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ÉCLAIRE

Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems

Seventh Framework Programme

Theme: Environment

D20.8: Policy recommendations and advice to other interest groups

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Dissemination Level		
PU	Public	☒
PP	Restricted to other programme participants (including the Commission Services)	☐
RE	Restricted to a group specified by the consortium (including the Commission Services)	☐
CO	Confidential, only for members of the consortium (including the Commission Services)	☐

1. Executive Summary

The ECLAIRE project provides information on vegetation impacts of air pollution for the current situation, and it assesses the variations that have to be expected under conditions of climate change. Taking advantage of a new biodiversity-related indicator, impacts of air pollution under different future scenarios have been assessed. An ECLAIRE optimization scenario allows to demonstrate the considerable advantage that biodiversity protection can take from health-related measures on air pollution: Regional European measures on health currently discussed under a commission proposal will also help ecosystems. This is in contrast to plant ozone damage, which preferably can be captured on a hemispheric level. Scenarios for future developments point out that the largest element of change in anthropogenic emissions, which still determine the impacts on ecosystems most strongly, is due to society's choice of ambition in abatement. A need to adapt to future climate conditions can be derived from the fact that, for an accepted level of impacts, climate change will create a need of additional abatement. Costs of such additional abatement will arguably be smaller but arrive at a similar order of magnitude as additional health-related air pollution abatement costs under discussion in the European Commission.

2. Objectives:

This report compiles policy-relevant results obtained in the ECLAIRE project. It provides policy recommendations and advice for dissemination to target groups like Task Forces to the LRTAP convention (TFRN, TFEIP or TFIAM), the International Cooperative Programmes (IPC’s) also under the convention, the European Commission (focussing on the DG Environment) and the European Environment Agency.

3. Activities:

The ECLAIRE component 5 final workshop was called to compile the information needed for this report. Individual results have been received from ECLAIRE component 5 as well as from other project components, as initially outlined in the workplan and refined during the annual project meetings. Individual results were sorted and displayed in a consistent manner.

4. Results:

Using a newly developed indicator to evaluate air pollution effects on biodiversity in protected areas, an ECLAIRE optimization scenario was developed. This scenario, a modification of a human-health related scenario developed under the auspices of the European Commissions, is able to demonstrate the benefits on ecosystems achieved from the efforts to mitigate health impacts. Biodiversity proved to be a robust parameter, both in terms of different valuations arriving at relatively similar results, and with respect of a firm legal basis. While interactions between effects of nitrogen and ozone are basically well known, results here show that piecewise combination of positive effects of N on plant growth and negative effects of ozone exposition can come to explain the major part of observations, with effects levelling off at larger amounts of N deposition. Future reductions of ozone-related damