth, and historical multipliers for the relationship between GDP and oil consumption in the absence of price changes. How demand would change for any given future price expectations is then forecast, based on a number of studies of oil sensitivity to price changes.
  - Demand for coal oil, gas and power under the low-carbon scenarios is based directly on the IEA low-carbon scenarios..
  - By comparing these demand estimates against the supply curves generated by the supply models, market price and which production assets will be needed in a given year can be estimated.

With this in hand, price minus cost is the value achieved per unit of production which can then be multiplied by quantity or output to define yearly profit. This profit is split between royalties and taxes and corporate profits, and then assigned the specific assets to companies and countries. Annual profits from 2015 to 2035 are then discounted to estimate value for any given asset. A discount rate of 8% is used to represent the return in the general market that the re-invested revenues from these assets could support were they not to be stranded. Higher or lower discount rates affect the headline number, but do not materially alter the relative impact and insight that this analysis brings. Finally, asset values are compared by owner between the business-as-usual and low-carbon scenarios to estimate the asset stranding impact on various players.

expects that carbon prices will return, over time, to 25 euros per tonne. As a result, some US$28 billion of the US$32 billion of stranding risk occurs in the US.

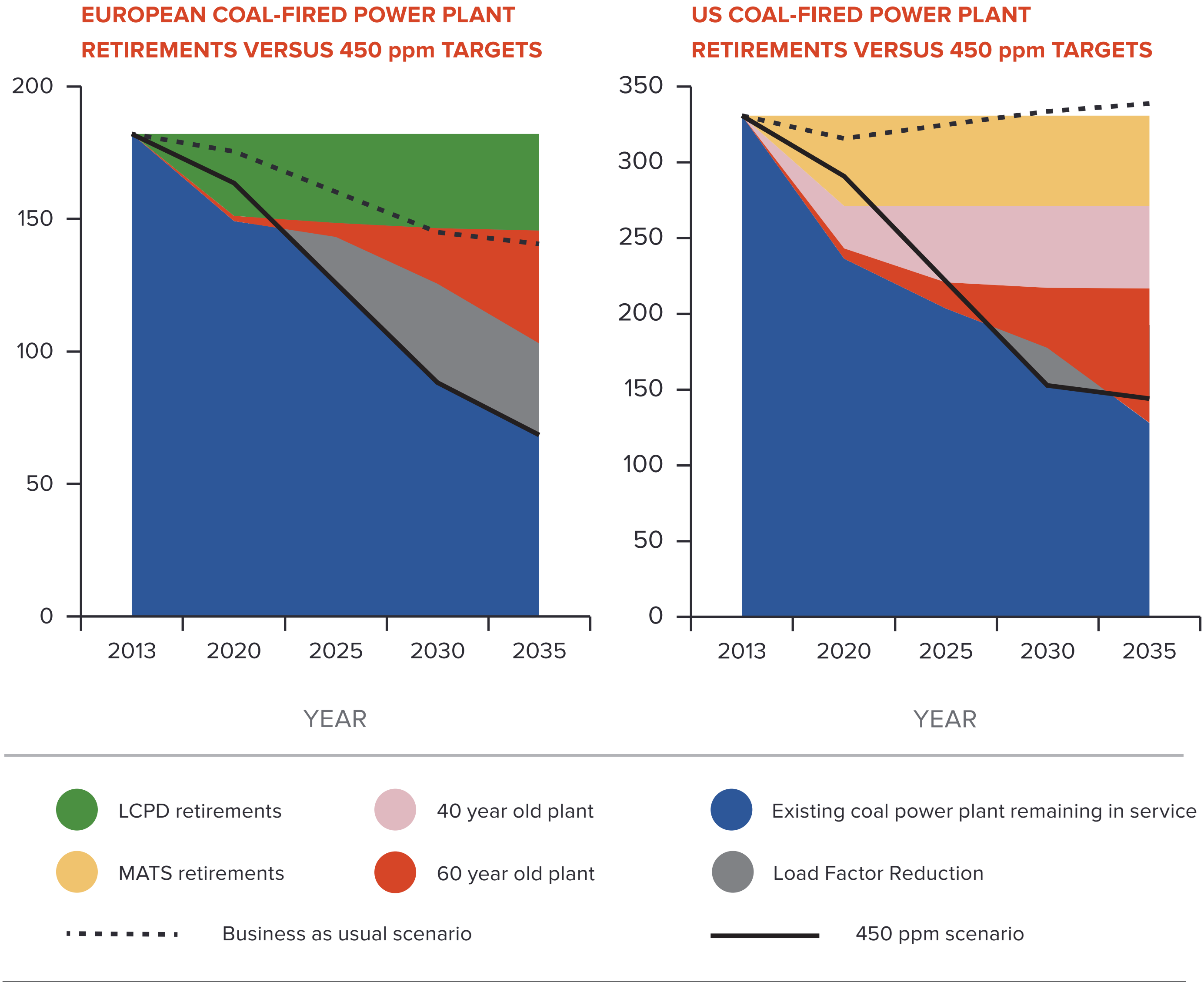
- Some of the plants that remain will be converted to low load factor, more highly flexible plants, and not therefore written off entirely. There are significant limits to the ultimate flexibility that can be achieved, depending on market design. The modelling conducted suggests that some power plants may be able to maintain profitability in a renewable-heavy generation system by offering flexibility services in support of the renewable energy build-out.

Here, asset stranding costs to meet the IEA low-carbon scenarios are comparatively even smaller, at just over US$32 billion

While there need be no risk of stranding to existing assets in the developing world, building of additional, new coal-fired plants will pose a dilemma. These additional power plants would either lead to stranding of existing assets, or the world would miss its low-carbon targets. In other words, the largest risk facing coal plant owners is that additional plants, once built, will reduce the value of their plant. Within the context of the IEA 450 ppm scenario, Figure 8 demonstrates the dilemma facing rapidly growing countries, particularly China and India. The figure shows coal-fired power plants that are under construction or planned, based on the Platts power plant database and the IEA. In India and China, the plants under construction alone, if completed, would push these countries past the targets outlined in the IEA 450 ppm scenario. (Russia includes 3 GW of early retirement.)

Beyond the stranded asset risk, this analysis highlights the urgent need to develop low-cost, low-carbon alternatives, including energy efficiency and renewables, to avoid the need to build more coal-fired power plant to support economic growth. CCS technology would also allow for more build-out of fossil fuel generation without stranding assets.

Figure 7
Current pollution regulation, retirements and load factor reductions are enough to meet IEA low-carbon scenarios for coal-fired power plant



Source: Climate Policy Initiative analysis, using data from the European Commission (LCPD retirement projections), IEA, and Platts

5.6 How policy can turn oil industry stranded asset risk into a net economic benefit

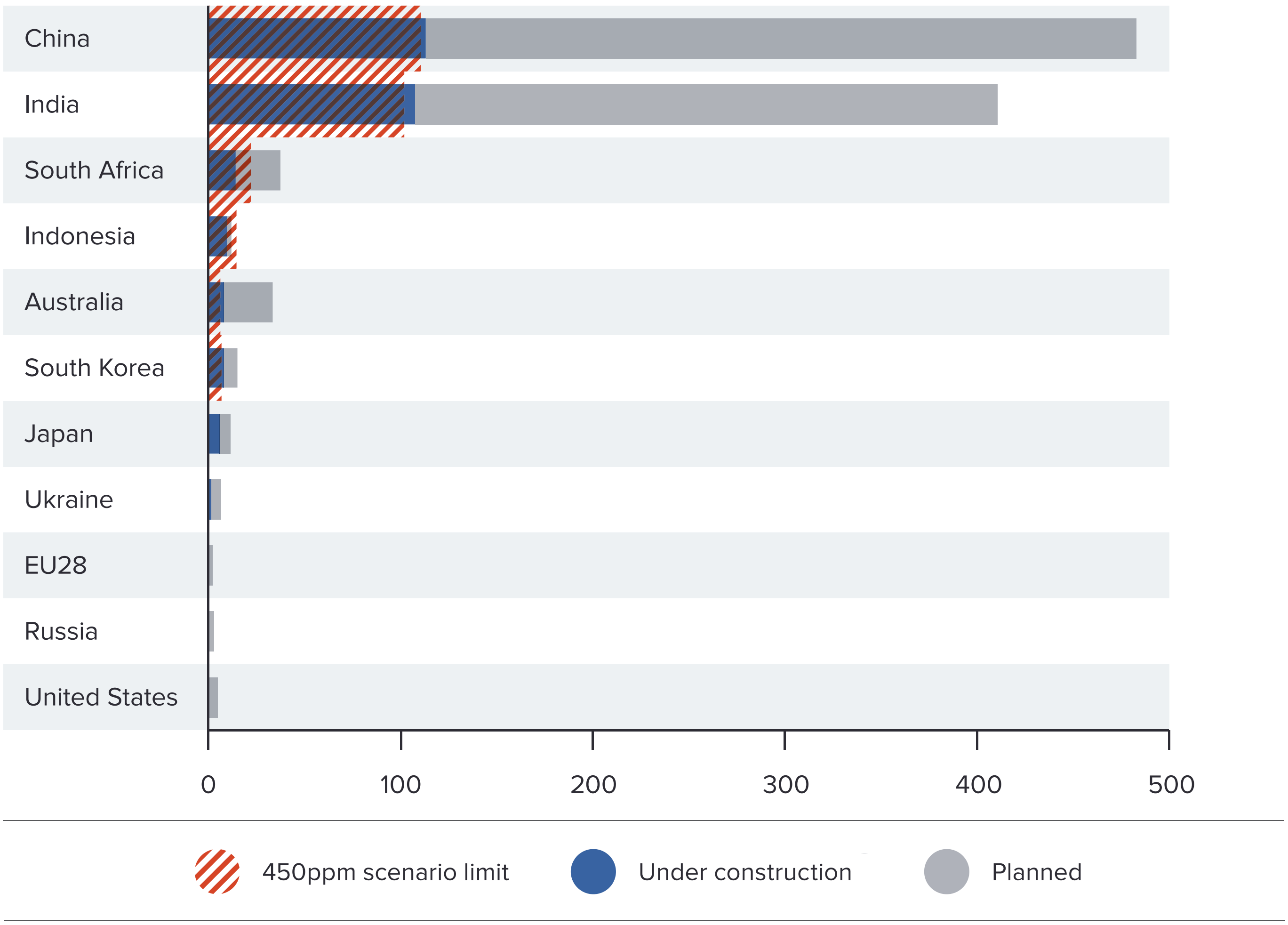
Nearly three-quarters of stranding risk lies in the oil industry. The risk is high partly because oil reserves are relatively large and continue to grow. The most important reason, however, lies in the global supply curve for oil and the relative sensitivity of oil prices to demand. As descried in Box 6, we have modelled supply and demand for oil through 2035 as a function of the oil price. When oil demand falls, the most expensive new production is no longer needed and the remaining producers compete to sell oil into an oversupplied market. Prices are likely to fall as a result, notwithstanding the unusual structural characteristics of the global oil market.

To assess the stranding risk, the producer price for oil that would be consistent with output at the IEA 450 ppm scenario levels was forecast. This was then compared with the forecast of oil demand and supply based on the analysis set out in Box 6. Additionally, the impact that the Organization of the Petroleum Exporting Countries (OPEC) members could have was modelled. It was found that given recent changes to non-OPEC supply and at these levels of demand, OPEC would be unlikely to be able to maintain, or benefit from, higher oil prices as the lost profit from production they would need to remove from the market would exceed the benefits of the higher prices.

This modelling demonstrates an important dilemma in the oil transition. If demand falls to the 450 ppm level, oil prices are likely to fall. By 2035, the 450 ppm price for oil could be less than half of our forecast for the business-as-usual scenario. This decline in price is the most important

Figure 8

Coal-fired power plant under construction and planned versus IEA 450 ppm scenario



Source: Climate Policy Initiative analysis, using data from IEA, Platts

contributor to oil asset stranding risk. Indeed, our natural gas market modelling suggests that by 2030, low oil prices would also begin to suppress the price of liquefied natural gas and cause further risks there.

Yet, if prices were to stay low, and no other action was taken, demand would grow. The demand modelling suggests that prices would need to be almost 40% higher than the business-as-usual case to supress demand to the 450 ppm levels. With higher prices, over time consumers would buy more efficient cars or electric vehicles and move closer to work, logistics chains would shift to reduce transport costs, and prices would spark innovation in new energy saving.

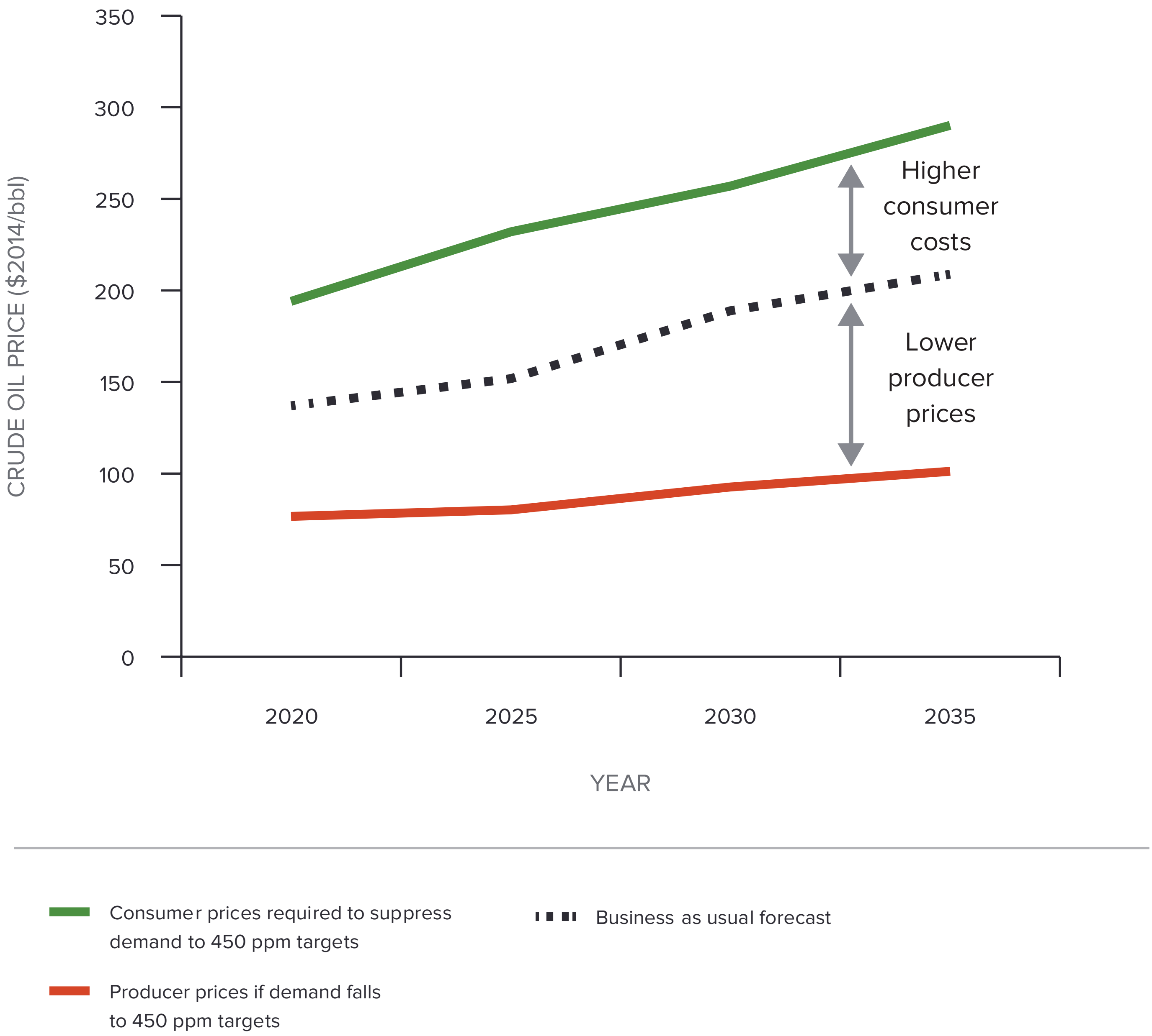
The question for the transition is how to bridge the gap between producer prices and consumer prices consistent with the lower demand. Two solutions emerge:

- Impose energy taxes (or in the case of many countries, remove subsidies) to give consumers price signals equivalent to that of higher commodity prices, while the resulting decline in demand leads to lower prices for producers; or,
- Innovate to shift demand by creating low-cost or more attractive alternatives. Governments can induce innovation through several channels, including implementing financial incentives, imposing fuel economy standards, and sponsoring research.

For either of these solutions, the impact on the economy and investment extends beyond just the stranding loss faced by producers. With taxes, governments will benefit from tax receipts, while consumers will suffer from higher prices; although governments could, presumably, lower other taxes to compensate them for their higher costs. In the case of innovation, consumers will benefit from lower fuel prices, as even in the 450 ppm case oil demand continues at around 80% of today's level.

When taxes are the primary mechanism for consumption reduction, the net stranding impact – broadly defined to include governments, producers and consumers – amounts to US$3 trillion of lost

Figure 9
Consumer prices required to suppress demand to 450 ppm targets versus implied producer prices



Source: Climate Policy Initiative analysis, using data from IEA, IMF and Rystad.

value.[61] This figure accounts for all of the investment required to make the transition happen on the consumer side as well as the producer side, as the consumer response inherent in our demand curves effectively value the trade-off that a consumer would see, for instance, in moving a warehouse closer to consumers to reduce transportation costs.

Alternatively, if innovation could spark a transition without the need for consumer trade-offs, taxes would not be needed and the benefits of lower fuel expenses to consumers would outweigh the stranding of producer assets by US$7 trillion. Clearly, innovation is unlikely to be costless and some consumer trade-offs could be useful.

This suggests that the eventual answer lies somewhere in between. A mix of tax incentives and investments in innovation will lead the net stranding costs to lie somewhere between these two extremes.

5.7 Investors face risks, but it is policy action that matters

While governments bear the majority of risk, the threat of asset stranding is real and could have a significant impact on overall investment performance. As in Box 8, many financial investors may choose to ignore the dilemma by maintaining equal weight positions – that is investments that reflect the share of fossil fuel in the overall market –

Box 8
Institutional investors manage their portfolios in ways that minimise stranding risk

Many institutional investors and sovereign wealth funds seek to maintain or grow their relative share of the global or regional economy. These investors diversify across the entire economy, owning shares of industries in correspondence to their weight in the market. They continually rebalance to maintain an equal weighted portfolio. For these investors, taking a position different from the benchmark constitutes a risk. Thus, owning less than the market share of the fossil fuel sectors constitutes a risk as much as having too much exposure.

If these investors are convinced that the market is underestimating the risk that policy will change, and therefore the oil and gas sector is overvalued, they might reduce their investments in the oil and gas sector, seeking to outperform the market based on this insight. If enough investors take this stance, the relative share prices of oil companies would fall and markets would rebalance. In this respect, current valuations reflect average market perceptions as to whether policies like taxation or innovation will be implemented, and how strongly.

The risk to investors is that they have over- or underestimated the impact and timing of the potential new policies, technology changes, or public opinion. Many investors avoid this risk by maintaining equal weight positions and then rebalancing their portfolios each time relative valuations change. An investor pursuing such a strategy would maintain their market-like performance. Only those investors who are overweight in sectors, especially those locked into illiquid, or difficult to sell, positions, would bear risk that policy change might accelerate. We note that many sovereign wealth funds in hydrocarbon-rich countries are already overly exposed to fossil fuels and derive new cash flows from their fossil fuel revenues; they would benefit from diversifying their investment portfolios away from hydrocarbons, and many are already doing so.

in the fossil fuel industry and avoiding illiquid assets that could trap them as policy changes.

Yet others may choose to bet that the market is not pricing all of the risk of the sector into asset values, and thus maintain little or zero exposure to the sector. Others may view the risk as being overstated by the market and thus increase their exposure to the sector. At the end of the day, it is policy that will drive the transition, and it is investors' views on policy development that will lead them to take a position on investing in the sector. Uncertainty around policy will lead to a wider range of investor views, which will, in turn, facilitate a divergence of views amongst corporate investors in actual projects. Where there is a divergence of views, there will be a greater risk that corporate investors may invest in assets that could eventually be stranded.

The short and simple lesson is that policy ambiguity not only increases the medium- to long-term risk of significant asset stranding. It also affects short-term economic performance by reducing investment activity, including the creation of associated jobs; and it also adversely affects medium-term economic performance by limiting the productivity benefits that better energy infrastructure could have generated. Sending clear policy signals – possibly including an effective carbon pricing or energy tax regime and investments in innovation together with appropriate sectoral policies – is the most direct way to limit stranded asset risk and at the same time, to reduce investor uncertainty.

6. Recommendations

Investment in low-carbon energy can both strengthen economic growth and cut carbon emissions. Mobilising capital presents a challenge, however, because a low-carbon transition requires new and sometimes unfamiliar assets and policies. Low-carbon policies will also impact the value of existing assets.

The Commission makes recommendations to governments, financial regulators, and national and multilateral development banks along these two themes: how to stimulate low-carbon investment, and reduce the cost impact of stranded assets.

6.1 Stimulating investment in low-carbon assets

- **Provide long-term policy signals possibly including carbon pricing, resource pricing and regulation.** These will ensure that there is a robust business case to invest in a low-carbon economy. Further details of policies to reform asset pricing are provided in Chapter 5: Economics of Change.

- **Develop financing arrangements, industry structures and market designs that reflect the infrastructure characteristics of many of the assets underpinning the low-carbon transition.** These assets particularly include renewable energy and the electricity sector:

    - Develop commercial investment vehicles that provide investors direct access to low-carbon infrastructure including renewable energy. This contrast with the present model of investing as shareholders in renewable energy developers including utilities. These alternative investment vehicles, including YieldCos, municipal finance, and crowd-funding, may reduce the annual investment return requirement by 1-2% and in so doing reduce the cost of renewable energy by up to 20%.

- Explore expanding direct financing of low-carbon infrastructure by regional, municipal and national governments, potentially using national infrastructure banks, infrastructure bonds, and green bonds to reduce capital costs. Such direct infrastructure finance also reduces renewable energy costs by as much as 20%.

- In middle-income countries facing high interest rate environments, replace all or a portion of support for low-carbon infrastructure, such as feed-in tariffs, with low-cost debt. This could reduce the total subsidy (including debt concession) by as much as 30% or more; reduce the cost of energy; and harness other benefits from renewable energy such as reducing foreign currency needs to buy imported fossil fuel.

- Develop or strengthen the capabilities of national development banks to perform this new role of providing low-cost debt to low-carbon infrastructure projects, while enhancing systems to ensure the efficiency of project selection and development. These banks may be an appropriate conduit for international financial flows into the industry.

- For low-income countries, continue multilateral and bilateral development bank assistance as a major source of investment and aid for energy system and infrastructure development. Enhance development cooperation to support country-led domestic policy and regulatory reforms that can strengthen enabling conditions for investment in energy infrastructure. These institutions should review their policies to ensure that development is consistent with a low-carbon transition, including the phase out of high carbon projects. Where needed, development finance institutions should be strengthened or created to support low-carbon financing.

- In both developed and developing countries, consider restructuring the electricity industry, market design, and regulation in accordance with the financial and operating characteristics of low-carbon infrastructure, and in so doing lower the cost of capital for low-carbon energy.

6.2 Reducing the cost impact of stranded fossil fuel assets

- Develop transition arrangements that account for and minimise the impact of asset stranding:

- In all countries, focus on opportunities to reduce consumption of coal. Commission modelling suggests that coal represents an opportunity to achieve 80% of the emissions reductions under IEA's low-carbon scenarios with only 12% of total stranded asset value.
- In high-income countries, avoid investment in coal-fired power plant, including new build and life extension. Retire existing plant at the end of their normal life or when major refurbishment would be required.

- One exception to the no new investment rule would be investment designed to increase the flexibility of coal-fired power plant in ways that would support renewable energy and enable reduced operating hours of coal-fired power plant (and emissions) while maintaining profitability.

- In emerging markets, slow down the construction and planning of new coal-fired power plant, as new-build plants could create a significant stranding risk to existing plants.

- To maintain economic growth in rapidly developing countries while slowing growth in coal-fired power plant, there is an urgent need to develop and scale alternative technologies, low-carbon manufacturing capabilities, energy efficiency and low-cost financing arrangements to create viable and cost effective replacements for coal as an energy source.

- In general, across all of the high-carbon investment sectors, the transition from the fossil fuel investment should be addressed by demand strategies. For example, oil use in transport should be gradually reduced through a combination of consumer taxes and innovation in alternatives and vehicle efficiency standards.

- With oil-producing country governments facing the greatest asset stranding risk, there will be a need to address and manage the budgetary consequences of reduced demand and the falling oil prices that would result. This should include more rapid phasing out of current fossil fuel subsidies.

- For net consuming countries, policies used to reduce demand will need to be developed carefully, but the benefits to net consuming countries of lower fossil fuel prices and energy savings could create room for policies to smooth the transition and avoid significant distortions associated with asset stranding.

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53 Stranded asset values are discounted at an 8% return, reflecting typical average capital costs for fossil fuel companies invested in moderate to low risk assets.

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62 Note that the reduction in oil transport stranded asset value includes only that portion of oil consumption that is dedicated to transport; this figure includes all oil use.


CAR 2GO
electric drive
.COM
007
LADEVORGANG
STARTEN BEENDEN
ENERGIE LADEN
Potsdamer Platz
POTSDAMER PLATZ
SHOPPING ARKADEN IN BERLIN

Chapter 7

INNOVATION

Main points

- Innovation is the fundamental engine of long-term growth, and is crucial to enabling economies to grow sustainably. Industrialised countries already enjoy the benefits of past innovations that have sharply increased resource efficiency. New and emerging technologies could allow them to go even further, while enabling developing countries to leapfrog to highly productive, low-carbon economies and improved living conditions.
- Materials science and digitisation hold particularly great potential for economic growth and climate change mitigation alike. Combined with business model innovations, technological advances in these fields are driving rapid progress in renewable energy and energy efficiency. They are also transforming multiple other sectors in both rich and poor countries, including personal transport, buildings, manufacturing, agriculture and consumer goods.
- One example is a shift to "circular" business models, which dramatically reduce the material and energy-intensity of production systems through greater durability and reuse of key product components, and could add up to US$1 trillion to the global economy by 2025.
- The potential for innovations to accelerate the transition to a low-carbon economy is enormous, but there are real barriers, including the market scale, sunk costs and entrenched incentives for incumbent high-carbon technologies. For example, in the construction sector, leading players have shown the potential to achieve radical efficiency gains, but those innovations have yet to be widely adopted.
- Energy-sector public research and development (R&D) is less than half of what it was in the late 1970s, in real terms, even amid growing concern about air pollution, energy security and climate change. Knowledge generated by clean tech R&D in particular has spillover benefits comparable with those from robotics, IT and nanotechnologies, and new patents associated with clean-tech R&D are much likelier to be used by other fields than those associated with fossil fuel-based technologies.
- Stronger incentives for low-carbon innovation – including much greater support for R&D, which has social returns estimated at 30-70% – could lead to large economic benefits while lowering the costs of climate risk management. Support for market creation is also vital, but needs to be carefully tailored to overcome specific market barriers, and to avoid subsidies that are excessive or inhibit competition.
- International collaboration, including financing, technical support and expanded use of patent pools, is essential to making low-carbon and climate-resilient technologies available to lower-income countries, and ensuring they have the capacity to adopt and adapt them.

1. Introduction

Innovation is central to economic growth, as long-term trends in productivity and growth are largely determined by trends in innovation. The importance of innovation is a recurring theme throughout this report; it is essential to transforming global energy systems, agriculture and cities – every aspect of the economy. It also depends on and is shaped by factors discussed in other chapters, from investment strategies, to effective regulation of markets, to international climate policy.

Innovation also makes it possible to continue growing our economies in a world of finite resources. The Organisation for Economic Co-operation and Development (OECD) has projected that if current trends continue, as the world population grows from 7 billion in 2010 to more than 9 billion in 2050, per capita consumption will more than triple, from roughly US$6,600 to US$19,700 per year, and global GDP will nearly quadruple, requiring 80% more energy.[1] Achieving growth at anywhere near that scale, sustainably, will only be possible with radically new business models, products and means of production.

The Green Revolution, which transformed agriculture in the 20th century, allowed humanity to grow more food than ever, by leveraging new technologies. Similarly, new technologies today, from smart meters to satellites, are helping societies use resources more productively. This chapter explores the role of innovation in building a strong, low-carbon economy. We begin by discussing two fundamental areas of innovation where rapid, transformative advances are being made – materials science and digitisation – and gauge their potential to accelerate the transition to a low-carbon economy, based on trends that are already being observed. In doing so, we also demonstrate the importance of business model innovations that leverage technological possibilities to transform markets.

Next, we explore what needs to happen in order to accelerate innovation and its diffusion to a low-carbon economy. Finally, we explore some "game-changing" low-carbon innovations that warrant targeted attention, given their potential to transform the economics of climate action. We conclude with a series of recommendations. We should note that innovation is also covered in other sections of this report, especially in Chapter 3: Land Use, Chapter 4: Energy, and Chapter 5: The Economics of Change.

2. Transformative innovation

Innovation continues to transform how we live, what we consume, and how we do business. Two innovation areas have large potential to drive systemic change, with particular significance for a low-carbon economy: materials science and digitisation. This section explores these two areas, along with the integral role of innovative business models. Other, often inter-related, advances in areas such as life sciences are also driving large-scale changes, but are not discussed here in detail.[2]

Innovations in materials and digitisation are already making an impact across the global economy, increasing productivity, reshaping entire industries, and creating opportunities for leapfrogging, by skipping less efficient and more polluting stages of development.

The impact of digitisation can be seen in "big data" – the large and complex data sets that are now available thanks to digital technology. Virginia Rometty, chief executive of IBM, has described it as "a vast new natural resource, which promises to be for the 21st century what steam power was for the 18th, electricity for the 19th and hydrocarbons for the 20th".[3] As more and more devices in our homes, businesses and public infrastructure are connected to data networks, they have the potential to dramatically increase efficiency, reducing consumption of energy and other resources.

Materials breakthroughs are also transforming products all around us. New materials have created new possibilities in practically every sector, from pharmaceuticals to aerospace. Nanomaterials, formed by particles a billionth of a metre, or five orders of magnitude smaller than the width of a human hair, are being used in computer chips, medical implants, flat-panel displays and satellites. More broadly, biologists can now create entirely new life forms that can be designed for a certain application, such as biofuels with high energy density characteristics targeted for aviation.[4]

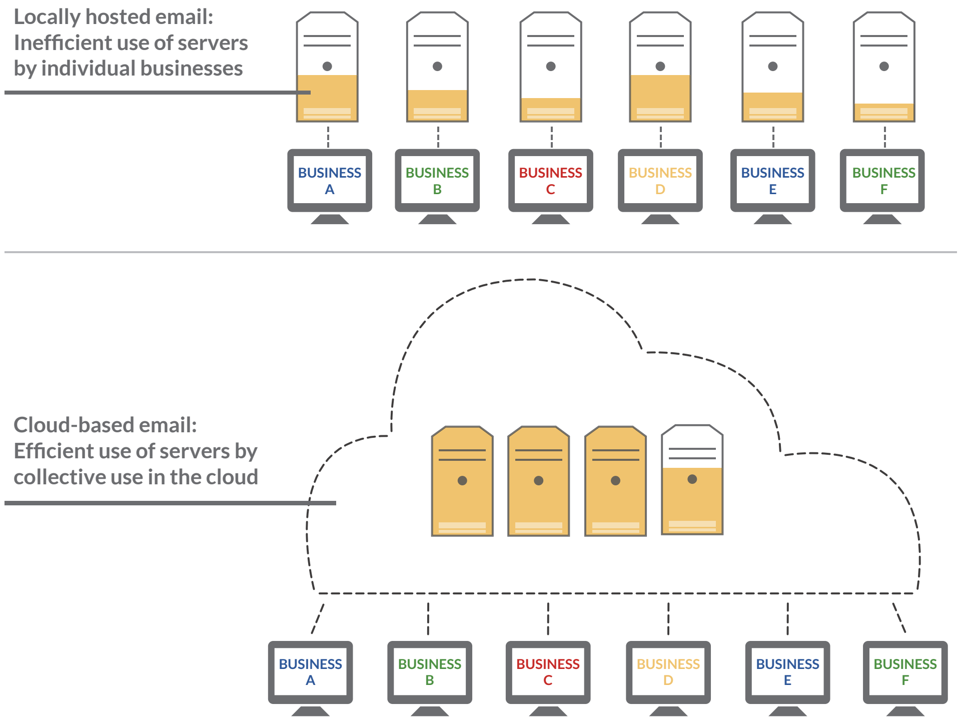
Digitisation and materials science, in tandem with innovative business models, are driving economic growth, both through incremental improvements and dramatic disruption of existing industries. The question we seek to answer below is how these forces of innovation can support the transition to a low-carbon economy.

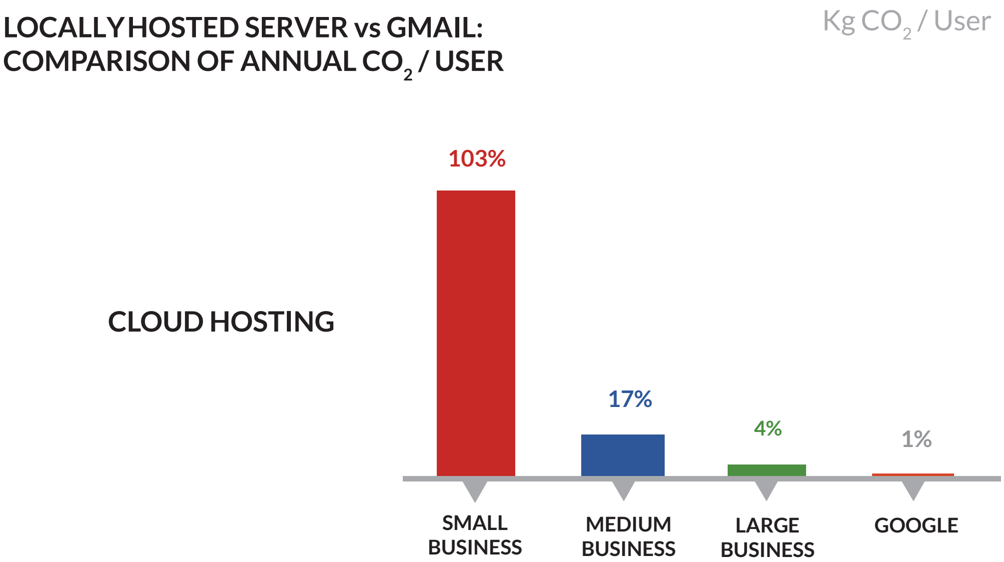
2.1 The potential for a low-carbon transition

The potential for innovation in areas such as new materials and digitisation to accelerate and increase the efficiency of the transition to a low-carbon, resource-efficient and resilient economy is enormous. In fact, such innovation is already reducing climate risk.

In the last 10 years, we have seen a number of materials-related advancements that lower GHG emissions. New and improved materials have driven down the cost and improved the performance of wind and solar energy. In the US, more than 30% of new electricity generation capacity added in 2010–2013 involved solar and wind power, up from less than 2% in 2000–2003.[5] Advances in materials have facilitated large improvements in the efficiency of lighting and appliances, including the rapid emergence of

Figure 1:
Cloud computing can lead to significant savings in energy and carbon





Note: PUE is the ratio of total amount of energy used by a computer data centre facility to the energy delivered to computing equipment. An ideal PUE is 1. Source: Adapted from Google Inc., 2011.[11]

Business type	IT power per user	PUE	Total power per user	Annual energy per user
Small	8 W	2.5	20 W	175 kWh
Medium	1.8 W	1.8	3.2 W	28.4 kWh
Large	0.54 W	1.6	0.9 W	7.6 kWh
Gmail	**<0.22 W**	**1.16**	**<0.25 W**	**<2.2 kWh**

INNOVATION

light-emitting diodes (LEDs). They have enabled a broad array of technologies that improve the energy efficiency of the building envelope,[6] and they have enabled continual improvements in the fuel efficiency of vehicles.[7]

For an office with 50 people, Google estimates IT energy use at 175 kWh per person per year, compared with 2.2 kWh when using Gmail.

Looking ahead, the potential remains large. New advances in materials will continue to drive improvements in renewable energy, and energy efficiency across the transport, buildings and industrial sectors.[8] By 2020, it is estimated that the US corporate sector could save $120 billion in annual costs, and reduce annual emissions by 890 million tonnes of CO_2e, by utilising renewable energy and energy efficiency technologies,[9] most of which rely on improved materials. Advances in materials are also critical to improving energy storage, and carbon capture, use and storage. This will include incremental improvements in existing materials, as well as the application of more advanced materials, such as nanomaterials.

Adoption of digital technologies is gaining traction through a range of new business models that reduce capital- and energy intensity across the economy. It makes it possible to share assets, such as "cloud" storage and online servers, or dispense with them altogether by working remotely and digitising information. Even in mature manufacturing industries, traditional process controls are intersecting with system automation to transform factory efficiency. Ten years ago, energy was too cheap and data too expensive for this to be feasible. Today, the shift in relative prices is changing the picture.

Cloud computing is particularly promising, as research shows it can increase efficiency and reduce companies' overhead costs, and energy usage and related emissions. For example, for an office with 50 people, Google estimates IT energy use at 175 kWh per person per year, compared with 2.2 kWh when using Gmail (see Figure 1).[10] Cloud computing also reduces the need for in-house hardware and software expertise, which can be particularly helpful in poorer countries where such skills are less widely available. In that sense, information technology is effectively replacing capital in many cases. Thus, while there is considerable evidence to suggest that a low-carbon economy will be relatively capital-intensive, due to the capital costs of renewable power, efficient buildings, smart appliances and electric vehicles, digital technologies could significantly offset those capital costs.

Box 1:
Remanufacturing at Caterpillar[14]

Caterpillar, the American machinery and engine manufacturer, has been in the remanufacturing business for almost 40 years. Its Cat Reman activities have improved and expanded over the years, and now employ 8,000 workers spread in 68 plants in 15 countries.

Materials make up almost two-thirds of Caterpillar's costs. Through Cat Reman, the company disassembles products (called "core") at the end of their lives, cleans all the parts, and salvages all that is reusable. This allows the company to boost profit margins, make "same-as-new"-condition products available to customers at a fraction of the cost of new ones, and in the process, reduce waste and greenhouse gas emissions.

In order to intercept products before they break, it is crucial to have consistent knowledge of the condition of the key components. Typically, this is monitored through a regular and simplified maintenance process between the dealer and the customer, but Caterpillar is now beginning to use digital technology to add a "Product Link" service to units in the field. This service provides customers with information about the condition of their equipment, through a satellite connection to a network of Caterpillar dealers.

The pricing structure for remanufactured products is different than for new products: an important part of the pricing is a core deposit, roughly equal to that of the unit itself. Increasing core recovery rates is a challenge for any manufacturer engaging in remanufacturing activity, so offering an economic incentive to return the component is a crucial part of the business model.

An additional advantage of remanufacturing is its faster turnaround of products, allowing delivery of remanufactured products at a fraction of the time

Digital technologies are also changing behaviours at the individual level, in ways that could dramatically reduce GHG emissions. Digital apps facilitate car- and ride-sharing schemes, guide riders through public transit, and help motorists avoid congested roads and find parking more quickly; services such as shopping and banking have moved online, reducing the need to travel. In our homes, data-rich systems are increasingly able to control heating and lighting on a much more reliable basis. In some cases, these technologies have the potential to scale rapidly: China has already installed nearly 250 million smart meters.[12] They can also create opportunities for lower-income countries to leapfrog higher-income countries – such as by using decentralised renewable energy sources and micro-grids to quickly and reliably electrify remote and hard-to-reach areas or provide backup for emergencies.

Below we look in more detail at examples of the impact of these and other key trends on both developed and developing countries. We also discuss how low-carbon technologies themselves are feeding back into, and accelerating, the underlying innovation trends.

2.2 Resource productivity, value chains and the 'circular economy'

Supply chains typically move in one direction: material extraction, manufacture, use, and ultimately waste. The result of this linear model has been landfills full of useful products and components, representing wasted resources and lost potential revenues. This is a particular challenge for the construction industry, which produces 30–40% of global waste and typically has very low reuse and recycling rates, except for steel and copper in many countries.[13]

Many companies are now looking to an alternative to the linear model, attempting to recycle, reuse and remanufacture wherever possible. Materials-related innovation is at the heart of the "circular economy", and new materials technologies can facilitate the transition, with better conversion of used materials to new materials. Similarly, digital technology supports market creation, helping to match used goods with potential reuse or remanufacture markets. This can help substantially with monitoring the product "phase", hence facilitating the reuse of product parts.

The practice of restoring used products for resale is expanding rapidly. The United States is the largest remanufacturer in the world, according to a recent US International Trade Commission (ITC) report. [15] The domestic remanufacturing industry grew by 15% between 2009 and 2011 to at least $43.0 billion, supporting 180,000 full-time US jobs. Even in the midst of a recession, every single remanufacturing sector sampled by the ITC reported some growth. The market has huge profit potential.

Should economies successfully move to circular models, the Ellen MacArthur Foundation estimates that over US$1 trillion a year could be generated for the global economy by 2025, with 100,000 new jobs created for the next five years, while also reducing greenhouse gas emissions. However, capturing these benefits requires businesses to operate in new ways, with high cross-sector collaboration and alignment. A marked shift to a circular economic model would require new skills and systems in areas such as reverse logistics and service-based revenue models.

It also requires regulatory change, from better labelling, to reduced consumption taxes on goods with refurbished components. Existing laws and regulations may stand in the way; for example, regulations on end-of-life of products and waste can prohibit higher-value reuse or remanufacture. The value-added tax (VAT) treatment can make a huge difference to the incentives for a circular economy. Effectively, without the right treatment, VAT can discriminate against reuse/remanufacturing, because it re-taxes goods at every stage of recycling of the product into the market.

Finally, it is crucial that recycling and remanufacturing efforts be underpinned by policies that ensure safe working practices and environmental protection, or else they can have substantial social costs. For example, the "ship-breaking" industry in Bangladesh, which employs over 100,000 people and is the source of 50% of the country's steel, has been found to have severe impacts on the environment and people's health, due to improper handling of toxic materials and poor working conditions.[16]

2.3 Making buildings and materials more sustainable

Buildings consume 32% of global energy and produce 19% of energy-related GHG emissions,[17] and the sector is expected to continue to grow substantially in the next few decades, fuelled by urbanisation in the developing world. For both economic and environmental reasons, it is important to maximise the efficiency with which energy and materials are used in construction, and the efficiency of new buildings once they are occupied.

Yet the industry is slow to change. In the words of Zhang Yue, chairman and CEO of Broad Group, a Chinese prefabricated construction company: "From city planning to infrastructure development and building construction, from resource consumption to energy use, the industry is lagging behind the time in which we live."[18]

This is due in part to the complexity of the building process. The energy intensity of a building depends on choices made by several different actors at different points in time, including architects, urban planners, constructors, owners and tenants. It is rife with misaligned incentives, as those who would benefit from savings are typically not the people making the choices. Finally, the common reliance in the sector on prescriptive standards and regulations, rather than performance or outcome-based ones, can slow innovation rather than encourage it.[19]

Nonetheless , the buildings value chain has huge potential for improving energy efficiency, reducing GHG impacts and creating economic value through various levers, including new products that reduce building energy use, modular construction and pre-assembly, improved building materials, process efficiency in cement and steel, circular business models, and sustainable architectural design. Digitisation and use of new materials cut across the levers, helping to enable previously inconceivable improvements.

New products with great promise include improved LED lighting, compressor-less air conditioners, high-performance windows, advanced thermal insulation, and sophisticated sensors and controls, among others. These new technologies are often linked to advanced building management systems, which optimise building performance and reduce energy consumption.

Modern technologies are also changing the building process. Modular construction and pre-assembly strategies could significantly reduce raw material use and lower construction time. The Broad Group in China, whose CEO is quoted above, recently built a 30-storey, earthquake-resistant hotel in only 15 days through modular construction – a process that typically takes two years – and it has managed in some cases to use 96% recycled steel.[20] Pre-manufacturing the components in a factory allows builders to optimise resource use during construction, achieving efficiencies similar to a manufacturing facility.

Even wood construction is being transformed. Cross-laminated timber (CLT) panels, made from inexpensive wood that is glued or pinned together in layers, can be engineered to be as strong as concrete, more energy-efficient and even fire-resistant. In March 2014, the US Department of Agriculture (USDA) announced a partnership to train architects, engineers and builders in the use of "advanced wood" building materials, and plans for a competition to design and build high-rise wood demonstration projects.[21] Sustainability is a key motivation; advocates note that wood is a renewable resource, requires less energy to make than concrete and steel, and contributes to carbon capture. In the UK, the Alliance for Sustainable Building Products (ASBP) estimates that policies to encourage increased use of wood, hemp, straw, wool and other "biogenic" materials in all UK buildings could yield net emission reductions of 10 $MtCO_2$ per year by 2020 and 22 $MtCO_2$ per year by 2050; the sector's total emissions in 2010 are estimated at 33 $MtCO_2e$.[22]

The Broad Group in China built a 30-storey, earthquake-resistant hotel in only 15 days through modular construction.

Developing countries are also innovating. A joint project by the Rwanda Housing Authority and the Global Green Growth Institute, for example, looked at ways to develop new, locally produced construction materials and sustainable and affordable housing units. Researchers focused particularly on unburnt bricks made with locally available clay mixed with cement, sand and limestone. Early results from the assessment of 54 samples identified four optimal mixing ratios. When using a semi-automatic brick machine, the bricks made following each of those ratios were found to have more than twice the average compression strength of traditional Rwandan bricks; they could also be produced at a fraction of the cost and emissions of high-spec bricks.[23]

Great potential, but real barriers as well

Without major improvements in energy efficiency and materials, building energy use may double or even triple by 2050 due to population growth, urbanisation and rising incomes – but if cost-effective best practices and technologies are widely adopted, energy use could instead stay constant or decline.[24] Even modest improvements can make a real difference: a 10% increase in the efficiency of US buildings' energy use, which now costs about $200 billion, would not only save money, but also improve air quality and reduce GHG emissions by as much as taking about 30 million vehicles off the road.[25]

However, adoption of these technologies is typically inhibited by upfront capital costs, coupled with the misaligned incentives discussed above. Innovations in business models are now helping to address the challenge. For example, through managed energy service agreements, independent providers will finance, own, operate and maintain efficiency upgrades. In return, property owners pay a fee based on their energy savings. This model is fast growing in popularity; the energy performance contracting market in China grew more than 40-fold between 2003 and 2010, to US$4.25 billion.[26]

New products could also disrupt the construction materials markets further up the chain. For instance, innovative cements have been developed that are low-carbon or even net-negative carbon.[27] Whereas traditional cement leaves a carbon footprint of around 0.6 tonnes of CO_2 per tonne of cement produced, a number of companies are developing cements and concretes that have the potential to capture as much as 0.75 tonnes of CO_2 per tonne of cement, locking it away indefinitely.[28]

However, the cement and steel sectors are often slow to adopt substitutes developed with new technology, even if they are economically and environmentally superior. Both manufacturers and consumers are often risk-averse; existing plants are often highly utilised and largely a sunk cost, while consumers are bound by internal or government standards. Government testing and standards for new materials is crucial to allay fears of latent defects. Without swifter updating of government standards, deployment could easily be delayed for years to come. Nevertheless, many governments or large purchasers continue to implement prescriptive input-based standards for construction materials rather than performance-based standards.[29]

2.4 Bigger, stronger and 'smarter' wind power

The development of wind turbines illustrates how digital and new materials technologies can transform a single product.

New materials are making wind turbines bigger, stronger and even quieter. The use of carbon fibre in turbine blades is allowing for larger and more efficient turbines, which achieve more power per land area used and dollar invested. Further efficiency gains could be achieved from new power electronics – for example, through silicon carbide.[30] For offshore wind, new materials are being used so wind turbines survive in harsh marine environments.[31]

The knowledge generated by clean tech has spillover benefits to other fields comparable to R&D in robotics, IT and nanotechnologies.

Digital technology is allowing for "smart wind" that can be more easily integrated into electric grids. In eastern Colorado, hundreds of wind turbines transmit their wind speed and electrical output to the National Center for Atmospheric Research (NCAR). There, that data is combined with data from weather stations, satellites and other wind farms in the state. NCAR uses software to make highly accurate forecasts that allow utilities to more easily and cheaply integrate the variable wind-generated electricity into the grid, by improving the prediction of wind speed and thus electricity generation.[32]

2.5 A virtuous cycle of low-carbon innovation

As demand for low-carbon technologies grows, and innovation aimed at those technologies increases, we are seeing a virtuous cycle in which innovation aimed at low-carbon technologies itself accelerates advances in other fields. A recent analysis of patent data across countries in the OECD[35] has shown that new patents associated with clean-tech research and development (R&D) are much more likely to be used by other fields than are new patents associated with R&D in fossil fuel-based technologies. In fact, the knowledge generated by clean tech has spillover benefits to other fields comparable to the knowledge generated from R&D in robotics, IT and nanotechnologies.

Another analysis, of global patenting rates across all energy technologies, shows that renewable energy patents (particularly solar and wind) have grown faster in recent years than patents in other areas (fossil and nuclear), despite there being no corresponding increase in total R&D funding.[36] The evidence suggests this increase is driven by the rapid growth in markets for clean energy technologies, and the greater overall potential for innovation in such emerging technologies. These factors together lead to a greater rate of innovation achievement at any given level of R&D funding.

This demonstrates how deeply low-carbon innovation is embedded in the current wave of innovation, driving economic growth. Further, it strengthens the case for public support for low-carbon innovation, and weakens the case for public support towards fossil fuel-related technologies.

3. Directing innovation to support a low-carbon economy

Innovation is agnostic. No matter how much potential there is for innovation to advance the low-carbon transition, it will not necessarily do so – not on its own. The application of new technologies, and the innovations that they spawn, are driven by a number of factors, primarily market demand for goods and services benefitting from those innovations.

Where the current wave of innovation has the strongest impact will be determined by two key factors: market demand and public policy. This section examines these two factors, with a focus on identifying and removing barriers to innovation.

3.1 Identifying barriers to low-carbon innovation

As discussed in the economic policy and energy chapters, to ensure our markets work efficiently, it is crucial that prices reflect the true costs of carbon and other environmental damages. Economic research shows that if these costs are not accurately reflected, investment in low-carbon technologies is likely to be lower than what would benefit society most.[37] Industry consultations by the Commission indicate a broad agreement that a strong carbon price or an equivalent policy that prices emissions would greatly accelerate the application of new technologies and new business models to low-carbon applications.[38] We discuss this further below, but first we examine several other kinds of barriers that inhibit low-carbon innovation.

Generally speaking, innovations enter the economy in a continual and iterative process encompassing "invention" (the creation and development of innovations) and "diffusion" (the adoption of new, innovative products and services across the economy, often replacing old ones).[39] Different obstacles and constraints arise at different points of the process.

The *invention* process is constrained by the fact that the value of innovations is often difficult to protect, and becomes, to an extent, widely accessible. While a technological solution, such as the formula for a new drug, can be patented, such patents can be difficult or prohibitively costly to exercise. And new business models can be copied with little payoff to the original inventor. At the same time, knowledge about, and the ability to replicate, a new technology or process can also be transferred as individuals move from one company to another.

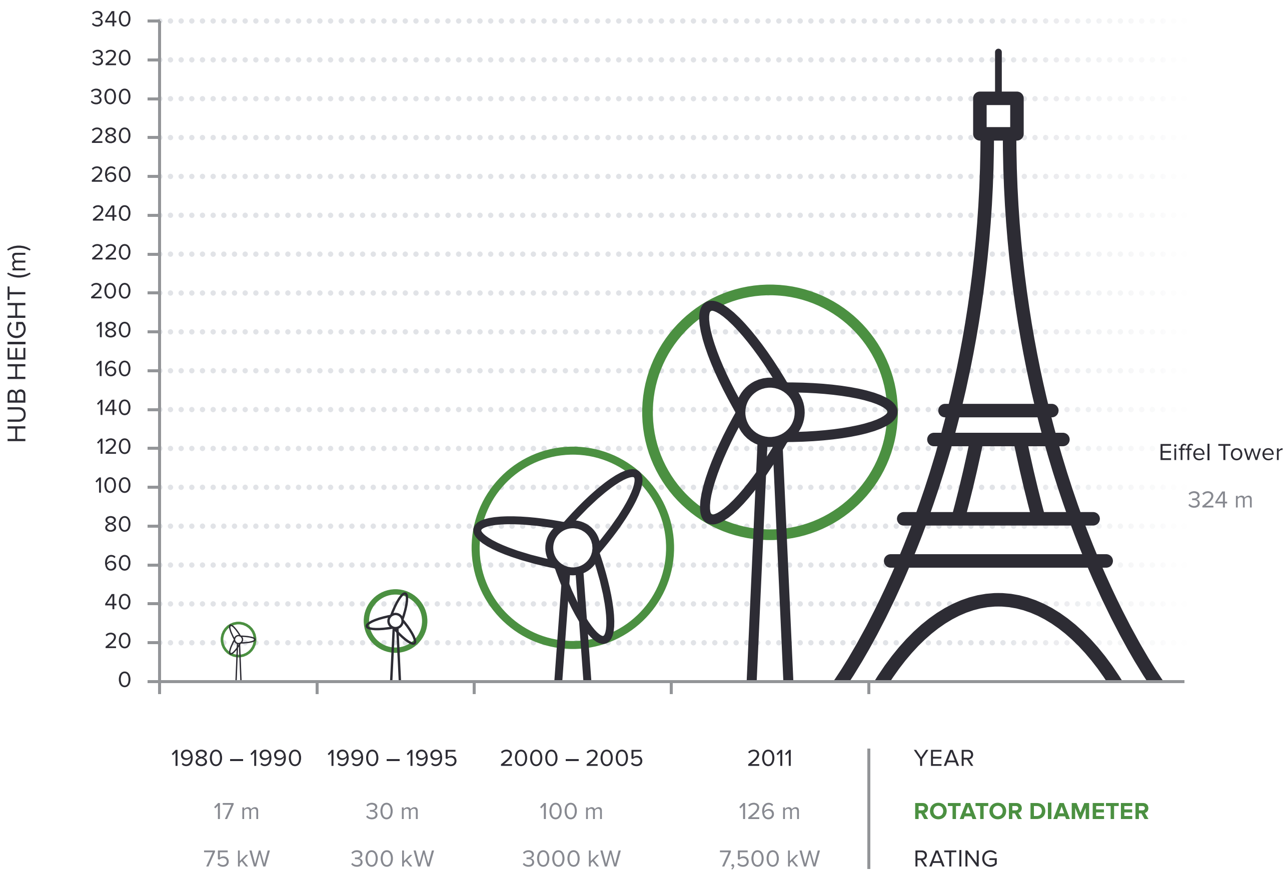
These spillover effects may be positive in terms of rapid diffusion of innovation, but they may also make businesses and financiers reluctant to invest, as the value of that innovation is difficult to protect. This market failure leads to lower-than-optimal levels of innovation.[40] Intellectual property rights are an important tool to protect innovation and create incentives for investment, but they also suffer from inherent disadvantages. We turn to this later in this chapter.

The *diffusion* of innovation, critical to reaping its economic benefits, involves companies and households purchasing new equipment, learning new ways of doing things, or adapting their existing capital to new business models and processes. This process can be hindered by an array of market failures, most notably – but not only – the failure to accurately price environmental damages and other externalities.

Market failures can hinder the uptake of innovations in several ways. For example, the success of many technologies depends on their widespread adoption. So while everyone would benefit if they all moved to the new technology, nobody has an incentive to be the first to adopt an untested technology. So-called "dynamic increasing returns" emerge gradually,[41] as early adopters are observed and copied by others, until the "learning-by-using" effect is substantial and adoption becomes widespread. This means that, absent some intervention, the adoption of such technologies would be slower than optimal. An example is smart meters, where both the effectiveness and cost of the technology depend on creating a large user base and leveraging learning-by-using effects.

Related to this, achieving network economies can also be a challenge for new technologies that require new infrastructure and a critical mass of users. Government

Figure 2:
Wind turbines can generate 100 times the power of 30 years ago



Source: Adapted from the European Wind Energy Association

Box 2: **Innovation and climate change adaptation**

Innovation plays a critical role not only in climate change mitigation, but also in adaptation. While the focus of this report is on mitigation, it is worth noting just how central digital technologies are likely to be in tackling the physical impact of climate change. Digitisation and access to big data is already helping communities to better understand and prepare for the effects of climate change by accessing data relevant to climate-related risks such as rising sea levels and extreme weather events. Google, for example, is using its cloud computing storage and access to support institutions that are exploring climate change resilience through its LatLong project.[33]

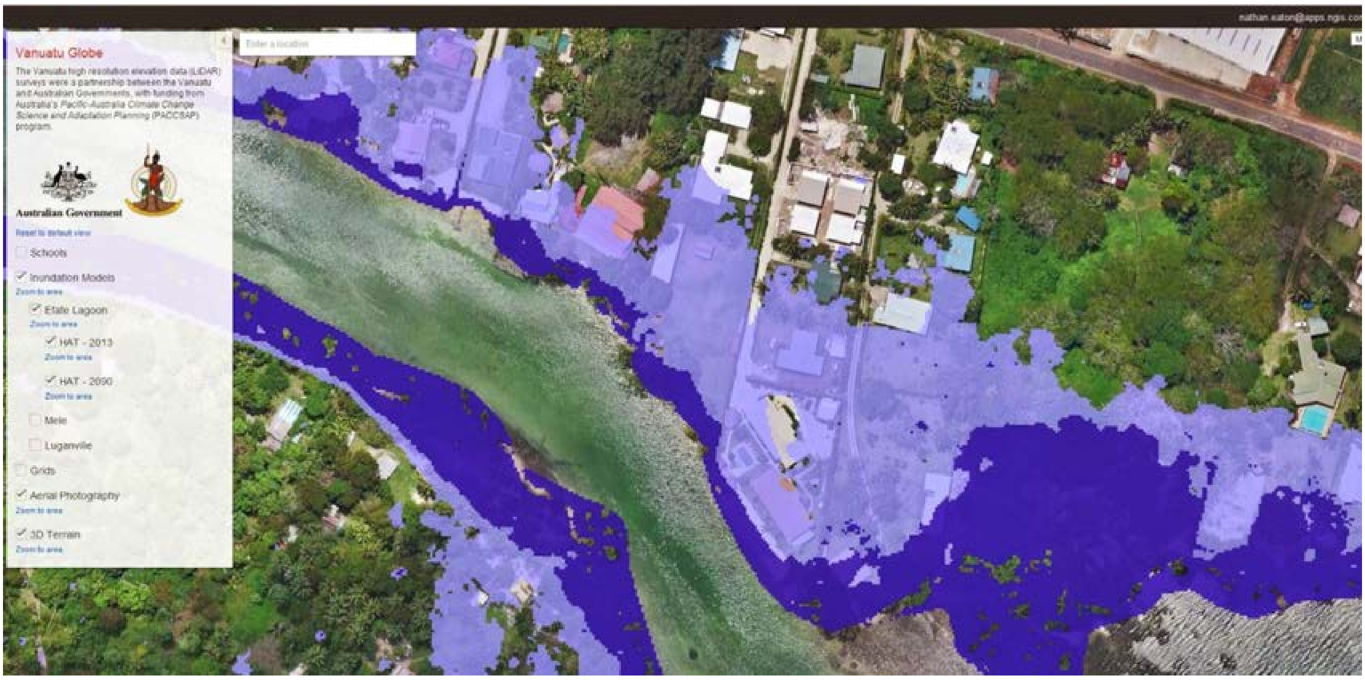
Google donated 50 million hours of high-performance computing to use the Google Earth Engine geospatial analysis platform that brings together the world's satellite imagery to help detect trends on the Earth's surface. This includes an interactive time-lapse of the planet for 1984–2012. One billion megabytes of cloud storage will be made available to house satellite observations, digital elevation data, and climate/ weather model datasets. Researchers and agencies from developed and developing countries are able to join in this project by contributing and curating data, and developing ad-hoc applications.

plays a key coordinating role as rule-setter. Just as governments help ensure the interoperability of electronics, requiring that different systems be compatible, they also need to set standards for new technologies and their associated infrastructure, such as electric vehicle (EV) charging and solar panel integration. EVs' market success, for instance, depends on having a strong network of charging stations; without a large EV user base, however, there is little incentive to build charging stations. If multiple companies build incompatible networks to charge cars, this exacerbates the problem and further inhibits the growth of the network. Mandating that charging stations all follow the same technical standard will speed the rate of network growth.

Another market failure relates to financing innovation. Information on new technologies is, by definition, scarce, and held primarily by the creator. This can lead to underinvestment in the adoption and diffusion of the new technologies, as investors may find it difficult to understand the new technology, and if they do finance it, they are likely to charge a premium. The added cost, in turn, will further reduce investment.

Misaligned incentives can similarly inhibit profitable investment in new technologies. For example, building owners are often not the ones paying the electricity bills, so they have few incentives to invest in equipment or insulation to reduce costs for their tenants.

Figure 3:
Mapping sea level rise to support adaptation



The Google Maps engine was used to highlight the vulnerabilities associated with rising sea levels, storm surges, and coastal inundations in the Republic of Vanuatu. The darker blue shows present-day inundation of the Efate lagoon during a high astronomical tide, and the lighter blue shows predicted inundation in 2090 due to sea level rise. Source: Google Inc., 2014.[34]

INNOVATION

In the context of environmental issues, and in particular GHG emissions, these general barriers to innovation are exacerbated by the uncertainties and lack of understanding surrounding the future impact of climate change. Even if we were to introduce a strong carbon price, uncertainty about the nature and magnitude of damages, about future policy responses, and about the nature of the untested technologies, would make investors reluctant and financing more expensive.[42]
Barriers to entry, such as regulations favouring incumbent industry, also inhibit new technologies. Government plays a key role in helping to reduce these barriers. Incumbency is powerful – the combination of capital invested (sunk costs), technology maturity, and outdated policy frameworks delay adoption of new technologies and business models. These barriers to entry appear to be entrenched in the global energy system, where new energy technologies can take over 20 years to achieve a 1% penetration rate.[43]

The discussion above makes it clear that, while pricing carbon and other externalities is crucial to unleashing the power of markets for a low-carbon economy, other measures also play a role in ensuring that investment in innovation flows to low-carbon technologies at the pace and scale that is optimal for the economy. The next section looks at potential solutions to these issues.

3.2 Fixing market failures to enable innovation and direct it to the low-carbon economy

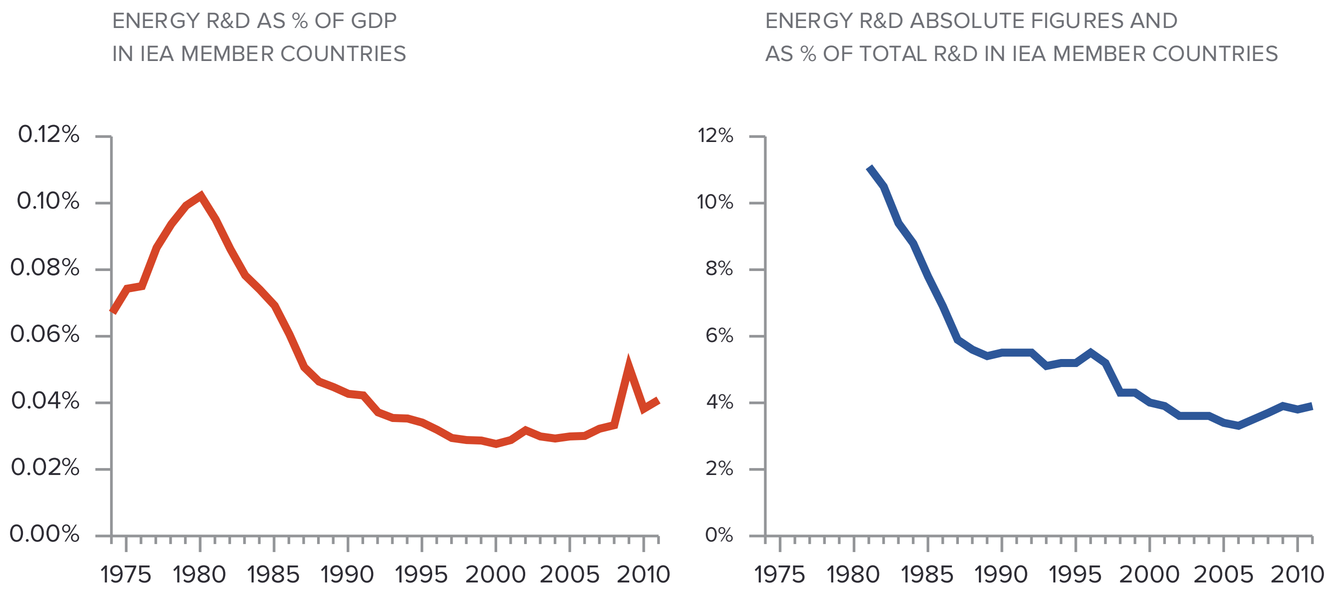
Innovation and the incentives around it are best understood in the wider context of industrial policies. Thus, any measures to address and correct the market failures discussed above should be seen as critical components of overall policies for growth. The potential interventions fall into three broad categories, which we will discuss in this section:

1. Support for research and development (R&D), including publicly funded basic research and links between public research and the private sector, to ensure the research remains relevant to market demand;
2. Building market demand for the new technologies through pricing mechanisms, regulatory standards or direct procurement;
3. Ensuring strong and fair competition through anti-trust and intellectual property regimes that protect the value of innovation and shape the diffusion of innovation.

Support for research and development

Historical analysis of innovation across several sectors indicates that commitments to support a specific type of innovation must be long-term in order to succeed. There is broad agreement that government has a role in supporting nascent technologies through R&D, as benefits often accrue to all of society, rather than just investors. This is particularly true for early-stage technologies, where they may have widespread applications. The economist William Nordhaus found that R&D can have a social return on investment of 30–70%, compared with private returns of just 6–15%.[44]

Figure 4:
Investment in energy R&D as a percentage of GDP and total R&D



Note: International Energy Agency (IEA) members mostly overlap with OECD countries. Sources: R&D figures from IEA, 2013. GDP figures from the World Bank's World DataBank (constant 2005 US$).

Governments' key role in R&D has been understood for decades, if not centuries. AT&T's first solid transistor, though developed by the private sector, was the outcome of decades of public spending on preparatory research in the 1950s. Similarly, the development of the internet was based on US federal funding in the 1960s, with no real expectation of a commercial application. Much high-risk, high-reward R&D has come from governments, and has paid high dividends to society. The economist Marianna Mazzucato notes that 75% of breakthrough drugs are funded by the US National Institutes of Health, and most of the key components of the iPhone grew out of government-funded research.[45]

Public support for R&D can take a number of forms, including direct vs. indirect methods, and grant- vs. investment-based. It can also take place at various points in the R&D process (from experimental research to large scale demonstration), and can involve public, private or other non-government actors, or consortia of different actors.

Direct, grant-based funding includes direct support for science, engineering, and other innovation-related education programmes. It includes direct financing of national labs, along with their R&D facilities and researchers. It also includes direct funding for individual R&D projects, as well as support for the creation of R&D networks across the public and private sector, and across academic researchers and commercial entities. In some cases, countries even provide direct grants as seed funding to start-ups.

Additional, often lower-cost, options for *indirect* support include orchestrated international knowledge-sharing and outcome-based competitions. For example, the Grand Challenge for driverless vehicles[46] and the Robotics Challenge,[47] both sponsored by the US Defense Advanced Research Projects Agency (DARPA), have spurred big improvements in these nascent technologies.

Finally, countries can utilise investment support mechanisms for R&D activities. These may include venture capital or other risk capital funds, either directly funded by the government, or directly guaranteed by the government. Such investment support may also be provided indirectly through tax incentives, which offer favourable tax treatment (e.g. deductions) to investments in R&D or early stage companies to encourage private investment in R&D.[48]

Still, even amid growing concern about air pollution, energy security and climate change, public funding for energy-sector R&D is lower than it was in previous eras. The US government invested $1.8 billion per year in energy R&D in 2007 (constant 2005$); in recent years this has risen to about $5 billion per year,[49] including a major one-time investment in 2009 under the American Recovery and Reinvestment Act. However, the current annual investment amount is still below the 1978 peak of $7.4 billion (constant 2005$).[50] Over the same period, health R&D spending has more than tripled and defence R&D spending more than doubled.[51] The picture is similar with the European Union. Energy R&D investments are down 32% while total R&D investment has risen 148% since 1980.[52] Several factors have contributed to this decline, including low fossil-fuel prices since the 1970s oil crisis and liberalisation of the utility industry. State-run utilities also used to run large R&D projects but have discontinued them in recent decades.

Yet there appears to be plenty of promising R&D worth investing in. For example, the US's flagship R&D support programme, ARPA-E, has been consistently over-subscribed.[53] In another example, a detailed assessment conducted by the UK's Low Carbon Innovation Coordination Group (representing stakeholders across sectors) assessed the potential benefits to the economy of low-carbon innovation, and identified concrete, high-value opportunities for government R&D support of roughly £600 million per year, which is two to three times the amount now being invested.[54] Finally, many developing countries, including relatively advanced middle-income countries, still do not have well-defined programmes for climate change-related innovation, and both their low-carbon and overall innovation spend remains very low relative to innovation leaders at similar income levels.[55]

South Korea and Japan offer a different perspective. With their gross domestic expenditure on R&D reaching over 4% and 3%, respectively, in 2012, they are two of the highest spenders on R&D in the OECD.[57] Korea, in particular, has focused its R&D spending on relatively few large-scale programmes, joint with large firms (chaebols), which provide substantial co-investment (see Box 3).[58]

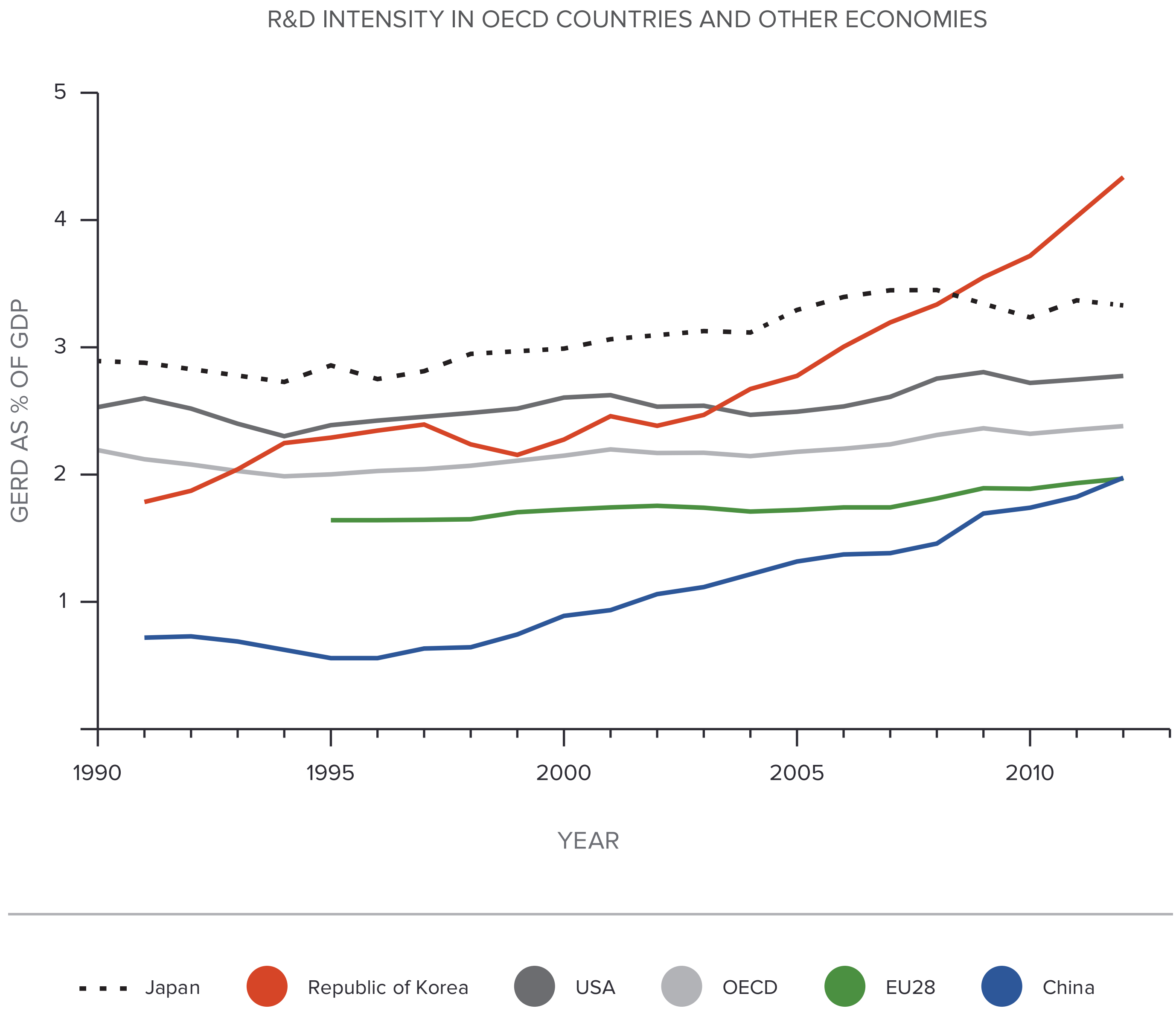
Japan's Science and Technology Agency (JST) also takes a strong and deliberate approach to R&D, focusing on a few, large-scale projects – peer-reviewed independently and carried out in partnership with different agencies and institutions, public and private. The impact of Japan's innovation policy is well documented: its "Top Runner" programme has achieved particular success by requiring appliances to meet the best-in-class energy efficiency rate within a certain number of years, thereby raising the overall standard progressively over time. From 1997 to 2005, the energy efficiency of computers rose by 99%, of air conditioners by 68%, and of televisions by 26%.

In addition to directly supporting R&D activities, the public sector plays a key role in promoting the development of underlying innovation capacity, especially through support to science, technology, engineering and other innovation-related education and training programmes. Such support is particularly important in developing countries, where the lack of such capacity presents an enormous barrier to the adoption and adaptation of new technologies and business models in the local market. International support can play a major role,[65] as in the case of the Consultative Group on International Agricultural Research (CGIAR), which is discussed in depth in Chapter 3: Land Use.

Another important insight from economic research is that policies should be carefully balanced to avoid "crowding out" private investment or subsidising an innovation that can stand on its own. Government policies can support the scale-up of new technologies, but good policy design will plan for the end of government support. The goal is to catalyse a market transformation in which the emerging technology becomes self-sustaining. Support to specific technologies should not become a long-term burden on taxpayers. It should not continue for technologies that have failed to develop as hoped, nor should it provide advantage to incumbent technologies in a way that is inconsistent with public policy goals. Reduction of government support sometimes happens too slowly, and mature industries may continue to benefit from measures taken when they were still nascent.[66] Continuing support for mature technologies then becomes a barrier to new technologies, obstructing the innovation cycle.

Mechanisms to support the exchange of knowledge between the public and private sectors is also crucial, even at early stages of R&D, to help ensure that the innovation remains economically relevant. There is evidence of this from across sectors: from life sciences – where the complex interaction of universities, start-ups, biotechnology companies, pharmaceutical firms,

Figure 5:
Gross domestic expenditure on R&D (GERD) across OECD countries and China



Source: OECD Main Science and Technology Indicators Database, 2014/1.

government and venture capitalists has often led to significant innovation and very rapid diffusion – to the agriculture sector, where R&D has been shown to be more successful when it is conducted in close contact with extension stations, ensuring the applicability of the solutions developed in the lab.[67] One example is the Latin American Maize Project, a multi-country partnership that successfully balanced developing public goods in terms of research and ensuring commercially viability.

Close interaction between the public and private sectors can also ensure that governments adapt regulations and standards to facilitate the spread of innovation while maintaining appropriate consumer protections. Two prime examples are Airbnb and Uber, pioneers of the "sharing economy" that have faced push-back from regulators and from market actors whose businesses they are disrupting (lodgings and taxi services). Legitimate issues do arise,[68] but if lawmakers and regulators don't understand peer-to-peer services and the value they add to the economy, they may cling to outdated rules that protect incumbents and stanch innovation.

Demand-driven innovation and public procurement

The role of demand in driving both invention and diffusion cannot be underestimated. Demand creates incentives for private-sector players to invest and provides a testing ground to improve innovative technologies, products and services. Strong demand is also crucial in starting the process of "learning-by-using" and "dynamic increasing returns" that derive from technologies being adopted by a critical mass of users. In the case of information and communication technologies, the interaction between technology providers and users generated a process of "co-invention" that was crucial to diffusing the benefits of the technologies more quickly and widely across the economy.[69] As mentioned earlier in the chapter, this is an important issue for low-carbon innovations trying to compete against well-established technologies.

The most common tools for creating demand for low-carbon innovations are those pricing mechanisms (e.g. a carbon price or fossil fuel tax) and regulatory standards (e.g. energy efficiency standards) used to encourage widespread deployment, and discussed in more detail in Chapter 5: The Economics of Change, and Chapter 4: Energy, respectively. In this regard, it is worth mentioning the particularly large gap in creating demand for "bottom-of-the-pyramid" innovation relevant to meeting the needs of the world's poorest populations.[70] Here too, international support may be critical to supplementing national policies.[71] In some cases, markets in lower

Box 3:
Innovation and climate change adaptation[59]

Korea's economic development over the last several decades was driven both by inputs such as labour and capital, and by the application of technologies that improved productivity. However, Korea's high growth was fuelled in part by technologies applied to energy-intensive heavy industries such as steelmaking, shipbuilding and automobiles. Energy consumption has risen steadily, reaching 157.4 million tonnes of oil equivalent (Mtoe) in total final consumption in 2010, up 6.5% from 2009 and up 23.8% from 2000.[60] Korea meets 97% of this energy demand through imports and has become one of the world's top energy importers.[61] It is also among the top GHG emitters, more than doubling its energy-sector GHG emissions since 1990, to 576 Mt CO_2e in 2010.[62]

Since the financial crisis in 1997-98, however, the Korean government has tried to shift its development towards a knowledge-based and innovation economy. The country has also made increasingly strong commitments to sustainability. In 2008, Korea launched the Low Carbon, Green Growth plan, following it with a voluntary pledge in 2009 to reduce GHG emissions by 30% below business-as-usual levels by 2020. In 2010, the Framework Act on Low Carbon, Green Growth made it a priority to pursue development that combines economic growth with environment protection, backed by a "green" fiscal stimulus plan of as much as 3% of GDP, with substantial incentives for green industries. The framework also provided a vehicle for mid- to long-term strategies for emissions reductions, including a foundation for carbon emissions trading. In 2012, Korea became the first country in Asia to approve national carbon markets legislation.

As part of these efforts, Korea has developed a Green Technology R&D plan focused on R&D and commercialisation of green technologies in five broad areas: i) forecasting technologies in climate change, ii) higher efficiency technology, iii) low-carbon energy sources, iv) post-production technologies, and v) pollution-free industries. In addition, a renewables portfolio standard was introduced in 2012, with an initial quota of 2% rising to 10% by 2022, with planned investments of US$8.2 billion in offshore wind to grow generation capacity from 0.4 GW in 2012 to 2.5 GW by 2019.[63]

In 2013 the government unveiled the Korean Creative Economy initiative as the next engine of economic growth and job creation, based on "the convergence of science and technology with industry, the fusion of culture with industry, and the blossoming of creativity".[64] The initiative can be seen as a way of harvesting the benefits of both the investment in green growth and the fast digitisation of the service sector to expand beyond previous manufacturing-oriented development strategies.

income countries can become leading markets globally, as with disaster early warning systems. Increasingly, developing countries are as important as developed countries in the innovation process, and the low-carbon transition is not going to be a one-way flow of technologies from North to South.

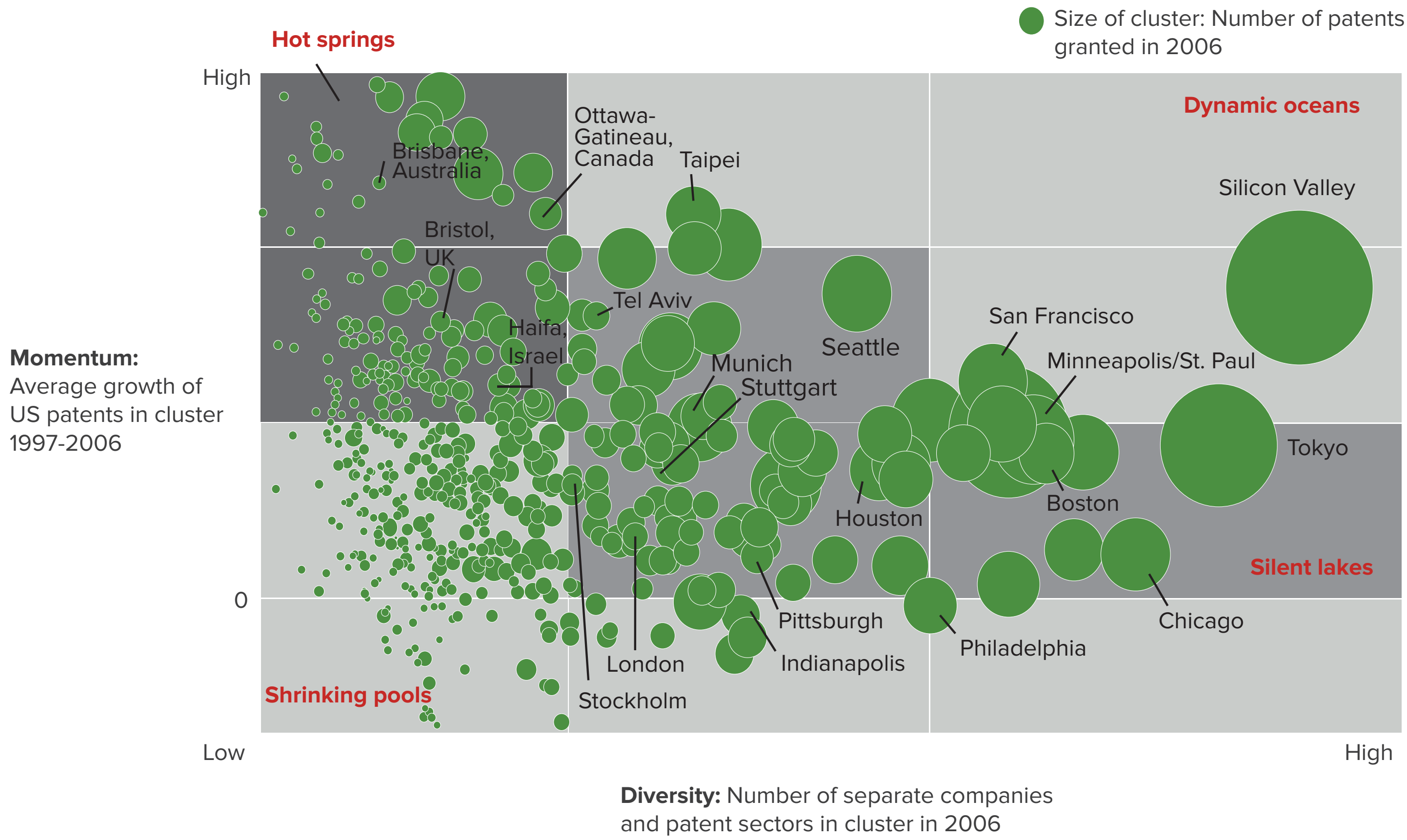
Demand for innovative goods and services can also be increased through more systemic approaches, such as creating innovative industrial clusters to spur innovation and new technology deployment. A high-profile example of such a cluster is Silicon Valley, which a 2009 McKinsey & Company analysis identified as the highest-performance cluster in the world in terms of growth and number of patents granted by companies and sectors.

As shown in Figure 6, McKinsey classified innovation clusters into four categories, based on their growth momentum and diversity: "hot springs" are small, fast-growing hubs; "dynamic oceans", such as Silicon Valley, are large and vibrant ecosystems with continuous creation and destruction of new businesses; "silent lakes" are older, slower-growing hubs with a narrow range of well-established businesses; "shrinking pools" have little diversity or growth.

New clusters are emerging all over the world, often close to large consumer markets that can generate large-scale demand for new products and services. Take the new economic corridor that is being planned between Mumbai and Bangalore in India, with the support of the British government. The corridor aims to raise US$50 billion in investment, generate up to 12% of the country's GDP along the 1,000 km corridor, and create 2.5 million jobs. It is well placed to capitalise on the creativity and innovation of Mumbai and Bangalore and on relatively cheap manufacturing capacity, while having access to one of the largest consumer markets in the world to test and deploy innovative technologies.[73]

Public procurement has also played a fundamental role in this context, across a number of sectors. Innovation in semi-conductors in the US, for example, was driven by the prospect of large military procurement contracts. Similarly, the first ever electronic computer was purchased by the US military, and the development of the IBM 650 – which became the first commercially successful computer in the 1950s – was only possible thanks to the upfront commitment to purchase 50 machines by the US government.[74] In the past few decades, the US and a number of European countries have

Figure 6:
Mapping innovation clusters



Source: McKinsey & Company and World Economic Forum, 2009, adapted with permission from Juan Alcacer.[72]

successfully introduced demand-led innovation research programmes whereby small businesses are invited to propose innovation projects that meet pre-identified public procurement needs.[75] In the realm of low-carbon innovation, a number of countries have also used large-scale demonstration projects to spur initial demand and foster the creation of network economies.[76]

Lessons from history show unequivocally that fostering strong market demand plays an important role in overcoming constraints to the invention and diffusion processes. The creation of innovation clusters, and the leveraging of public procurement and large-scale demonstration projects, have also shown to be effective means of fostering demand in more focused ways to spur the broader innovation eco-system, enable user-feedback and co-invention, and overcome the inertia of network economies.

Intellectual property rights and innovation support programmes

History shows that intellectual property rights have enabled innovation revolutions through the centuries. James Watt, inventor of the steam engine, led his first financier, John Roebuck, to bankruptcy by failing to develop a workable engine, but managed to secure further funding by Matthew Boulton after committing to extending his patent though an Act of Parliament. Thomas Edison, a century later, managed to make his light bulb a viable commercial product only thanks to George Westinghouse's foresight to purchase Nikola Tesla's patent for alternating current. As it turned out, Westinghouse had to purchase many more patents to put in place a workable system for street lighting, and he ran out of money in the process. He raised further finance by using the patents he had acquired as collateral.[77]

Intellectual property rights are not the only means of protecting and encouraging innovation. Companies generally employ a number of other means of protecting and leveraging their innovations. These include strong internal processes for confidentiality, non-disclosure agreements, and non-compete contractual clauses; in some cases, such trade secrets can provide legal protection.[79] Companies also protect their innovations through non-legal means: by creating a rewarding environment for their innovation-related staff, by building market advantage as quickly as possible, and by continually innovating to remain ahead of the competition.

Nevertheless, intellectual property rights provide commercial incentives to invest in risky technologies, often for markets that are yet to be formed. They allow transactions, transfer and sharing of technologies to happen in a legally controlled manner. They allow for choice on how to manage and charge for technologies, as the decision to secure intellectual property rights on a technology is independent of how it will be used. Intellectual property rights do not imply a "closed innovation" model, and are often key to the willingness and ability of firms to engage in more networked "open innovation" models.[80]

Over the next decades we will need to see billions of dollars invested in innovation and diffusion of new technologies, much of it coming from private investors. Some investors will need to take on substantial risks, as some of the technologies and business models are untested. Some of them will fail, while others will succeed at producing financial rewards. These rewards will need to be substantial in order to attract investment capital, and can only be generated if a clear and strong intellectual property rights regime is in place.[81]

Intellectual property rights can also present barriers to the diffusion of environmental technologies, however, along three fundamental issues:

- Cost: proprietary products cost more than generic ones;
- Access: owners of intellectual property can choose to license a techn≠ology only to certain manufacturers and countries;
- Capacity: countries with weaker institutions are often unable to deal with the legal complexity of patent licensing and cannot finance the complex and long process of negotiations related to intellectual property rights.

A famous example that illustrates the difficulties faced by developing countries relates to the Montreal Protocol.[82] Once the Protocol entered into force, ozone-depleting substances (ODS) were phased out, with industries having to adopt ODS-free technologies. Indian and Korean agrochemical companies tried to access ODS-free technologies, but the manufacturer DuPont refused to enter into a commercial licensing agreement, citing concerns about illegal appropriation of the technology by potential national and international competitors.[83]

This example illustrates a fundamental issue with intellectual property rights. As indicated earlier in this chapter, public- and private-sector investment in innovation (particularly basic research) is often motivated by industrial policy and international competitiveness considerations. In practice, many countries choose to drive domestic market deployment of new technologies, and support them through intellectual property rights, clustering and tax incentives, in hopes of gaining an international competitive advantage. For example, Denmark deployed wind energy throughout the 1980s and 1990s, gaining an advantage when other countries looked to deploy wind in the 2000s. A similar pattern has been seen historically with high-speed rail, whereby

France, then Japan, and then China deployed national rail systems, in the process creating leading global businesses in the sector.

This is a desirable process, as it allows for innovation and, eventually, growth. Intellectual property rights are central to it. At the same time, the comparative advantage created for a country or company, once protected by those rights, increases costs and complicates access to the new technologies for everyone else.

Access to technologies by poorer countries has been a hotly debated issue. These countries need to adopt low-carbon technologies in order to meet agreed targets for emission reductions, or indeed to transform their economies into sustainable, resilient low-carbon ones. The concern is whether they will be able to access those technologies at fair and affordable prices. While eliminating intellectual property rights cannot be the optimal solution, as it destroys incentives for investment, there is a need for mechanisms to accelerate the sharing of technologies with lower-income countries, and to ensure that countries have the capacity to adopt and adapt those technologies.

In fact, for most technologies, patents are not filed in poorer countries, as the size of the potential market and the complexity of procedures often discourages companies. In such cases, inventions can be used freely in the countries. The issue of transfer and capacity still persists, but patents do not create additional barriers. Many companies also offer differentiated prices to poorer countries, on the condition of non-leakage in richer countries. But when market sizes are large or leakage risks are perceived as higher, patents are put in place, and constitute barriers for technology diffusion.

Denmark deployed wind energy throughout the 1980s and 1990s, gaining an advantage when others looked to deploy wind in the 2000s.

A number of potential solutions to this issue have been discussed, both in the literature and in negotiating forums, including for low-carbon technologies.[84] One important solution that is being put forward is the creation of patent pools: consortia created by owners of similar technologies to pull together, and sometimes cross-license, common or complementary technologies. These are then made available at standard prices, licensed to any third party, with no right of exclusion by the members of the consortium. The advantage of a pool is that it ensures access to environmental technologies, avoids the cost and difficulties of entering into legal agreements with multiple patent owners, and doesn't discriminate, as it guarantees access to all. (For an example, see Box 5.)

Even with patent pools in place, the cost of licensing will remain an issue. This could be addressed by setting up such a mechanism in conjunction with funding support by the Global Environmental Facility or the new Green Climate Fund to cover the cost of licensing. Both of these institutions include support for technology transfer within their mandate.

Other potential, and complementary, solutions include the establishment of a platform for "nationally appropriate innovation actions" (NAIAs) where countries take action on specific innovation agendas that have implications for emissions, and these are recognised as actions that "count" towards an overall target on emission reductions in the context of an international agreement. Such NAIAs could also be used to recognise contribution of countries that decide to share intellectual property rights they hold and make them accessible for free to other countries.[85]

The US-China Clean Energy Research Center provides an example of bilateral collaboration on technology with a strong focus on mitigating intellectual property concerns.[86] It was established in 2009 as part of several US-China clean energy agreements signed by President Hu and President Obama, and it includes representatives from universities, government research laboratories, and private companies from both countries. It focuses on three key areas: buildings energy efficiency, advanced coal technology and clean vehicles. One of the more innovative aspects of this collaboration has been the development of a Technology Management Plan, which has helped mitigate some of the intellectual property concerns of the participants.[87] In July 2014, the US and China announced another raft of agreements to tackle climate change, including demonstration projects on carbon capture, use and storage (CCUS) and smart grids.[88]

In addition to bilateral collaborations, multilateral initiatives such as the Clean Energy Ministerial (CEM)[89] and the Major Economies Forum on Energy and Climate (MEF)[90] provide platforms for sharing best practice and exploring multilateral cooperation around clean energy with tailored arrangements for intellectual property protection.

Some principles on intellectual property rights emerge from this review:

- Support a strong intellectual property rights regime for developing and diffusing new low-carbon technologies, without prejudice on how these will be used and shared.

- Identify effective, inclusive international forums for addressing intellectual property rights issues, and make it a priority to resolve disagreements that are impeding the diffusion of innovations. Given these issues' implications for trade, the World Trade Organization may be the most appropriate venue for many of these debates. For low-carbon technologies in particular, the technology transfer institutions within the United Nations Framework Convention on Climate Change (UNFCCC) are also crucial, but they need to be streamlined and simplified to be more effective and ensure transparency and accountability.
- Support the development of patent pools for low-carbon technologies, with support from existing institutions to enable poorer countries to access them.

3.3 The success of innovation policy in driving down costs

The section above lays out a substantial agenda for government intervention. But there is significant debate about the role of policy in supporting the deployment of innovation, fuelled largely by fears of governments "picking winners" as acts of political favouritism. There also remain significant differences in the means employed by different countries to encourage innovation.

Governments have a plethora of policies from which to choose to assist with deployment and scale-up of new technologies and business models. Some require government money; for example, tax breaks for businesses producing renewable energy or direct consumer rebates for the purchase of new technologies have supported significant market growth in solar, wind and certain building technologies and appliances, in both the EU and the US. Other deployment policies don't require government money, but instead mandate that a market embrace new entrants via renewable portfolio targets, performance codes and technology standards. These regulatory measures have had impact in Japan, Korea, China and the US, among others.

There is no single "right answer" for which policy instrument to use, although the above sections provide a number of insights into the types of policies governments should consider as they determine the best approach for their particular context.[92] Overall, harnessing innovation to drive down costs and improve performance requires a range of policy interventions in order to address multiple market failures, to cultivate the broad innovation ecosystem, and to support innovation at different points in the process (e.g. across invention and diffusion). Moreover, effectively implementing such a range of policy interventions requires a coherent innovation strategy and priorities, and stable funding.[93] The case of US government support for solar energy (see Box 6) illustrates the success of comprehensive low-carbon innovation policies in radically improving cost and performance.

At the same time, policies that monitor and evaluate results, set cost and performance targets, and dynamically respond to cost changes over time, have proven to be particularly effective. This is true of policies across the innovation process. In terms of R&D support, the US, Korea, Japan and other leading countries have deployed

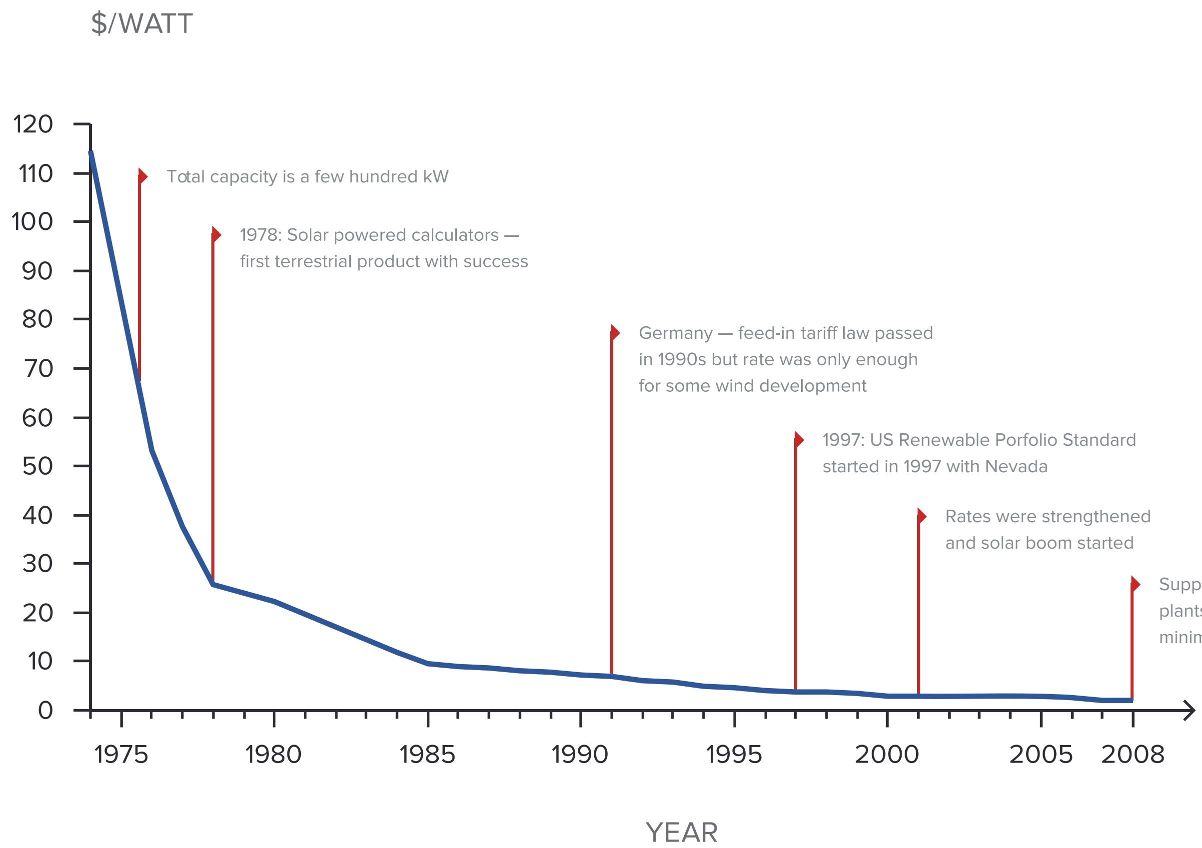
Box 4:
What are intellectual property rights?[78]

Intellectual property rights are legally enforceable rights over inventions and other "creations of the mind". The most important such rights for low-carbon technologies are likely to be patents, which allow the patent owner to stop the use of an innovation by others. They do not automatically allow the use of the patented technology by the patent owner, because the new invention may incorporate inventions already patented by others, for which permission to use must be sought. This is an important point. A patent also requires publication of the invention so that others may build upon the ideas it contains. Other intellectual property rights include copyrights, trademarks and design rights. With the exception of copyright, however, these are granted rights (i.e. they have to be examined and approved by a granting body), and they apply only to the country in which they have been granted.

Most patents are applied for only in substantial markets where they will be manufactured, sold or used. Most companies do not file patents in Least Developed Countries (LDCs). Other than trademarks, which can last indefinitely, intellectual property rights have a limited life, which is generally 20 years in the case of patents. Statistically, radical new technologies take about 12 years after first patenting to reach the marketplace. Evolutionary technologies, which are usually less dominant, may reach the market in five years. In sectors with complex technologies and products, there are often many inventions (and therefore intellectual property rights), owned by different parties, which are used in the final product. Examples include mobile phones, computers and medical technologies such as magnetic resonance imaging (MRI). This situation is known as a patent thicket.

Where patents covering some elements of a product are owned by others, agreements to grant each other rights to use the other's inventions are called cross licences. Where standards are set, particularly where interoperability is important (such as mobile phones and TVs), patent pools may be created where

Figure 7:
Solar photovoltaic production cost: 1974-2008



Source: US Department of Energy, 2013; O'Connor et al, 2010.[98]

clear and increasing cost/performance targets to encourage significant advances and benchmark overall progress.[94] In terms of supporting demand, ratcheting-up performance codes and standards has driven successive waves of innovation, while ensuring that the worst performers exit the market. This is often referred to as the "California effect", after the state that has been a frontrunner of tighter environmental regulation, spurred by the need to remain competitive in export markets that already had similar stricter regulation.[95] Recent research on the "California effect" indicates that it can have important spillovers: a global study on automobile standards found that when developing countries export automobiles and related components to countries with more stringent automobile emission standards, they are likelier to raise their own domestic standards.[96]

Finally, the lessons from recent experience in the rapid reduction in cost of clean technologies (the technology "cost curves") are important to take into account when modelling the future cost of new technologies in the context of economic planning. Often models used by policy-makers for economic planning purposes assume technology as a constant, or at best treat innovation as an

Box 5:
GreenXchange: a patent pool for 'green' technologies

GreenXchange was a virtual exchange of technology patents related to sustainability, created in Davos in 2010 by Nike, Best Buy and Creative Commons. The purpose of the exchange was to foster innovation in non-competing industries. The rules were that members would control the degree to which their intellectual property was made available and the fees for sharing that property, and could exclude competitors. Patent holders would then be able to retain the rights they believed were critical to maintaining their competitive edge, while non-competitors could access technologies simply and efficiently. Three years into its launch, more than 400 technologies had been made available through the platform, including Nike's environmentally preferred rubber. Although the GreenXchange website is not active anymore, Nike says the company has "gained significant insights from this collaboration which continue to inform our strategy to bring sustainability innovations to scale".[91]

Box 6:
US government support for solar energy[97]

Today, photovoltaic (PV) solar modules in the US cost about 1% of what they did 35 years ago. This impressive learning rate has been achieved with the support of multiple government interventions, including:

- Support through the US Department of Energy's national laboratories to pioneer scientific discovery and new innovations that can break through the limits of current solar technologies.
- Financial policies to leverage private sector investment. This includes up to $4 billion in loan guarantees to overcome financial barriers to commercial-scale deployment and a 30% investment tax credit for residential and commercial solar systems.
- Support for projects that help solar manufacturers make improvements in a broad range of manufacturing processes across the supply chain.
- Targeted initiatives, such as the SunShot Initiative, to support research in existing solar technologies with the aim of reducing the costs to a nationwide average of $0.06 per kWh by 2020.
- Policies to alleviate workforce development barriers within the solar industry. This involves training programmes and sharing of best practices. Support for training programmes is provided at nearly 400 community colleges around the US, including programmes to provide skills to veterans; around 13,000 veterans now work in the US solar industry.

economy-wide process, as opposed to a sector-specific process that is itself determined by new markets, policies and incentives. This is dangerous: inadequate modelling will underestimate the importance of innovation (and innovation support policies), bias assumptions on the likely costs of a low-carbon transition and, ultimately, lead to wrong policy choices.[99]

4. Potential game-changers

Both broad-based innovation policies and targeted interventions are important to driving the development of new technologies. In previous sections, we looked at the potential impact of broad-based innovations in the areas of materials science and digitisation, and at the business model innovations integral to creating this impact. We also looked at related low-carbon innovation areas benefitting from these broader innovations, such as resource productivity and the circular economy; cities and sustainable buildings; and renewable energy. We showed the importance of broad-based policies to support innovation, and also showed how targeted support (see the US solar energy case study) has been critical to advances in low-carbon innovation.

Early investment in potentially transformative technologies can help manage risk in the future.

Targeted interventions are most essential for technologies that reduce market externalities, like avoiding dangerous levels of climate change. Such interventions are also essential to overcoming path dependency and the inertia of incumbency that may lead to under-investment in low-carbon technologies.[100] Targeted investment in such technologies can have a transformational impact, and lead to large returns in the future.[101] History shows that new technologies can take several decades to generate new products, often to meet needs and mitigate risks that are themselves difficult to predict. Hence, government support for early investment in potentially transformative technologies is crucial to manage risk in the future.

Below we have chosen to highlight three examples of technologies that have the potential to be transformative in terms of reducing emissions, with substantial additional benefits: energy storage; carbon capture, use and storage, and advanced bioenergy. We also highlight the example of Tesla Motors, where a number of different technological innovations (including energy storage) were combined with business model innovation, leveraging an open-innovation approach, to create a potentially game-changing product.

This does not mean to be a comprehensive list. Our aim is to highlight examples of innovations that have the potential to transform products and business models in the future, and to show the potential role of government in enabling such advances.

4.1 Cutting-edge energy storage

Energy storage technology has advanced considerably in recent years as a result of increased R&D, a renewed focus on grid resiliency and reliability, increased interest in low-carbon transport options, and improved information and communications technology.

Several energy storage technologies are under development, including thermal storage and batteries with various electro-chemistries and configurations.

Technology options with the same storage capacity may differ in other important specifications – such as round-trip efficiency, discharge time and cycle life – and so it is expected that multiple technologies will co-exist in the energy storage market and be used for different applications.[102]

Energy storage could provide value to many different economic actors. Homes and businesses could use energy storage to save money on energy bills, by storing electricity when prices are low and consuming it when prices are high. Those without grid access can use energy storage coupled with distributed solar power to meet their energy needs, and increasingly, this may become a competitive option for on-grid customers as well.[103] Utilities can save money, and reduce their carbon footprint, by using storage for ancillary services, such as frequency and voltage regulation, and operating reserves. Currently, grid operators often rely on peaking natural gas plants or part-load plants to provide these services. These plants have fast ramp rates but are inefficient and as a result are more expensive than conventional baseload plants.[104]

Energy storage can also have a substantial indirect impact on carbon emissions by facilitating the integration of renewable energy sources such as wind and solar PV. In the long term, energy storage allows for high penetration of renewables (i.e. 80% or more), which is infeasible with today's electric grid. It can accomplish this by smoothing the intermittency of renewable sources over both short and long time scales. Storage can smooth output and avoid voltage spikes over short time intervals, such as when a cloud temporarily reduces output from a solar array. It can also shift intermittent generation profiles to better match demand; for example, wind energy generation that is strongest at night could be stored for use during higher demand periods during the day. In this respect, energy storage is likely to function as a critical element in a suite of technological solutions, including smarter grid infrastructure and integrated demand-side management.[105]

Government decisions will have a critical role in determining the future of energy storage, particularly because storage does not fit neatly into the traditional utility business model. Policies should be designed to ensure that renewable energy and storage systems receive proper value for the benefits they provide while also paying their fair share of fixed grid infrastructure costs. At the grid scale, governments can play a major role in accelerating the deployment of energy storage by allowing storage to participate in well-designed electricity markets. Since 2011, the US Federal Energy Regulatory Commission has taken major steps towards this goal, through two orders that enable energy storage technologies to compete in the frequency regulation and ancillary services markets.[106] At the same time, government support for research, development and deployment can facilitate technological advances and cost reductions. The UK's Department for Energy and Climate Change recently conducted competitions to award demonstration funding to new storage technologies.[107] As there are many technologies in the energy storage space, government

Box 7:
Tesla Motors: Innovative business models to advance low-carbon technologies

Tesla launched its stock in June 2010 on the NASDAQ Stock Market and saw its price increase by 40% in the first day of trading, valuing the company at US$2 billion and raising over US$226 million. It wams the first initial public offering by an American automaker since Ford's debut in 1956. By 2013, Tesla's market capitalisation had grown to US$26 billion, even though the company was selling only 25,000 cars per year. For comparison, in the same year General Motors sold 9.7 million cars, with a market cap of US$54 billion. Clearly Tesla has managed to capture people's imagination about the future of the automobile – and raised substantial capital in the process.

The Tesla Motors story – from the outsourced manufacturing of the Roadster, the first fully electric sports car, to in-house production of the Model S, a fully electric luxury sedan – is a success story about open innovation. The idea of open (vs. closed) innovation is based on three fundamental observations: good ideas are difficult to protect and hence are quickly shared; innovation increasingly happens through partnerships and networks of firms and public institutes, rather than within an individual company; and it is very hard to hire and retain highly skilled workers.

Key partnerships across the car value chain were instrumental to Tesla's success. This includes supplier alliances, R&D alliances and Original Equipment Manufacturer (OEM) alliances with other automobile manufacturers. Lotus Cars and Panasonic were partners on supplies, crucially including batteries, while Toyota and Daimler were partners on other components of the cars. A partnership with Sotira (France) was crucial in the development of the carbon fibre body. Many of these alliances were based on equity, creating joint incentives for partners. These partnerships also allowed Tesla to leverage a broad accumulation of technology advances that had themselves benefited from government support. Recently, in line with its open innovation approach, Tesla released all its electric vehicle patents to the public, arguing that all car companies would "benefit from a common, rapidly-evolving technology platform."[108]

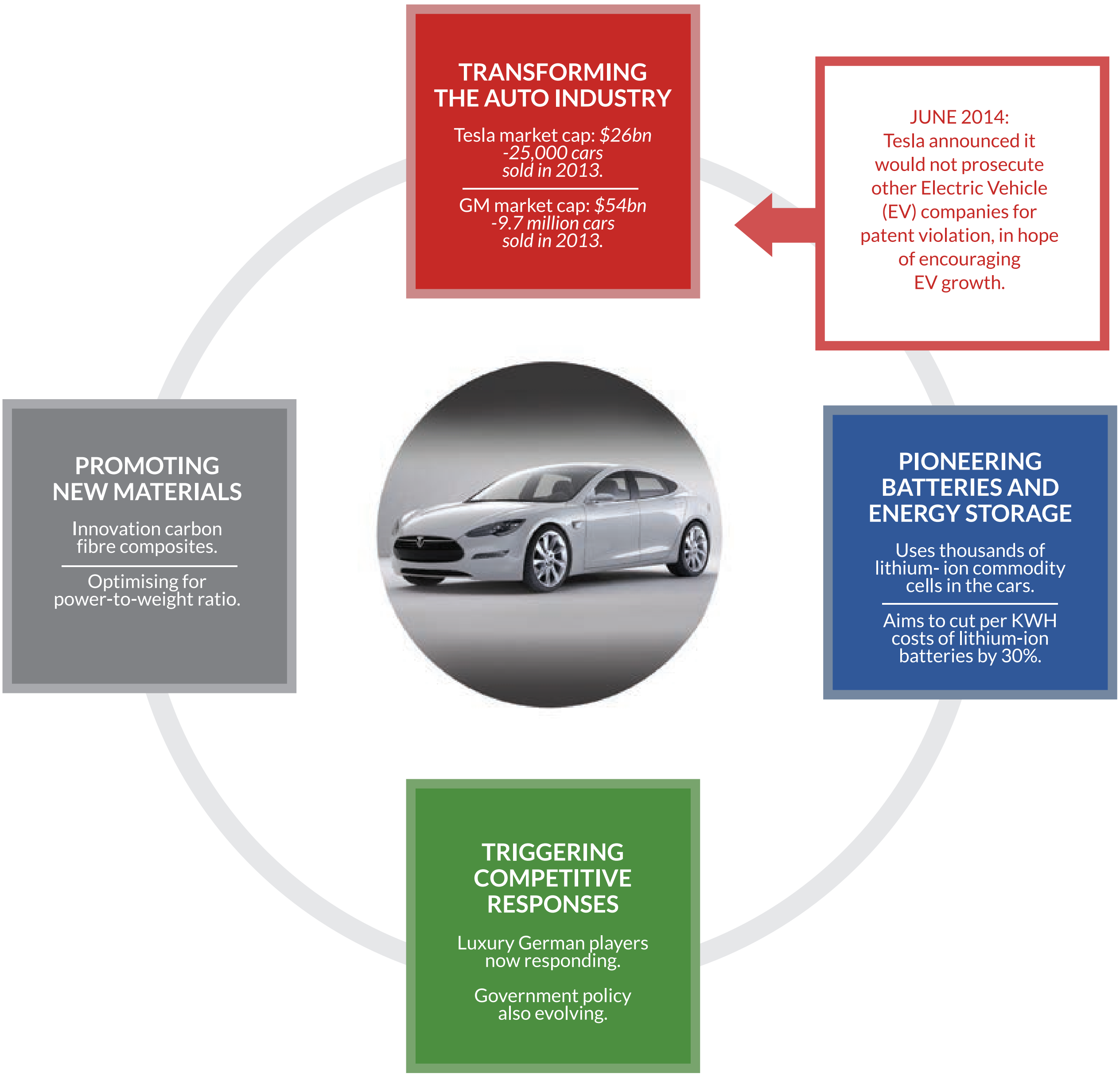
policy should always be applied in a way that promotes competition between them.

Tesla managed to apply substantial innovation through the value chain, even in a mature and saturated market. It picked a very specific niche, foreseeing potential growth, and was able to effectively fix initial quality glitches. Through its open innovation partnerships, it benefited from substantial existing automobile and battery supply-chain experience, and developed internal expertise on the electric drive-train. Thus, while "cooking with the same ingredients" as other manufacturers, it managed to create a substantially innovative product. Tesla also leveraged public support for market demand (by selling US$130 million in zero-emission vehicle credits in 2013) and secured public lending to set up production facilities (a $465 million loan from the US Department of Energy in 2010, which it paid off nine years early in 2013).

Finally, the company's business model is to sell the car through factory-owned direct points of sale – similar to Apple's stores – and it is working to remove market barriers by fighting regulations that would require franchised dealership to sell the cars. The latter is an important aspect of Tesla's success, showing the importance of business model innovation, and the potential barriers to such innovation posed by incumbent models and government regulations

Figure 8:
Tesla's innovative business model

TESLA MOTORS IS CHALLENGING THE STATUS QUO IN MANY INDUSTRIES AND CREATING HUGE WEALTH IN THE PROCESS



Sources: Tesla motors website, scdigest.com, autonews.com.

that support such incumbency.

4.2 Carbon capture, use and storage

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report indicates that technologies to remove carbon dioxide from the atmosphere will likely be crucial to keep global warming under 2°C.[109] While the IPCC sees potential for extensive use of carbon capture and storage (CCS), on its own and combined with bioenergy, there could also be other, more profitable applications of carbon capture technologies at various scales in the future, should they receive the right support over the coming years.

Carbon capture technologies have substantial room for improvement. For example, capture technologies for fossil-based power plants carry a heavy economic penalty by reducing their efficiency. A certain efficiency penalty is unavoidable, but there is wide scope for reducing it. Additionally, new research by a number of companies and universities suggests that carbon dioxide or methane can be economically captured from other, less concentrated sources, such as landfills, water treatment sites or even from the air, although the cost of this option is still very high.[110] At the same time, very long-term and secure carbon storage has yet to be proven, and further R&D and demonstration of storage methods remains critical, including in the areas of measuring, monitoring and verification, and mitigation and remediation of leakage.[111] Finally, the government has a critical role in creating a sound regulatory regime that ensures protection against potential storage-related accidents, and as a result, facilitates deployment by mitigating public opposition and reduces the risks for investors.

As discussed in Chapter 4: Energy, however, the biggest challenge for CCS is that capturing and storing CO_2 is not inherently profitable (except in the context of a carbon price). Thus, any way to profitably use the captured CO_2 would make CCS more economically viable. Some existing operations already use captured CO_2 for enhanced oil recovery profitably. While other technologies are still early-stage and typically high-risk, there are some emerging possibilities: a number of companies and research institutes are demonstrating that CO_2 can be converted to carbon-negative plastics, carbonates and other minerals.[112] Methods to make biofuels by feeding concentrated CO_2 to algae are also being developed.[113]

Apart from enhanced oil recovery (EOR), no application has yet been able to simultaneously capture CO_2 at a significant scale, avoid re-emitting the CO_2 or using additional fossil energy, and significantly reduce the net cost of CCS, but further research may change this. Research in CO_2 use is now being funded by the EU's main climate innovation initiative, Climate-KIC, which has identified it as a priority research area.[114] All applications, including EOR, face the challenge that the mass of CO_2 that must be captured to significantly reduce climate risk exceeds the conceivable demand for most products made from it. Even so, commercial CO_2 use can greatly improve the economics of CCS demonstration projects and initial large-scale deployment.

For CO_2 use to become widespread, incentives and funding must be put in place. Governments wishing to explore this technology could fund R&D, support demonstration projects, and design policy programmes, such as carbon markets and subsidies, to allow for CO_2 use solutions. Such policy tools could ease the transition to commercialisation. A carbon price or feed-in-tariff equivalent of US$50 per tonne of carbon dioxide would greatly accelerate the deployment of these technologies.[115]

4.3 Advanced bioenergy

Breakthroughs in materials science are leading to new types of bioenergy that could conceivably replace a large proportion of fuels. The widespread use and/or displacement of food crops for biofuels in some countries, driven by poorly designed policies, has led many to oppose bioenergy as a threat to food security. However, there are many ways to scale-up bioenergy production without decreasing food security.

Second-generation biofuels convert biomass to fuel, using dedicated energy crops such as miscanthus (a species of fast-growing perennial grasses), food waste or by-products of agricultural production, such as corn stover or sugarcane bagasse. In 2013–14 there has been significant progress in commercialisation of second-generation technologies, as several players have built out commercial-scale plants. One projection forecasts second-generation ethanol capacity in the US to rise from 12 million gallons per year in 2013 to 140 million gallons in 2016.[116] Other forecasts are more cautious, given difficulties in creating the new supply chains in feedstock and getting the conversion process to scale efficiently.

Third-generation biofuels are typically made from microalgae, grown with waste carbon dioxide, generating minimal pressure on land and water resources. They are ideal for regions with substantial sunshine, non-arable land, and sources of carbon dioxide. While third-generation biofuels have not yet been deployed at commercial scale (and there are considerable scaling challenges), many pilot projects are operating successfully and attracting significant interest from biotech, genomics and software engineering communities. Development of third-generation biofuels will require further R&D, as well as incentives for investors to build the first commercial scale plants.

Fast-growing trees and grasses can also be developed as a feedstock for bioenergy. While these clearly should not displace crops or forests, there is potential for fast-growing biomass to be developed on non-arable land and in harsh environments. Trees and grasses could be bred either for efficient carbon sequestration purposes or potentially as a source of biomass for energy, potentially as feedstock for power generation.

Advanced bioenergy, of different types, is an accessible opportunity for most countries, including regions with deserts or degraded land and a lot of sunlight. It could generate many economic benefits, including improved energy security, as fuels are produced domestically rather than imported. Waste, in the form of food waste or carbon pollution, can be converted into a profitable product. Urban pollution can be reduced, as combustion emissions from fuels or power plants could be reduced, as bioenergy burns cleaner. In some sectors, such as chemicals, biomass offers perhaps the only way to reach zero net emissions. It also creates an option to reduce atmospheric concentrations of carbon, if coupled with CCS solutions. As noted above, the IPCC's Fifth Assessment Report envisions widespread use of bioenergy combined with CCS to help keep global warming under 2°C.[117]

Advanced bioenergy can also work in tandem with other game-changers. It can be an output of CO_2 use, as algae-based bioenergy systems take carbon as an input. It can also be a means to store energy, as bioenergy can be stockpiled in the same way as fossil fuels.

As with CCS, government has a role not only in providing R&D and demand incentives, but also in ensuring a sound regulatory environment that addresses public concerns related to, the impact on food security, the threat to natural forests and biodiversity, and the safety of genetically modified crops, among others.

5. Recommendations

In order to accelerate the pace of change to create a new climate economy, the Commission recommends that governments:

- Create market pull for new technologies: To meet climate and economic growth objectives in the necessary time frame, every economy must put policy measures in place that help spur demand for clean technologies.
- Carbon pricing is the first critical instrument in using the power of markets to create such demand, and in the context of innovation it has two key advantages: it is technology-neutral (letting the market decide), and it sets credible long-term expectations.
- Alongside a carbon price, the Commission recommends that by 2015–2020 (depending on income level) all countries adopt performance-based, technology-neutral codes and standards that are continually ratcheted up over time. This is especially important in sectors where economic benefits are ample and price signals less likely to be effective (such as energy efficiency in buildings, appliances and vehicles).
- Finally, the Commission recommends that all countries and international institutions assess their public procurement processes and insert guidelines so that minimising energy use and carbon emissions become procurement criteria for all publicly procured goods and services by 2015-2020 (depending on income level). Public procurement has proven to be a large and credible market for technology developers, accelerating innovation, and supporting user-based refinements.
- Governments of major economies should at least triple their public energy-related R&D by the mid-2020s, to take it well over US$100 billion a year (exceeding 0.1% of their GDP), and target it towards game-changing technologies.

R&D annual spending for new energy-related technologies in the major economies should be at least tripled by the mid-2020s to take it to its late-1970s levels, over 0.1% of their projected GDP in 2020, across public research, development and demonstration. In a rapidly changing sector in which more than US$6 trillion changes hands every year,[118] it is essential to invest at least US$100 billion per year to pioneer improved technologies.

This would include a phase-out of support from more mature, "dirty" technologies, which neither offer large economic spillovers, nor suffer from market failures that inhibit demand. Other countries should also increase their support for climate-related innovation, with a focus appropriate to their local context.

The energy sector is undergoing a transformation that has the potential to dramatically improve global human welfare. While solar and wind technologies are at, or approaching, cost-competitiveness, a number of others could get to that stage with additional, early-stage support. Coordinated programmes and roadmaps for game-changing technologies such as, among others, energy storage, carbon capture, use and storage, and advanced bioenergy will be of great importance. For more mature technologies, such as wind and solar, more R&D could be focused on driving continued technical improvements based on technology-neutral cost and performance targets.

- Encourage new business models by removing poor regulations and other barriers to entry.

The Commission recommends that countries work with the private sector to identify and remove regulatory and other barriers to the adoption of new business models and technologies. Of particular relevance are regulations that inhibit the shared use of capital-intensive goods, such as cars, and regulations that deter entry into highly networked systems, such as the power distribution markets. Other examples include overly prescriptive input standards in building regulations, various electricity network standards favouring incumbent supply technologies, and the regulatory and tax treatment of reuse, remanufacturing and asset sharing. In addition, this should include separate, more favourable tax treatment for high-risk investment, where lack of access to financing is recognised as a major barrier to the development and scale-up of new technologies.

- **Establish a robust system of intellectual property protection and sharing, while supporting poorer countries in accessing, adapting and adopting low-carbon technologies.**

Developed and developing countries should recognise the need for clear and simple intellectual property rights to incentivise public and private investment in low-carbon innovation, but also acknowledge the need for mechanisms that expand access to these innovations. Governments and companies should promote the creation of patent pools for low-carbon technologies, and seek additional mechanisms for IP sharing. Financial and technical support to access these pools, and to drive innovation appropriate to the needs of lower-income economies, should be provided to poorer countries by bilateral and multilateral institutions such as the Green Climate Fund and the Global Environmental Facility.

Such support should focus not only on direct technology transfer, but also on building the broader innovation capacity and local institutions required to adapt, adopt and further develop such technologies. "Nationally Appropriate Innovation Actions" could also be used to encourage and recognise countries that develop and share key low-carbon technologies in the context of an international agreement.

- **Use realistic assumptions on cost trajectories for new technologies when making economic policy and public service and infrastructure investment decisions.**

Getting policy right will require understanding how the process of learning about new technologies will reduce their cost. Few ministries of finance around the world do this well because it is difficult to predict future technological change. But the default assumption that technology costs will remain constant is clearly incorrect. As we saw in the chapter, industries at early stages of development are typically on steep learning curves, yielding dramatic cost reductions. This has been seen across industries, from semiconductors to genetic mapping to smartphones. At a 10% performance improvement per year, a shift from two years' backward-looking to two years' forward-looking cost comparisons can reprioritise investment decisions. By systematically modelling and incorporating learning curves for new technologies, ministries of finance across the world can better decide how to allocate scarce resources.

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Chapter 8

INTERNATIONAL COOPERATION

Main points

- International trade and supply-chain integration have played a key role in driving down the costs of low-carbon technologies. International trade in environmental goods and services totals nearly US$1 trillion per year, or around 5% of all trade. Trade in low-carbon and energy-efficient technologies alone is expected to reach US$2.2 trillion in 2020, a tripling of current levels.
- A new international legal agreement on climate change is essential to enable the large-scale transition to a low-carbon pathway needed to have a good chance of keeping global warming under 2°C. A strong agreement could act as a powerful macroeconomic policy instrument, sending clear signals to businesses and investors about the direction of the global economy. This should include a long-term goal to reduce greenhouse gas emissions to near-zero or below in the second half of the century.
- It is important that a new international agreement is equitable. This means developed countries will have to make deep long-term cuts in their emissions, and mobilise finance, capacity-building assistance and technology to support developing-country efforts. Larger developing countries will have to make serious commitments to reducing their emissions trajectories.
- Globally, financial flows to low-carbon and climate-resilient investment totalled around US$359 billion in 2012, much of it to renewable energy projects. Only about a quarter (US$84 billion) of these flows were international, of which an estimated US$39–62 billion (46–73%) were directed at developing countries, mostly from public sources in developed countries.
- Around a third of climate financing comes from development finance institutions, including multilateral development banks, national development banks, and bilateral and regional financial institutions. These have considerable potential to scale up low-carbon and climate-resilient financing, both directly and by leveraging private capital.
- Some 14% of World Trade Organization trade disputes concern renewable energy technologies, as competition has increased for market share. Faster dispute resolution processes are needed, and the environmental elements of international trade agreements should be strengthened.
- There is potentially significant scope for business-led initiatives to reduce emissions in some internationally traded sectors dominated by relatively small numbers of firms, such as commodities deriving from forest areas.
- The rules and norms of the international economic system need to be aligned more closely with the transition to a low-carbon, climate-resilient global economy. Corporate reporting on climate risk and mitigation strategies should now be integrated with financial reports and standardised. Investors with around half of total institutional assets (US$45 billion) under management now subscribe to responsible investing principles, and climate risk management now needs to become part of investors' fiduciary duty.
- Economic growth and climate risk are intertwined; the institutions and forums charged with fostering economic cooperation – such as the World Bank, the International Monetary Fund, the Organisation for Economic Co-operation and Development, and the G20 – should reflect climate risk assessment and reduction in their national economic surveillance processes and assessments.

1. Introduction

Globalisation has been a major driver of both high- and low-carbon growth over the last 25 years. World trade more than tripled in that period, reaching US$18 trillion in 2012.[1] This has provided an important boost to developing and emerging economies as well as developed ones, but, as discussed in Chapter 1: Strategic Context, it has also led to a significant shift in production to countries with weaker pollution controls and predominantly coal-based energy systems. Thus, the trade boom has likely increased global greenhouse gas (GHG) emissions.[2]

Yet trade has also played a major role in accelerating the diffusion of low-carbon technologies such as solar and wind power, and light-emitting diodes (LEDs). The ability to produce components in low-cost countries, combined with expanding global markets, has led to a dramatic reduction in the cost of those technologies, enabling broader deployment.

The low-carbon economy is now a global phenomenon. International trade in environmental goods and services totals nearly US$1 trillion per year, or around 5% of all trade.[3] Trade in low-carbon and energy-efficient technologies alone is expected to reach US$2.2 trillion in 2020, a tripling of current levels.[4] Two-fifths of that market are expected to be in emerging and developing economies,[5] and the companies supplying these markets come from all over the world.

Most of this new activity has been driven by national and sub-national policies. This new global economy has largely been driven by national policy-making, as individual countries have introduced incentives for low-carbon energy supply and energy efficiency and other climate-related policies. Outside the European Union, whose single market policies cover 27 countries together, there has been little attempt to harmonise national policies. In some cases, such as vehicle fuel efficiency standards, independent policy-making has led to a convergence of policy between countries; in others, such as carbon pricing, coordination has proved more elusive.[6]

But there is considerable potential for international cooperation to expand and enhance it. This chapter focuses on five areas in particular:

- A new international legal agreement to provide a foundation of multilateral rules and principles to underpin national climate action.
- International climate finance, including both public- and private-sector investments in mitigation and adaptation.
- Trade agreements to lower tariffs on environmental goods and services, enable faster resolution of trade disputes, and raise standards for low-carbon goods.
- Voluntary collaborations among businesses, governments and other actors in the global economy to help catalyse action in specific sectors and fields.
- Changes to the international rules and norms which influence the economic behaviour of businesses, financial institutions and governments.

This review is by no means comprehensive; it focuses on areas where international cooperation has the potential to make a significant impact on the prospects for low-carbon and climate-resilient growth. It cross-refers to other chapters of this report which also discuss cooperative actions of various kinds, particularly Chapter 3: Land Use, Chapter 5: Economics of Change, Chapter 6: Finance, and Chapter 7: Innovation.

2. A new international climate agreement

Most of the recommendations presented in this report can be implemented by individual countries – or by the cities, states, regions and businesses within them. Much of what needs to be done to achieve better growth and a better climate is in these actors' economic self-interest even if comparable action is not occurring elsewhere.

Still, an international agreement on climate change is vital, for several reasons.

First, the more action is taken globally, the easier it is to win political support for action at home. Climate change mitigation requires collective action; greenhouse gas molecules have the same effect wherever their origin, and no single country (or small group of countries) can slow the processes of warming alone. Thus, it is easy to resist climate action by asking, "What difference can our contribution make if other countries are not acting?" The greater the collective effort, the easier it is for political and business decision-makers to justify the effort and costs required for actions at home. (This is discussed further in Chapter 5: Economics of Change.)

Second, the wider the international field of low-carbon policies, the less likely they are to affect business competitiveness. When firms face different climate policies in different jurisdictions, there is always a risk that those facing more stringent regulations or higher carbon prices might lose market share, or even seek to move to areas with weaker policies.

Third, an international agreement is needed to strengthen the climate finance flows, technology transfer and capacity-building that developing countries need to implement low-carbon strategies and adapt to climate change. Even where measures are economically beneficial, they are often not affordable, particularly when their upfront costs exceed those of equivalent but higher-carbon investments.

Fourth, as the report has argued, actions and policies with net economic benefits are unlikely to be sufficient to keep the average global temperature increase under 2°C. Other measures will be required whose sole or primary purpose is to combat climate change, such as deployment of carbon capture and storage (CCS) or early retirement of coal power plants. These will be much more feasible in the context of a global agreement to tackle climate change.

A new legal agreement is thus essential to drive the investment and innovation in low-carbon, climate-resilient growth at a sufficient scale to reduce the risk of dangerous climate change. Such an agreement is currently being negotiated under the United Nations Framework Convention on Climate Change (UNFCCC), as a successor, or supplement, to the Kyoto Protocol signed in 1997.[7] That agreement had been the subject of considerable controversy. The United States refused to ratify it because it did not require binding emission reduction commitments from major developing economies. The US withdrawal, in turn, discouraged stronger action by those countries. The emission reduction targets for the first Kyoto commitment period, which amounted to just a 5.2% reduction by 2012 from 1990 levels, were also clearly inadequate to the growing scale of the climate problem.[8] The commitments have also proven difficult to enforce, as became evident when Canada, which was not on track to meet its target, withdrew in late 2011 and thus avoided any penalties.[9]

Negotiations to achieve a new international agreement have not been easy. Hopes that a new legally binding agreement might be secured at the UN Climate Change Conference in Copenhagen in 2009 were not fulfilled. The conference ended with only partial agreement, and amid considerable acrimony.[10] The following year, in Cancun, Mexico, a UN agreement was reached, under which countries made pledges to reduce their emissions trajectories and to provide financial support to developing countries, but it was not legally binding.[11]

This experience has led some commentators, businesses and others to question whether a global legal agreement is either possible or necessary. Some have argued that, since the vast majority of global emissions come from a relatively small group of countries, it might be better to shift international efforts away from the often tortuous negotiations of the UN, where all countries have to agree, to smaller forums of the major emitting countries, such as the G20.[12]

But this analysis underestimates both the importance of a global agreement and the viability of the UNFCCC negotiations. Even if only a few countries are major GHG emitters, the impacts of climate change affect all – particularly some of the smallest and least developed countries, including small island states whose very survival is threatened by sea-level rise.[13] An agreement reached without these countries at the table would be neither fair nor legitimate. At the 2011 UN Climate Change Conference in Durban, South Africa, countries laid the groundwork for negotiating a new legal agreement to come into effect in 2020.[14] The agreement is expected to be finalised and approved at the UN Climate Change Conference in Paris in December 2015.

An international agreement cannot force countries to tackle climate change. They will act of their own volition, through domestic political and policy processes. This is recognised in the ongoing negotiations, which have agreed that each country should submit its "intended nationally determined contributions".[15] What an agreement can provide is the global framework that facilitates stronger action by all countries simultaneously. Only strong and simultaneous action will make it possible to keep global warming under 2°C.

Countries need to feel confident that all are doing their fair share, so it is important that the new agreement be equitable. Climate change embodies a form of injustice: it has been overwhelmingly caused by the historical emissions of the now developed countries,[16] but its impacts will hit some of the poorest, lowest-emitting countries the hardest. A majority of the accumulated greenhouse gases in the atmosphere today were emitted by the developed economies. Yet developing countries' emissions now exceed those of high-income countries, driven primarily by fast-growing upper-middle-income economies, and their share is increasing.[17] Slowing emissions in developing countries is thus essential to avoiding dangerous climate change. The question is how to do this fairly, as these countries still have significant populations living in poverty, and they rightfully wish to continue developing their economies. Most also have much lower per capita emissions than developed countries.[18]

For these reasons the perceived fairness of an international agreement matters. In practice, what this means is that, while both developing and developed countries will have to take serious action, developed countries will have to make earlier and deeper absolute cuts to their own emissions, on a path to near-complete decarbonisation of their economies by mid-century. They will need to provide strong examples of how good policy can drive economic growth and climate risk reduction together; develop and disseminate new technologies; share know-how, including through collaborative ventures; strengthen funding sources and financial institutions to bring down the cost of capital; and provide climate finance to developing countries for adaptation, mitigation and capacity-building.

By providing a core framework of multilateral rules, an international legal agreement on climate change would represent a strong form of global governance. But an even more important goal is economic. The ultimate purpose of an international agreement should be to drive investment into low-carbon and climate-resilient growth and development.

One of the key observations of this report, as argued in particular in Chapter 5: Economics of Change, is the importance of expectations in determining the level and direction of investment and consumption. Uncertainty weakens both. Yet it is uncertainty which currently characterises low-carbon policy in many countries. Businesses and investors frequently have little confidence that government targets will be met or policies sustained. Weak and inconsistent policies send mixed signals about governments' own commitments, creating "policy risk" which raises the cost of capital. The result is lower investment overall, and the now-familiar strategy of investors hedging their bets between high- and low-carbon assets.

An international agreement cannot in itself give confidence in the policies of specific countries – that comes from the credibility of domestic action. But it could send a powerful overall signal on the future direction of the global economy. A strong agreement in which all countries commit to a low-carbon future could significantly change business and investor expectations about the relative returns on low- and high-carbon investments. It would indicate to the suppliers of low-carbon goods and services that their markets are going to grow, not just in individual countries, but throughout the world. The stronger the agreement's legal form, and the longer-term its commitments, the greater the confidence generated that low-carbon policies are likely to endure, and not be reversed.

For these reasons a strong international agreement has the potential to act as a powerful macroeconomic policy instrument, sending clear signals to businesses and investors about the future low-carbon direction of the global economy.

The 2015 agreement looks likely to combine a set of common rules and norms, internationally agreed, with "intended nationally determined contributions" submitted by each participating country. These contributions will be decided through domestic political and economic policy-making processes, which has the important advantage of grounding the agreement in national realities. But it also carries the evident risk that the contributions will not add up to a collective effort sufficient to put the world on track to meet the agreed 2°C goal. There has therefore been discussion of potential processes to compare intended contributions with one another and against the 2°C goal, to encourage further effort.[19]

What are not likely are negotiations which seek to divide up a global GHG budget among the different countries. But if it is recognised, as this report shows, that prosperity and a low-carbon future can go together, climate negotiations should not be a competition for the right to emit as much as possible. Some countries, especially those with ample fossil fuel resources, will unquestionably find it challenging to make the low-carbon transition. But the incentives should not be to maximise each country's "carbon allowance". Instead, the aim of the new agreement should be to help all countries seize the opportunity to improve their growth prospects and living standards while reducing their dependence on emissions-generating activities.

It is not the Commission's place to recommend the detailed components of a new agreement. From an economic standpoint, however, there are several features which would greatly enhance its ability to send a clear signal to businesses, investors and governments on the future low-carbon character of the global economy.

First, it is important that the agreement establish a clear long-term direction. A good way to do this is to include a long-term goal. Countries have agreed to the goal of keeping global warming below 2°C, but while this is valuable, it is unclear what it means for actual emissions. One idea which has gained some attention recently is that the long-term goal should be to phase out net greenhouse gas emissions altogether.[20] ("Net" emissions allows for the fact that increasing the stock of forests and other natural "sinks" and using effective carbon capture technologies could compensate for some level of emissions, and even potentially generate "negative emissions".)

The Intergovernmental Panel on Climate Change (IPCC) shows that for a two-thirds or better chance of holding warming to 2°C, GHG emissions will need to fall to near-zero or below in the second half of the century.[21] A world of no net emissions (sometimes described as "carbon neutrality") sounds radical today, but within 40–50 years, technological innovation is very likely to make it achievable – even likelier if governments adopt the goal and incentivise its achievement.[22] One only needs to compare today's technologies with those of the 1960s and 70s to appreciate this. Adoption of a long-term goal of this kind within an international agreement would send a powerful economic signal about the direction of the future global economy.

Second, the agreement should aim to establish a **predictable and synchronised process of national policy-making**. Under a five-year cycle of international negotiations, for example, countries would set targets for 5–10 years ahead (in 2015 this would be for 2020–2025), with an indicative, revisable target for a further five years. A specific requirement that emissions targets must be progressively tightened would be particularly helpful. The degree of tightening would need to be determined by each country on its five-year cycle, but the principle would ensure clarity of direction. A combination of firm five-year commitments, plus indicative 10-year targets aiming for the long-term goal, would provide appropriate time frames for action and planning across sectors and governments.

For major economies, the agreement might go further, obliging or encouraging governments to publish long-term economic development and growth strategies outlining how they plan to move in a long-term low-carbon and climate-resilient direction. Such strategies – and the underlying political and policy-making processes – would greatly help businesses, investors and the wider public to understand and debate the possibilities, benefits and costs of the low-carbon transition. Guidance for such strategies could include encouragement of carbon pricing (including the removal of fossil fuel subsidies), along with strategies to shift towards low-carbon energy and low-carbon policies in transport, urban development, agriculture, forests and other sectors.

Third, an agreement should strengthen countries' **incentives and capacities to adapt to climate change** and to reduce their vulnerability. In particular, it could encourage all parties to develop and implement national adaptation plans. These should incorporate action by sub-national governments and municipalities, and set out the requirements on businesses and others to understand and take action to address climate risks. It should incentivise regional collaboration to support adaptation planning, given shared exposure to some climate risks and the benefits of pooling resources for climate change research and information systems. Adaptation plans will benefit from including a diverse set of government agencies, alongside business, academia and civil society, and can provide a vehicle for international financial and technological support.

Fourth, it is important that an agreement establishes **common accounting and reporting rules** on the commitments countries make, and their progress towards achieving them. International confidence in the agreement, and in the national actions which follow it, will be undermined if there is doubt about whether claimed emissions reductions are accurate or credible. Transparency and clear verification processes are therefore vital.

Last, a new international agreement should provide a **framework for increased financial flows** into low-carbon and climate-resilient investment and development. This should include the obligations of the richest countries to provide support to developing countries, and mechanisms designed to facilitate increased flows of private-sector finance. It should also include provisions to enhance the development and dissemination of low-carbon technologies, and those which can improve climate resilience. These are discussed further in the following section.

An international agreement will contain many other provisions; this is by no means a comprehensive description. But an agreement which included these elements would provide a major boost to international economic confidence.

3. Increasing climate finance

In 2012, global investment to support GHG emission reductions, low-carbon development, and climate change adaptation was about US$359 billion.[23] Three-quarters of these financial flows involved renewable energy projects (particularly solar and wind power), with most of the remainder directed at energy efficiency, transport, agriculture and adaptation activities. Just under half of total investments (US$177 billion) occurred in developed countries (members of the Organisation for Economic Co-operation and Development), particularly in the EU and US; just over half (US$182 billion) were in developing countries (non-OECD), particularly in China. Total investment in 2011–12 was around the same as in 2010–11.

Around a quarter (US$84 billion) of these financial flows in 2012 were international; the rest were in the investor's own country. An estimated US$39–62 billion (46–73%) of international climate finance flows went to non-OECD countries from sources in OECD countries. Most of this "North–South" financing (US$35–49 billion, or 80–90%) came from public sources. These included official development assistance (ODA) provided directly by governments, and funding through multilateral development banks, UN agencies, bilateral finance institutions and national development banks.[24]

Development finance institutions (DFIs) play an increasingly important role in climate finance. These include not only the multilateral development banks (the World Bank and regional development banks), but a range of national development banks, and bilateral and regional financial institutions. Altogether, they committed around a third (US$121 billion) of all domestic and international climate finance in 2012.[25] The ability of DFIs to raise funds of their own on the capital markets gives them additional resources beyond their public capital base. They are able to blend low-cost project debt with market-rate loans (and occasionally also equity and grants), and co-finance projects with the private sector. This makes them particularly suited to investments that may involve some additional risk or unfamiliarity to private investors.

Most national development banks are focused on domestic lending, but increasingly the larger ones, such as the Brazilian Development Bank (BNDES) and the China Development Bank (both considerably bigger than the World Bank), are also financing projects outside their home countries. At the same time, new multilateral banks are being established, such as the Asian Infrastructure

Investment Bank (AIIB) and the New Development Bank set up by the so-called BRICS countries (Brazil, Russia, India, China and South Africa).[26]

The growth of development institution financing presents considerable opportunities to increase global investment in low-carbon and climate-resilient infrastructure and related projects. Over recent years the "traditional" multilateral development banks have all considerably increased their commitment to climate finance, even adopting quantitative targets for their lending portfolios. Some, including the World Bank, the European Bank for Reconstruction and Development, and the European Investment Bank, have also pledged to limit or cease funding for most coal-fired power generation projects.[27] But there are now many more players in this field. If commitments of these kinds were adopted across the wider group of development finance institutions, a considerable increase in global funding could be mobilised.

A major target for this must be financing for developing countries. At the Copenhagen conference in 2009, developed countries made two climate finance pledges: to provide US$30 billion in "Fast-start Finance" in 2010–2012,[28] and to mobilise US$100 billion per year in public and private finance by 2020. In 2013 they reported that the first goal had been achieved, with US$35 billion in public climate finance having been provided in 2010–12.[29] Some concerns have been raised over how much of this was "new and additional" funding, as agreed in Copenhagen: most of it came under ODA, and therefore from sums which many developing countries felt they were due to receive anyway.[30] But in terms of climate-specific funding, it represented a significant increase on prior levels.[31] The issue now under discussion therefore is how developed countries will meet the second pledge. There is still no consensus on what precisely it means to "mobilise" US$100 billion, how much should come from public sources, and how different forms of finance should be counted.[32]

Given that private-sector investment accounts for over 60% of current global climate finance (in 2011–12, around US$224 billion), but under 20% of North–South flows,[33] it is widely accepted that a key priority should be to encourage greater private-sector investment in low-income countries. As discussed in Chapter 6: Finance, the problem in general is not lack of global capital; rather it is a lack of low-carbon and climate-resilient development projects which can provide the required risk-adjusted returns to investors. In many countries this is partly due to a shortage of viable projects in the pipeline, partly due to lack of investor confidence in regulatory frameworks and policies, and other related risks.[34] For national governments, and the multilateral development banks and international agencies working with them, improving investment conditions while maintaining national determination of policy is therefore often the priority.

A number of countries are now establishing national financing strategies of various kinds to coordinate their low-carbon and climate-resilient development financing needs.[35]

At the same time, there have been several efforts in recent years to use public finance and policy instruments to mitigate the risks faced by private investors, in order to leverage greater private flows. Such instruments include partial risk, "first loss" and export credit guarantees, policy risk insurance and various kinds of pooled funds.[36] The World Bank Group and other multilateral banks have pioneered these, but only a few types of instruments have yet been used to any great extent, and institutional investors in particular have not yet been attracted at scale into the low-carbon and climate-resilient project field.[37] Developing instruments and funds which can attract larger flows from these sources needs to be a priority.

The more traditional forms of direct grant funding and concessional lending also remain vital. This is particularly true for adaptation projects in low-income countries, where commercial returns from investments (making them suitable for lending) may not be available. Adaptation expenditure, in areas such as water, land use and resource management, coastal and infrastructure protection, and disaster risk management, accounted for a little under half of all direct government climate finance to developing countries in 2012.[38] As this report has argued, the distinction between adaptation and wider development expenditure is increasingly difficult to define, and many investments can meet both low-carbon and resilient development objectives. Nevertheless, it is clear that current funding levels represent only a fraction of total adaptation investment requirements.

There is also considerable scope for direct public finance of low-carbon development projects and other mitigation activities. Increasing attention is being paid to various options for "performance-related" funding, in which finance is tied to specific emissions reduction outcomes. As discussed in Chapter 3: Land Use, the Commission recommends that funding to prevent tropical deforestation and forest degradation is increased to at least US$5 billion per year from 2015 to 2030, increasingly linked to performance. In some countries, the additional or incremental costs of renewable energy policies such as feed-in tariffs are also now being supported by international climate finance.[39] There are considerable opportunities to develop and expand such schemes further.

Public financial flows are also needed for capacity-building, technological cooperation (see Box 1) and various kind of policy support for developing countries pursuing low-carbon and climate-resilient development strategies. Public finance is likely to flow through a range of bilateral and multilateral channels, but significant capitalisation of

Box 1:
Accelerating the diffusion of low-carbon and climate-resilient technologies

Access to new technologies is an important requirement for developing countries seeking to pursue low-carbon and climate-resilient development. A Chatham House analysis suggests that recent diffusion rates of relevant technologies need to be at least doubled if the 2°C goal is to remain within reach.[46] As discussed in Chapter 7: Innovation, several mechanisms are being pioneered that could enhance technology transfer by making climate-related patents available free or at low cost. These include voluntary patent pools, open source innovation and open licensing arrangements.

For example, an Eco-Patent Commons launched in 2008 by IBM, Nokia, Pitney Bowes, Sony and the World Business Council for Sustainable Development (WBCSD) has already collected 100 environment-related patents pledged by companies to be made available for free use by all.[47] In June 2014 Tesla Motors Inc. announced that it would open the company's patents for electric cars freely to others. CEO Elon Musk argued that this would speed the adoption of electric cars without damaging Tesla's competitive position, in which its main competitors are gas and diesel-fuelled vehicles.[48]

Experience in other areas, such as medicines for infectious diseases, shows that multilateral financing to cover licensing fees or to buy out patents on key technologies of public interest can be useful if they are well designed. One example in the climate field might be new crop varieties that are more resilient to climate change impacts, for which the intellectual property rights may constitute a significant part of the costs. But they may not be as relevant for clean energy technologies and their components, many of which are variations on what is already available in the market. In many cases developers have not applied for patent protection for these technologies in developing countries, as there is little commercial benefit from doing so; there are therefore often no patent-related restrictions on their use.[49] Less than 1% of the world's principal climate mitigation-related technologies have been registered as patents in Africa.[50]

More generally, there is strong evidence that a key factor in enabling greater clean energy technology transfer is having local capacity to successfully adopt the new technologies.[51] Strengthening technical and scientific capacities in developing countries is therefore a critical step toward enhanced technology transfer.

One option might be to establish a platform for public–private collaboration on innovation in access to distributed energy. Governments and others could collaborate to establish a network of regional institutions which would undertake publicly funded research and development in off-grid electricity, household thermal energy, and micro-grid applications. It could also support the incubation of new enterprises to apply the new technologies and develop new business models for distributed energy access.[52] Such a network could build on the strengths of the Consultative Group on International Agricultural Research (CGIAR) model for key agricultural applications, discussed further in Chapter 3: Land Use.[53]

the Green Climate Fund established under the auspices of the UNFCCC will be an important signal of confidence in a new international agreement.[40]

There is no doubt that increasing the flows of public finance from developed countries in the current economic conditions will be challenging. It is therefore important to identify new sources of public revenue which can expand the existing funding base. In 2010 the High-Level Advisory Group on Climate Change Financing (AGF) established by the UN Secretary-General identified a series of potential sources of new and additional public finance which could together meet the US$100 billion per year goal. These included revenues from carbon taxes and emissions trading schemes and from reductions on fossil fuel subsidies, new taxes on the emissions of the aviation and maritime sectors, and an increase in the capital base of the multilateral development banks.[41] A financial transactions tax was also discussed, but was regarded as too difficult to implement without a global agreement.

In addition, the AGF's report noted the potential for increasing revenues under the Clean Development Mechanism (CDM). Established under the Kyoto Protocol, the CDM allows buyers in developed countries to offset their emissions by purchasing emission reduction credits from projects in developing countries. Since 2004, the CDM has registered more than 7,000 projects in 89 countries and is estimated to have leveraged around US$315 billion in capital investment in mitigation and sustainable development projects.[42] But (as also with funds from auctioning emissions trading permits) the revenues from CDM depend on tight emissions reduction targets and a strong carbon price. The demand for offsets declined dramatically in 2013 as the European carbon price fell.[43] Still, there is continued interest in market-based approaches, and as part of ongoing UNFCCC negotiations, a new market-based mechanism is being discussed.[44]

None of these new funding sources will be easy to achieve. But there is a strong case to revisit them as part of the process by which developed countries identify a pathway to achieve the US$100 billion goal by 2020. This should also include a clear and agreed set of accounting methods for climate finance adopted by all donors and recipients.[45] It is important that these flows, and their additionality over existing funds, are transparent and verifiable.

4. Trade agreements

The international trade in low-carbon goods and services increasingly reflects the globalisation of supply chains, with companies optimising manufacturing costs by taking advantage of the comparative advantage of different locations for producing different inputs or services (see Box 2). This growing interdependence has stimulated a widespread move to reduce import tariffs on such products, in order to boost trade and lower costs. However, it has also led to some bitter disputes between major trading partners.

Although import tariffs on environmental goods are not especially high in many countries relative to those of other product groups, they can rise to 35% in some countries. As the global trade in such goods increases, there would be clear benefit to low-carbon growth if they could be reduced. In 2011 leaders of the Asia-Pacific Economic Cooperation (APEC) countries committed to cut tariffs on a list of more than 50 environmental goods, including wind turbines and solar panels, to 5% or less by 2015.[55] And in early 2014, 14 countries accounting for 86% of global trade in such goods (including the US, China, the EU, Japan and the Republic of Korea) announced plans to eliminate tariffs on them altogether through the World Trade Organization (WTO).[56] These are promising intentions.

Yet at the same time, many of the same countries have become embroiled in serious trade disputes over specific low-carbon products in which there is particularly fierce competition for market share. It is estimated that 14% of WTO disputes since 2010 have related to renewable energy, at least in part.[57] They are of two principal types.

First, separate disputes between the EU and China and the US and China over the price of Chinese solar panels (and in the US case wind power equipment as well) have centred on claims that Chinese manufacturers were effectively subsidising production and therefore “dumping” cheap goods onto export markets in contravention of WTO rules. These, it was claimed, were unfairly undercutting domestically produced products. The Chinese government vigorously denied the allegations. Both the EU and US reacted by imposed “anti-dumping” duties against these goods, leading China to place comparable duties on EU and US exports. Although the EU and China reached an agreement in 2013 (placing a minimum price and a maximum volume on Chinese solar panel imports to the EU), disagreement over compliance remains, and China has made a counter-claim against EU solar-grade polysilicon. The US and China remain in dispute.[58]

Box 2: Global value chains and clean energy trade: the case of solar power[54]

A striking example of the growing trade in low-carbon goods and services is the solar photovoltaic sector, for which the various components can be produced in multiple countries. The US and China traded more than US$6.5 billion worth of solar photovoltaic products and services in 2011. According to a study by the Pew Charitable Trusts, finished solar modules account for 95% of the solar products exported by China to the US, in addition to US$151 million of solar cells. These products reflect China’s relative strengths in mass assembly and high-volume manufacturing.

The US competitive advantage is in producing high-value inputs (such as polysilicon wafers used in photovoltaic cells) and the capital equipment and systems for solar factories. Firms based in the US exported more than US$3.7 billion worth of solar photovoltaic goods and services to China, while Chinese companies exported US$2.8 billion worth of products to the US. The globalisation and increasing integration of these supply chains has helped to drive down the costs of renewable energy production, allowing the different components to be produced wherever costs are lowest.

Second, a number of trade cases have arisen over subsidies for renewable energy supply such as feed-in tariffs. These include disputes between the EU and Canada, and between India and the US. The principal issue at stake has been the use of “local content” rules, under which renewable energy subsidies are only available to suppliers using locally sourced equipment. These rules are usually designed to support local industry and employment, but to overseas manufacturers they frequently look like protectionist measures designed to keep imports out.[59] In a ruling on the EU–Canada case, the WTO declared that local content rules were indeed discriminatory and had to be rescinded. But the feed-in tariffs themselves were not held to be in violation of anti-subsidy rules, since there was no “unregulated” price of energy against which they could be compared.[60] A more general declaration of the compatibility of renewable energy subsidies with WTO rules would now be of considerable assistance.

These disputes reflect the increasing importance of markets for renewable energy products as low-carbon policy spreads throughout the world, and in some respects they are inevitable as domestic producers compete with those overseas. But they are damaging to the growth of low-carbon policy, raising prices for renewable energy just as it becomes competitive with fossil fuels. It is notable that the installers of solar panels in the US have not supported the countervailing duties against Chinese imports, arguing that higher prices are slowing down the growth of solar power in the US, with a larger overall impact on jobs – as well as emissions – than in domestic solar manufacturing.[61] The increasing interdependence and complexity of global value chains means that trade restrictions may even backfire, with domestic producers facing higher costs for imported components.[62]

It would clearly be beneficial to all sides if these disputes were avoided if possible, and resolved more quickly when they occur. One option would be to change WTO rules to prohibit in these cases the use of "trade remedies" such as anti-dumping and countervailing duties, which tend to lengthen disputes, and to establish a more rapid dispute resolution procedure.[63] Another would be to use bilateral and regional trade agreements between smaller groups of countries to do this.

Regional trade agreements in fact offer wider potential in this field. As negotiations under the WTO have stalled in recent years, such "plurilateral" agreements have become more common: there are now over 350 in force between various groups of countries.[64] Most now incorporate an environmental chapter, but this in itself determines very little: it depends whether the provisions of the agreement strengthen or weaken environmental protection across the signatory countries.[65] But there are clear opportunities in trade agreements currently being negotiated – such as the Transatlantic Trade and Investment Partnership (TTIP) between the US and Europe, the Trans-Pacific Partnership (TPP) in the Asia-Pacific region, and the EU–China Investment Agreement – to strengthen measures which can support low-carbon growth.

Such measures include common energy efficiency standards for appliances and industrial equipment; common technology standards for low-carbon systems, such as electric cars and their associated charging infrastructure; liberalisation of public procurement rules in low-carbon sectors; strengthening the rules governing investment in natural resources such as forests and energy; and liberalisation of trade in services in major sectors such as construction and urban planning. In the context of the development of more connected and compact cities, as proposed in this report, the latter offers considerable potential. Traditionally largely closed to international trade, these sectors now have major opportunities for innovation, such as modular construction techniques and use of information technologies in energy and transport, which could help accelerate the development of lower-carbon production methods and urban design.

5. Voluntary cooperative initiatives

A growing number of international cooperative initiatives have been established in recent years to support and enhance the impact of climate action by national and local governments, businesses and civil society. Most of these initiatives focus on specific sectors and fields such as renewable energy, energy efficiency, transport, avoided deforestation, agriculture, short-lived climate pollutants[66] and finance. Some are collaborations between governments; some are collaborations in specific business sectors; most are "multi-stakeholder" in form, bringing together governments, the private sector, civil society and others.[67] They have different functions. Some are aimed at disseminating best practice and providing technical advice and support to public authorities and businesses wanting to take action in specific areas; others are coalitions of such actors wanting to take more ambitious action than their peers. Box 3 provides some examples.

These voluntary initiatives should not be seen as substitutes for formal multilateral agreements between governments, or national regulatory processes. Their purpose is generally to support governments in implementing nationally determined climate goals and policies. Some may even offer the potential to achieve additional impact through the independent decisions of important actors such as cities and major businesses.

The voluntary nature of these initiatives is both a strength and a weakness. As "coalitions of the willing", their impact is inevitably limited by the number and scale of the participants they can attract. But because they do not need universal participation, they have considerable scope for ambition and innovation. They can have particular value in fostering learning. Integrating economic goals with climate risk management is not easy; governments, businesses, city authorities and others are all working out how to do it as they go along. In this context, voluntary cooperative initiatives can play a useful role in exchanging best practices and supporting mutual "learning by doing".

Nevertheless, the diverse (and in some cases overlapping) nature of these initiatives, and in some cases their relatively recent creation, makes it difficult to assess their impact in any systematic way.[69] For many, an important next step will be to develop quantifiable commitments subjected to standardised and verifiable methods of measurement and reporting. This will help ensure both clarity of impact and public accountability. Building on the UN Secretary-General's Climate Summit in September 2014,[70] and using protocols developed by international research institutes, welcome moves are now under way in many of these initiatives to move towards such commitments and methods.[71]

One of the most interesting developments in this field has been the establishment of business-led initiatives in certain sectors of the global economy where products are internationally traded and it is therefore almost impossible to achieve strong national regulation of emissions. If complying with such regulations is perceived as costly by

Box 3:
International cooperative initiatives

International cooperative initiatives which aim to reduce climate risk while promoting economic and business growth come in a variety of forms. Recent surveys have suggested that, depending on what is included within the scope, there are around 100 such initiatives.[68] The following list provides a flavour of the kinds of initiatives which now exist.

Renewable Energy and Energy Efficiency Partnership (reeep). A non-profit organisation focused on supporting clean energy business models in developing and emerging economies. The Partnership has 400 official member organisations, including businesses, NGOs, industry associations, financial institutions and other civil society entities, as well as 45 national governments. To date, reeep has funded more than 180 clean energy projects in 58 countries. See: http://www.reeep.org.

en.lighten. A joint initiative of United Nations Environment Programme (UNEP), OSRAM and Philips Lighting, with the support of the Global Environment Facility (GEF), en.lighten aims to eliminate inefficient lighting by 2030. The initiative estimates that achievement of the goal could cut carbon emissions by 500 million tonnes of CO_2 annually in 2030, and cut electricity bills globally by more than US$100 billion. See: http://www.enlighten-initiative.org.

Partnership for Clean Fuels and Vehicles (PCFV). A partnership of 72 governments, international organisations and industry. It aims to reduce air pollution through the introduction of cleaner fuels and vehicle standards. See: http://www.unep.org/transport/new/pcfv.

R20 – Regions of Climate Action. A group of more than 500 sub-national regions that work to promote and implement major GHG emission reduction and other environmental projects. R20 aims to address barriers that prohibit sub-national governments from developing low-carbon and climate resilient economic development projects. See: http://www.regions20.org.

Climate and Clean Air Coalition to Address Short-Lived Climate Pollutants (CCAC). A coalition of around 40 countries and 60 non-state partners aiming to address short-lived pollutants such as black carbon, methane and hydrofluorocarbons (HFCs), which are responsible for a substantial proportion of current global warming. CCAC's aims are to raise awareness, enhance national action by overcoming barriers, promote best practices, and improve scientific research. See: http://www.unep.org/ccac.

C40 Climate Cities Leadership Group. A global network of more than 60 large cities committed to sustainable urban development and GHG emission reduction, providing best practices, advice and support. Together C40 cities represent more than 20% of world GDP, and have taken over 8,000 actions to mitigate and/or adapt to climate change since the network's founding in 2005. See: http://www.c40.org.

REDD+ Partnership. An intergovernmental partnership of 75 countries to improve the effectiveness of measures to tackle deforestation and forest degradation in developing countries, including the transparency and coordination of REDD+ initiatives and financial instruments. The Partnership facilitates knowledge transfer, capacity enhancement, mitigation actions, and technology development and transfer. See: http://www.reddpluspartnership.org.

Low Emissions Development Strategies Global Partnership (LEDS-GP). Launched in early 2011, the partnership brings together more than 120 governmental and international institutions, aiming to strengthen support for low-emissions development in regions and to foster capacity-building. See: http://en.openei.org/wiki/LEDSGP/home.

the companies that would be regulated, they will almost certainly put up resistance; and since the benefits of such emissions reductions are global, not local (unlike, for example, air or water pollution standards), governments may find them hard to justify. Yet if businesses in such sectors cooperate to regulate themselves on a global basis, they can, at least in principle, overcome the competitiveness problem.

The Consumer Goods Forum (CGF), an association of around 400 manufacturers, retailers, service providers and other stakeholders across 70 countries, has established a number of initiatives to reduce GHG emissions from the consumer goods sector on this basis.[72] One is the Global Protocol on Packaging Sustainability (GPPS). Launched in 2011, it provides a means for consumer goods firms to assess the sustainability of their packaging practices throughout their supply chains.[73]

A second initiative is the Tropical Forest Alliance 2020 (TFA 2020).[74] As described in Chapter 3: Land Use, TFA 2020 is a partnership of businesses, governments and non-governmental organisations (NGOs) committed to reducing the deforestation in Southeast Asia, Latin America and Africa which is driven by production of four major global commodities: palm oil, soy, beef, and paper and pulp. It includes many of the major global companies that trade these products, manufacture consumer goods and foodstuffs containing them, and sell them in supermarkets.

The participating companies undertake to remove products deriving from deforested areas from their supply chains by 2015–2020. TFA 2020 works with national and state governments to introduce appropriate regulatory and enforcement policies and support for local producers. A group of banks brought together by the Banking Environment Initiative have also committed to work with companies and their supply chains to develop appropriate financing solutions for sustainably produced commodities.[75]

In the case of palm oil, companies participating in the initiative have 15% of the total consumer market by volume, and well over 50% of the global trade in the commodity. Analysis suggests that such significant participation rates might be sufficient to tip the entire global market towards sustainable palm oil, since it is highly inefficient to separate out differently sourced kinds of bulk-traded commodities.[76]

It is too early to say whether this will happen. But the potential to transform the environmental and climate impact of these major agricultural and forest commodities is clearly significant. Between them, the four commodities targeted by TFA 2020 are estimated to be responsible for around 40% of global deforestation. So if by 2020, the Alliance's target of ending deforestation throughout the supply chains for these products could be achieved, that would represent a reduction of up to 6% of total global GHG emissions.[77]

Why would companies collaborate in this way? There are a number of reasons. Fierce campaigning by NGOs such as Greenpeace has provided a powerful motivation.[78] For companies with well-known brands, adverse publicity for their role in causing deforestation provides a strong market incentive to adopt more sustainable policies. Many companies increasingly acknowledge a social and ethical responsibility to reduce their environmental impact. Many have also found that the costs of doing so have not been very large relative to the companies' size and profitability. Indeed, high environmental standards demanded by retailers and consumers tend to support the market position of large multinational companies, requiring local firms in regional markets to meet the same standards despite otherwise lower costs.

There is clearly potential for business-led initiatives of these kinds in other sectors where products are globally traded and national regulation is therefore particularly difficult or unlikely. (The desirability of common carbon regulation is also discussed in Chapter 5: Economics of Change, with the possibility of border tariffs to adjust for differential carbon regulation.) Examples of such sectors, with high emissions and relatively small numbers of large companies, include oil and gas, iron and steel, and cement.

Such cooperation need not be confined to individual sectors. Although in recent years many businesses have begun to identify and invest in measures to improve their energy efficiency, there is still huge scope for further energy and resource productivity improvement in industry throughout the world.[79] There is clearly the potential for a new initiative in this field to take up this challenge, led by existing business organisations such as the World Business Council on Sustainable Development (WBCSD). The WBCSD's Action2020 initiative, which has developed roadmaps for a variety of key fields of business action on sustainable development, provides a valuable template.[80]

6. Changing the rules and norms of the global economy

Cooperative initiatives provide valuable ways to make progress in specific sectors and fields of activity, but they are not enough. To achieve a broad, long-term transition to low-carbon growth and development, a deeper shift is needed. All major economic actors – national governments, sub-national and city authorities, companies and financial institutions in both the private and public sector – will need to integrate climate risk management into their core economic and business strategies.

Each can act individually, but many more will do so if it is demanded by the "rules of the game" under which they operate. In a global economy, these rules are increasingly determined at an international level.

Business reporting provides an important example. In recent years, more than 4,000 global companies have been reporting their greenhouse gas emissions at the behest of their major investors. CDP (formerly the Carbon Disclosure Project) operates on behalf of more than 750 institutional investors, publishing annual reports on corporate emissions using data collected under a standardised methodology, the Greenhouse Gas Protocol. By publicly scoring companies' performance, CDP aims to strengthen their emissions reductions programmes.[81]

But these reports are not part of these businesses' mainstream financial reports, and are not treated in the same way by the companies or by their shareholders. The same is true of the reports that many companies produce today on their wider environmental and social impacts, which have no common reporting framework and which vary widely in scope and depth. Financial reports – which are legally required – are standardised around the key indicators that measure business performance. They allow shareholders to benchmark individual companies against one another and to assess the financial risks they face. Climate risk – the extent to which business assets, activities and future profits are made vulnerable by climate change and climate change policy – now needs to be understood as a significant additional risk factor facing most major businesses. It therefore needs to form part of their standard reporting processes, giving managements and shareholders the information and analysis required to address it properly. The same is true of companies' exposure to natural disasters.[82] There is therefore a strong case for business reporting on each of these wider issues – GHG emissions, climate risk, and environmental and social impacts – to be integrated with financial reports and standardised.[83]

That is beginning to happen. The Carbon Standards Disclosure Board, a consortium of business, investor and environmental organisations, has published a Climate Change Reporting Framework which enables businesses to report on their climate impacts in a systematic way linked to information about their financial performance.[84] At the same time the concept of "integrated reporting" has gained momentum under the auspices of a global business and investor partnership, the International Integrated Reporting Committee. Results from the partnership's pilot study suggest that integrated reporting leads to higher-quality data collection and provides management with a better understanding of how the business creates value over time.[85] This is consistent with the results achieved by existing forms of social and environmental reporting. Companies required to report on these issues consistently perform better in areas such as energy and water consumption and waste (which, in turn, almost always leads to lower costs) than those not facing mandatory reporting.[86] This should not be surprising. The rules under which companies operate affect their behaviour. Integrating the reporting of climate and other environmental and social risks into financial reports will almost certainly motivate company boards to pay closer attention to these issues and to give higher priority to their management.

There are two routes through which integrated reporting could become the new internationally agreed norm. One is through investor demand. As they have already done with emissions reporting, major shareholders could require companies to report financial and non-financial information together, with climate risk a standard feature. A second route is through national stock exchanges. The Johannesburg Stock Exchange has already pioneered this, introducing listing rules in 2010 which include the requirement to publish an integrated report.[87] The Brazilian Stock Exchange has announced that it will encourage businesses to produce an integrated report on a "report or explain" basis.[88] There is clearly significant scope for other stock exchanges to follow suit. Cooperation between stock exchanges in different countries and global investors would enable momentum to be accelerated towards mandatory and standardised integrated reporting.

Moreover, if investors require stronger climate risk management and reporting of the companies they own, they also need to apply it to themselves. As discussed in Chapter 6: Finance, investors' asset portfolios are subject to climate risk in different forms – both the risks resulting from climate change itself, and the risks of devaluation or "stranding" arising from changes in climate policy and fossil fuel prices. In the last few years a number of investors have begun to recognise this and conduct more systematic and integrated assessments of their portfolios. A few have also examined how far they are, and should be, investing in lower-carbon sectors.[89]

But though sector leaders can set precedents for change, individual investors do not determine the behaviour of the sector as a whole. That arises from the rules and norms which apply to all. The UN Principles for Responsible Investment, which seek to drive greater consideration of economic, social and governance factors in investment decision-making and ownership practices, have provided some impetus for this. Signatories now include 1,200 investors with US$45 trillion in assets, around half the global institutional total.[90] Smaller associations of institutional investors are also seeking to drive change.[91] But this could be considerably accelerated through collaboration among stock exchanges and financial regulators in major economies. By requiring investors to conduct climate (and wider environmental) risk assessments of their portfolios as part of their recognised fiduciary duty, stock exchanges and financial regulators could drive significant behaviour change throughout the global economy.[92]

A comparable shift in rules and norms is needed in government accounting systems. As discussed in Chapter 5: Economics of Change, some governments and international institutions are now experimenting with forms of measurement of national economic activity which more strongly reflect environmental conditions. These include adjustments to GDP to account for the depreciation of natural capital, the introduction of "natural capital accounts", and the establishment of alternative indicator sets of national progress.[93] Again, it will be at the international level that such practices will become established as the global norm. The adoption by the UN Statistical Committee of a "central framework" for a System of Environmental-Economic Accounting is a start, but there is considerable way to go before such measurements become a routine part of governments' mainstream economic performance measurement.[94]

International institutions can play a particularly helpful role here. Over the last few years a number of major international economic organisations have begun to integrate climate and environmental risk management into their core economic analyses, policy advice and operations. These include the OECD, the World Bank, the major regional multilateral development banks, and UN agencies such as the United Nations Development Programme (UNDP) and the Food and Agriculture Organization (FAO). Most would acknowledge that more integration is still needed to cover all areas of their work, with sufficient priority given to climate risk among other growth challenges. The multilateral development banks in particular are under some pressure to reconcile the demands they face to finance high-carbon infrastructure with their own analysis of the benefits, both national and global, of lower-carbon pathways. Attention is also now focusing on how finance provided by export credit agencies can be shifted to support efforts to tackle climate change.[95]

In other cases there is potential to do much more. The International Monetary Fund (IMF), for example, has acknowledged that climate change is a long-term risk to growth in its overall analysis of the global economy, and has contributed valuable research and policy advice on key aspects of fiscal policy, including fossil fuel subsidy reform.[96] But climate risk is not a routine element in its country advice or its influential economic analyses, such as the annual World Economic Outlook. There is now considerable scope for the IMF, along with other major international organisations concerned with the management of the global economy, such as the OECD and the multilateral development banks, to reflect climate risk assessment and reduction in their national economic surveillance processes and assessments.

It is particularly noticeable how small a role climate risk has played in many of the major international and regional forums where countries gather to discuss international economic cooperation and coordination.[97] The G20 group of nations, for example, has developed a strong interest in long-term and infrastructure investment as a key driver of growth. Yet it has not integrated this either with concern about climate risks to investment or the potential for low-carbon infrastructure. At some of its high-level meetings the G20 has acknowledged the potential for "green growth" strategies to combine economic development with climate risk reduction, and in 2009 agreed to the phasing out of inefficient fossil fuel subsidies.[98] But its attention has been sporadic at best, and on some occasions it has deliberately sought to avoid discussing climate issues. This is no longer a tenable position. Economic growth and climate risk are intertwined; institutions and forums charged with fostering economic cooperation – particularly those involving the countries with the highest emissions and emissions growth – should be engaging deeply with the challenges discussed in this report.

7. Recommendations

In light of this analysis, the Global Commission recommends that:

- **All countries should seek to achieve an equitable, ambitious and durable international legal agreement on climate change at the UN conference in Paris in 2015**, with a view to sending a clear policy signal to businesses and investors about the future low-carbon direction of the global economy. Such an agreement should include a long-term goal to reduce annual GHG emissions to near zero or below, should establish a coordinated five-yearly policy-making cycle with a clear downward trajectory underpinned by long-term economic strategies, and should support developing countries to move towards lower-carbon and climate-resilient development paths.
- **Developed countries should increase financial support for developing countries' efforts to tackle climate change**, drawing up a clear pathway to meet the goal to mobilise US$100 billion per year in public and private finance by 2020, and exploring new and innovative sources of revenue. Multilateral and national development banks, including the new banks created by emerging economies, should increase their lending for low-carbon and climate-resilient infrastructure, both in direct lending and to leverage much greater flows of private investment.
- **Governments should negotiate the elimination, where possible, of import tariffs on low-carbon goods and services, and agree more rapid resolution processes for trade disputes in low-carbon sectors.** They should strengthen the environment-related elements of Regional Trade Agreements.
- **Major international businesses in globally traded sectors with high emissions, such as food and forest commodities, HFCs, oil and gas, steel and cement, should seek to establish and strengthen cooperative initiatives to reduce their GHG emissions.**
- **Institutional investors and stock exchanges should establish a timetable to move towards mandatory integrated corporate reporting of financial and non-financial performance and risks on a standardised model.** They should require institutional and other major investors to undertake mandatory climate risk assessments.
- **All global economic institutions and forums should integrate climate risk into their economic growth and development strategies and discussions.** The G20 should make climate risk assessment and reduction a standing agenda item in its meetings. Major international organisations concerned with the management of the global economy, such as the IMF, the OECD and the multilateral development banks, should reflect climate risk assessment and reduction in their surveillance processes and policy assessments as relevant to their mandates.

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PART III: GLOBAL ACTION PLAN

Introduction

Each chapter of this report sets out detailed recommendations for governments and other decision-makers. The Commission highlights here 10 transformative areas for action which can deliver both significant economic benefits and reduce the risk of dangerous climate change. These actions offer the prospect of better economic growth that yields multiple benefits, including more energy, water and food security; improved rural livelihoods; better protection of the natural world; less traffic congestion; improved air quality and public health; as well as lower greenhouse gas emissions and more climate-resilient growth. A key insight of the New Climate Economy study is that these actions make good economic sense, even before their climate benefits are considered. Countries can gain a net benefit from implementing the proposed actions, when these full advantages are considered. Implementing these actions can achieve at least half of the cuts in global greenhouse gas emissions required by 2030 to stay on a 2°C pathway, and potentially up to 90%, if they are implemented in the right way. Taken together, the proposed actions would send a strong, clear signal that the world economy is poised to follow a low-carbon direction. They would reduce uncertainty for investors, businesses, farmers and consumers, and so reduce the transitional costs of change. The more countries, cities and businesses that move in this direction, the easier it is for everyone to join in. But the right policy signals and actions are needed urgently. If this does not happen now, there is a serious risk that we will lock in a growth path with significant risks of climate change and weak economic performance. Delaying action will also increase the costs of changing course later on.

The world can only achieve such ambitious, deliberate change with leadership and collaboration. It requires the engagement of economic decision-makers at every level. Countries have different abilities to realise the opportunities highlighted here. Developed countries must show real leadership: both politically, demonstrated through their own domestic ambition, and by supporting the development and dissemination of low-carbon technologies and know-how, providing finance, and strengthening the financial institutions needed to bring down the cost of low-carbon investments. Developing countries will require financial, institutional and technological support. For their part, developing countries already account for two-thirds of global greenhouse gas emissions, largely as a result of emissions growth in rapidly industrialising, middle-income economies. Global emissions reductions on the scale required will therefore only be possible if all countries participate in delivering these actions.

By implementing the recommendations in this Global Action Plan, the world's economic decision-makers have a remarkable opportunity to set the world on the path to better growth and a better climate. The Commission urges them to seize it.

The Commission's 10 recommendations are divided into two main classes of policy action. Recommendations 1 to 6 define the necessary conditions for better, low-carbon, climate-resilient investment and growth; recommendations 7 to 10 focus on the potential for sectoral change which drives future growth and lower climate risk, specifically in urban, land use and energy systems.

The Commission recommends that national, sub-national and city governments, businesses, investors, financial institutions and civil society organisations:

1. Accelerate a low-carbon transformation by integrating climate action and risk into strategic economic decision-making.

The risk of severe climate change threatens long-term economic growth and business performance. Tackling climate change, meanwhile, presents significant opportunities to strengthen growth and create new market opportunities. Business leaders have started to monitor, report on and actively manage the climate (and other environmental) impacts of their activities, under increasing scrutiny by civil society. Companies, cities and countries are strengthening their approaches to climate resilience and adaptation. Many long-term investors recognise that accounting for and addressing material environmental, social and governance factors is part of their fiduciary duty. At the same time, there is a growing risk that investments in fossil fuel assets may be "stranded" (prematurely scrapped or devalued) as countries move to a low-carbon growth model.

Decision-makers must integrate climate and other environmental impacts into their core economic, development and investment strategies. Taking a long-term approach, integrating these factors into investment and business decision-making, can reduce investor risk without harming performance.

To implement and support this recommendation:

- All governments, major businesses, investors, development, commercial and investment banks, international organisations and leading cities should work to integrate climate risks and opportunities into their economic and business strategies.
- Climate and other environmental risks should be integrated into core decision-making tools and practices, such as economic and business models, policy and project assessment methods, performance indicators, discounting approaches used to estimate

the present value of longer-run costs and benefits, risk metrics and models, resilience tests, and reporting requirements.

- Businesses, working through associations such as the World Business Council on Sustainable Development and with government regulators, should adopt and implement a standardised Integrated Reporting Framework for financial and non-financial performance that includes the assessment of climate risk and risk reduction strategies. Investors and stock exchanges should require companies to disclose this information.

- Investors, working together with government financial regulators, should develop an approach to report transparently on the carbon exposure of their assets, and the potential risk of stranded fossil fuel assets. Banks should deepen their assessment of environmental and carbon risk in transactions.

- The G20 should make climate risk assessment and reduction a standing agenda item in its meetings. Major international organisations concerned with the management of the global economy, such as the International Monetary Fund, the Organisation for Economic Co-operation and Development, and the multilateral development banks, should reflect climate risk assessment and reduction in their surveillance processes and policy assessments as relevant to their mandates.

2. Create the confidence needed for global investment and climate action by entering into a strong, lasting and equitable international climate agreement.

The Commission's analysis shows that the national actions and investments that drive economic growth can also reduce climate risks. But these actions and investments will not be sufficient to put economies worldwide on a pathway to avoid dangerous climate change. International cooperation is essential to reduce the global cost of climate action; provide sufficient finance and technological cooperation to support developing country action; send a strong and predictable signal for investment; open opportunities for trade; and ensure a level playing field to reduce competitiveness impacts. An international climate agreement is also essential to provide the confidence and trust needed for robust domestic policy action. The Commission urges leaders to achieve a strong, lasting and equitable agreement under the United Nations in 2015.

To implement this recommendation:

- All governments should set clear, ambitious medium-term (e.g. 2025) national greenhouse gas emission targets or actions which reflect their common but differentiated responsibilities as part of the global agreement. They should agree a global goal which would achieve annual greenhouse gas emissions of near zero or below in the second half of the century. The agreement should include a mechanism for regular strengthening of national commitments (e.g. on five-yearly cycles); financial and technical support for developing country action, and strong commitments to take adaptation action. It should also provide as much transparency as possible to build confidence. The principles of equity and a just transition should underpin the agreement, reflecting the current and changing circumstances of countries.

- Developed countries should commit to a clear pathway for meeting the Copenhagen commitment to mobilise US$100 billion annually by 2020 in public and private finance, combined with greater transparency of financial commitments and identifying new sources of finance (see Recommendation 5).

- Businesses, cities, states, national governments, international institutions and civil society organisations should complement an international agreement by strengthening (and where appropriate, creating) cooperative initiatives to drive growth and climate risk management in key sectors, including major commodities and energy-intensive industries, and to achieve the phase-out of hydrofluorocarbons (HCFs).

3. Phase out subsidies for fossil fuels and agricultural inputs and incentives for urban sprawl.

Globally, subsidies and tax breaks to fossil fuel exploration, production and consumption amount to around US$600 billion each year, while support to agricultural input use in advanced and some emerging economies totals about US$80 billion per year. Phasing out these subsidies can enhance economic efficiency; free up scarce government resources to provide better targeted support to low-income households and affected workers; build agricultural resilience; and reduce greenhouse gas emissions. Perverse subsidies which support urban sprawl, either explicitly or implicitly, also persist in many countries, for example through under-pricing of the conversion of land, and of the costs of public services and infrastructure provision. These subsidies can be costly to taxpayers. To implement this recommendation:

- National governments should develop comprehensive plans for phasing out fossil fuel and agricultural input subsidies. These should include enhanced transparency and communication and targeted support to poor households and affected workers. Governments should explore innovative approaches with multilateral and national development banks on how to finance the upfront costs of reducing

- the impact on low-income households, and enhancing service delivery as or before the subsidies are phased out.
- Export credit agencies should agree to restrict preferential terms for new coal power stations to supercritical or more efficient technologies, and then to a timetable for phasing out these preferential terms, initially for middle-income countries, and then for low-income countries (See Recommendation 5).
- Regions, cities and urban development ministries should phase out incentives for urban sprawl. Multilateral and national development banks should work with countries to redirect infrastructure spending away from projects that enable urban sprawl and towards more connected, compact and coordinated urban development.

4. Introduce strong, predictable carbon prices as part of good fiscal reform.

Carbon prices are an essential element in the growth and climate policy mix. About 40 countries and over 20 sub-national jurisdictions now apply or have scheduled to apply carbon pricing through a carbon tax or emissions trading scheme (ETS). A further 26 countries or jurisdictions are considering carbon pricing. The Commission finds no evidence that implementing carbon pricing slows growth. The effective use of the significant fiscal revenues generated – including to reduce other taxes – can instead boost growth and employment, even in the short term, and be used to address distributional concerns. Even a low initial carbon price, if accompanied by transparent mechanisms to increase it over time, can send a strong signal, incentivising producers and consumers to shift behaviour and to invest in assets, technologies and systems that foster low-carbon growth.

A broader policy approach is needed to complement carbon prices, in order to address other market failures and overcome the inertia embedded in the current, high carbon economy, and to strengthen investor confidence. This broader policy mix includes market-based resource pricing; better regulations and performance standards; improved information provision; targeted research and development; public procurement policies; and measures that can reduce government-induced regulatory uncertainty. This uncertainty is the enemy of low-carbon jobs, investment and growth.

To implement this recommendation:

- National governments should introduce a strong, predictable and rising carbon price as part of fiscal reform strategies, prioritising the use of resulting revenues to offset impacts on low-income households and finance reductions in other distortionary taxes.
- Major companies worldwide should apply a "shadow" carbon price to their investment decisions and support governments in putting in place well-designed, stable regimes for carbon pricing.
- Efficient regulations, standards and other approaches should be used to complement pricing; these can also help to put an "implicit" price on carbon for countries where a low level of carbon pricing is politically difficult, preferably with flexibility built in to facilitate the introduction of explicit pricing later.
- National governments should seek to reduce policy risk and uncertainty by enacting domestic climate legislation, modifying their national plans and developing the institutional arrangements needed to meet their commitments under an international climate agreement (see Recommendation 2).

5. Substantially reduce the capital cost of low-carbon infrastructure investment.

It is estimated that around US$90 trillion will need to be invested globally in infrastructure between now and 2030 to deliver economic growth and prosperity. Analysis for this report suggests that a low-carbon growth path can be achieved with only slightly higher investments. The lower operating costs of clean energy choices may partially or fully offset the cost of any additional investments in the energy sector. New and existing finance tools and approaches are needed to ensure there is sufficient access to finance for the up-front investments in low-carbon and climate-resilient cities, transport, land-use and energy. Given the capital intensity of many low-carbon technologies, reducing the costs of capital could significantly boost investment in these solutions.

To implement this recommendation:

- Donors, multilateral and national development banks should review all lending and investment policies and practices, and phase out financing of high-carbon projects and strategies in urban, land use and energy systems, except where there is a clear development rationale without viable alternatives.
- Governments and multilateral and national development banks should help provide new and existing financing institutions with the right skills and capacity to provide finance for low-carbon and climate-resilient infrastructure, and to leverage private finance towards this goal. This would include finance for distributed off-grid and mini-grid renewable energy solutions, as a contribution to achieving universal access to modern energy services.

- In rapidly developing countries facing high interest rate environments, governments should shift their support models for low-carbon infrastructure more towards low-cost debt, and away from price subsidies such as feed-in tariffs. This could reduce the total subsidy required, bring down the cost of energy over time, and in some cases, may reduce the need to buy imported fuel.

- Governments, working with investor groups, should help develop well-regulated asset classes, industry structures and finance models for renewable and other low-carbon energy investment which match the needs of institutional investors, and identify and remove barriers that may hamper these investments.

6. Scale up innovation in key low-carbon and climate-resilient technologies and remove barriers to entrepreneurship and creativity.

Innovation is a fundamental engine of long-term growth in a world with environmental constraints. Advances in material sciences and digitalisation, in combination with new business models, are already driving a low-carbon industrial transformation. Digital technologies have shifted services on-line, enabled end-users to actively manage their energy demand, and driven the rapid development of car- and other asset-sharing schemes. Together with new materials, they have the potential to enhance resource productivity in energy-intensive sectors such as construction and transport, to drive the development of new industries, such as advanced manufacturing and renewables, and to enable the development of a more "circular" economy in which materials are recycled and reused. Strong market signals, together with smart government interventions, will be needed to unleash the power of innovation to accelerate the transition to a low-carbon, climate-resilient economy and make it cheaper.

To implement this recommendation:

- Governments of the major economies should at least triple their energy-related research and development expenditure by the mid-2020s, with the aim of exceeding 0.1% of GDP; in addition, all countries should develop coordinated programmes to support the development, demonstration and deployment of potentially game-changing technologies, such as energy storage and carbon capture, use and storage.

- Governments should strengthen the market pull for new low-carbon technologies, in particular through carbon pricing, performance-based (technology-neutral) codes and standards, and public procurement policies.

- Governments should work individually and together to reduce barriers to the entry and scaling of new business models, particularly around "circular economy" and asset-sharing mechanisms, and trade in low-carbon and climate-resilient technologies.

- Donors, working with international agencies such as the Consultative Group on International Agricultural Research (CGIAR), the UN Food and Agriculture Organization and national research institutes in emerging and developing countries, should double investment in agriculture and agroforestry R&D, with the aim of boosting agricultural productivity, climate-resilient crop development and carbon sequestration.

- Learning from the CGIAR experience, governments should collaborate to establish an international network of energy access "incubators" in developing countries. These should enhance public and private R&D in off-grid electricity, household thermal energy, and micro- and mini-grid applications. They should also boost business model development for new distributed energy technologies.

7. Make connected and compact cities the preferred form of urban development.

More connected, compact and coordinated urban development based on mass public transport would raise infrastructure productivity, reduce the costs of providing public services, and could lower urban infrastructure spend by over US$3 trillion from 2015-2030. When managed well, connected and compact cities are not only more productive, they are also more competitive, socially inclusive, resilient, safer, cleaner, and generate lower greenhouse gas emissions. Urban sprawl, on the other hand, has significant economic, social and environmental costs, estimated for example to cost the equivalent of US$400 billion each year in the United States alone. Regeneration and densification of inner urban areas can help to rejuvenate sprawling cities by making them more attractive for people and investment.

To implement this recommendation:

- Finance and urban planning ministries, national development banks, and city mayors should commit to a connected, compact and coordinated urban development model, centred on mass transport and resource-efficient service delivery.

- City authorities, working with national and sub-national governments, should identify ways to increase locally generated revenues to finance and incentivise smarter, more compact and resilient urban development – for example, through greater use of congestion charging, parking fees, land development taxes and land value capture mechanisms.

- Governments, multilateral and national development banks should work with major cities and private banks to strengthen the creditworthiness of cities. They should work together to set up a global city creditworthiness facility.

- Networks of cities, such as the C40 Cities Climate Leadership Group and ICLEI (Local Governments for Sustainability), working with international organisations and the private sector, should create a Global Urban Productivity Initiative aimed at significantly increasing the economic and resource productivity of the world's cities. The initiative could start by developing, quantifying and disseminating best practices in boosting urban productivity, and support countries' efforts to put sustainable urbanisation at the heart of their economic development strategies.

8. Halt the deforestation of natural forests by 2030.

Forests are a vital natural resource. They support the livelihoods of hundreds of millions of people who live in or next to them or work in forest-related sectors. As well as timber and other forest products, they provide watershed protection, flood management, landslide prevention, climate mitigation, recreation, eco-tourism, and other economically valuable services. Between 2000 and 2010, the world lost on average 13 million hectares (gross) of forest each year to deforestation, as a result of the clearing of forests and subsequent conversion of land to other uses, most commonly agriculture. Some estimates suggest that conserved and sustainably managed forests can generate US$6,000 or more in aggregate value per hectare per year through the provision of a wide array of goods and services.

To implement this recommendation:

- Developed countries should scale up payments for Reducing Emissions from Deforestation and forest Degradation (REDD+) to at least US$5 billion per year, focused increasingly on payments for verified emission reductions.
- Forest-rich countries should take steps to correct the governance and market failures undermining natural forest capital, including actions to improve land use planning, secure tenure, strengthen enforcement of forest laws, and increase transparency concerning the condition and management of forests.
- Companies and trade associations in the forestry and agricultural commodities sectors (including palm oil, soy, beef, and pulp and paper) should commit to eliminating deforestation from their supply chains by 2020, for instance through collaborative initiatives such as the Consumer Goods Forum and its Tropical Forest Alliance 2020 and in cooperation with banks willing to incorporate environmental criteria into their trade financing instruments.

9. Restore at least 500 million hectares of lost or degraded forests and agricultural land by 2030.

About one quarter of the world's agricultural lands are presently degraded. Lost or degraded forest landscapes account for about two billion additional hectares. Restoring these will enhance the natural capital that countries, companies and citizens depend upon for economic growth and human well-being. Restoring degraded agricultural land and lost or degraded forest is important for food security, biodiversity, rural livelihoods, watershed protection, and climate mitigation and adaptation. Restoring agricultural land can also reduce pressures on forested lands.

To implement this recommendation:

- National governments, working together with farmers, development banks, non-governmental organisations (NGOs) and the private sector, should commit to and start the restoration of at least 150 million hectares of degraded agricultural land, to bring this back into full productive use – for example, through agroforestry measures. This target could be scaled up over time, based on learning from experience. It is estimated that such action could generate additional farm incomes of US$36 billion, feed up to 200 million people and store about 1 billion tonnes of CO_2e per year by 2030.
- Governments, with the support of the international community, should commit to and start the restoration of at least 350 million hectares of lost or degraded forest landscapes through natural regeneration or assisted restoration by 2030. This could generate an estimated US$170 billion per year in benefits from ecosystem services, and sequester 1-3 billion tonnes of CO_2e per year.

10. Accelerate the shift away from polluting coal-fired power generation.

Coal remains the energy source for over 40% of the global electricity supply. The widespread use of coal partly reflects the use of subsidies which lower or hide the costs of fossil fuel use. Coal is often the most lightly taxed fuel, despite being the most polluting. Globally, pollution from burning coal is a contributor to the estimated 3.7 million premature deaths each year from outdoor air pollution, and coal production also causes ill health, injuries and deaths. There is increasing risk of coal sector assets becoming "stranded" as climate and other policies make them less profitable. In the absence of clear policy signals, however, this risk is often beyond the investment horizon of capital providers. There are already signs that investments in a low-carbon energy system are rising, with renewables increasingly cost-competitive in a number of countries and regions, and increasing recognition of the costs savings and energy security benefits of energy efficiency improvements. But behavioural and institutional barriers often limit their uptake, so further policy action and assistance is needed to ensure more rapid deployment of low-carbon solutions.

To implement this recommendation:

- Governments should reverse the "burden of proof" for building new coal-fired power plants, building them only if alternatives are not economically feasible, bearing in mind the full range of financial, social and environmental costs associated with coal power.
- All countries should aim for a global phase-out of unabated fossil fuel power generation by 2050. High-income countries should commit now to end the building of new unabated coal-fired power generation and accelerate early retirement of existing unabated capacity, while middle-income countries should aim to limit new construction now and halt new builds by 2025.
- Governments and multilateral and national development banks should adopt an integrated framework for energy decisions, ensuring a public and transparent consideration of all the costs and benefits of different energy sources, including demand management options, based on consideration of supply costs, energy security impacts, health costs of air pollution, other environmental damage, risks related to climate change and technology learning curves.
- Governments worldwide should steer energy sector investments towards renewable energy sources, energy efficiency improvements and other low-carbon alternatives. Energy efficiency should be prioritised, given the cost savings and energy security benefits it provides.
- Governments should provide assistance to support workers, low-income households and communities in coal-dependent regions and carbon-intensive sectors that may be adversely affected by these policies, to ensure a just transition with appropriate social protection measures, using where relevant some of the revenues from carbon taxes and subsidy reform for this purpose.

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The Project Team

The research partnership and project team have been led by:

Jeremy Oppenheim (Global Programme Director), Manish Bapna, Felipe Benítez, Nicholas Bianco, Milan Brahmbhatt, Sarah Chapman, Tan Copsey, Ian de Cruz, Chris Delgado, Nick Godfrey, He Jiankun, Tom Heller, Michael Jacobs, Rajat Kathuria, Per Klevnäs, Helen Mountford, Måns Nilsson, Mattia Romani, James Rydge, Andrew Steer, Teng Fei, Firew Woldeyes

The global project team (working in various capacities) has comprised:

Nate Aden, Eduardo Assad, Tewodros Assefa, Juliano Assunção, Ferzina Banaji, Kuntala Bandyopadhyay, Fausto Barajas, Ruby Barcklay, Nakia Bell, Russell Bishop, Enrico Botta, Arthur Bragança, Barbara Buchner, Haily Chan, Clementine Chambon, Joana Chiavari, Yong Woon Chung, Cao Jing, Ben Combes, Purnamita Dasgupta, Elena Dawkins, Dong Wenjuan, Lisa Drescher, Jason Eis, Peter Erickson, Gloria Escobar, Graham Floater, Sarah Forbes, Bruno Friedel, Clarissa Gandour, Rebecca Gasper, Ipek Gençsü, Linda Gillespie, Lucy Godshall, Andrew Goggins, Amrita Goldar, Alexandra Gomes, Andrew Gouldson, Gu Alun, Ashok Gulati, Karl Hallding, Karl Hausker, Kirk Hamilton, Craig Hanson, He Kebin, Catarina Heeckt, Stefan Heck, Kimberly Henderson, Cameron Hepburn, Morgan Hervé-Mignucci, Gaetan Hinojosa, Anwarul Hoda, Hong Chaopeng, Mallika Iswharan, Vijay Jagannathan, Frank Jotzo, Tae Yong Jung, Marie Jürisoo, Sung-Jin Kang, Jan Ivar Korsbakken, Ayoung Kim, Soojung Kim, Steven Kyum Kim, Robert Kirchner, Roland Kupers, Johan C.I. Kuylenstierna, Maria-Konstantina Laina, Michael Lazarus, Carrie M. Lee, Eungkyoon Lee, Annie Lefebure, Jeff Lin, Liu Bin, Liu Jiemei, Liu Xiaodong, John Llewellyn, M. S. Mani, Cecilia Mattera, Christoph Mazur, Colin McCormick, Kristin Meek, John Moody, Jennifer Morgan, Austin Morton, Mun Ho, Agastya Muthanna, David Nelson, Michael Obeiter, Michael Oko, Emma Owen, Ou Xunmin, Brendan Pierpont, Breno Pietracci, Amy Pollard, Poorva Puri, Qi Ye, Adriana Quintero, Eustáquio Reis, Leonardo Rezende, Romero Rocha, Philipp Rode, Elysha Rom-Povolo, Daniel Russo, Aparna Singh, Song Ranping, Song Xiulin, Kevin Steinberger, Dan Storey, Claudia Strambo, Anant Sudarshan, Elizabeth Sullivan, Michael Sullivan, Sarah Jo Szambelan, Li Tang, Meenu Tewari, Nikolas Thomopoulos, Caspar Trimmer, Jennifer Tsau, Harry Vallack, Daniele Viappiani, Tom Vladeck, Monica Wang, Wang Yu, Bob Ward, Robert Watt, Lauren Zelin, Dimitri Zenghelis, Zhang Huanbo, Zhang Qiang, Zhao Xiao, Zhou Jian, Zhou Sheng, Cathy Zoi, Julia Zuckerman

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The Global Commission on the Economy and Climate

New Climate Economy
c/o World Resources Institute
10 G St NE
Suite 800
Washington, DC 20002, USA
+1 (202) 729-7600
www.newclimateeconomy.net
www.newclimateeconomy.report

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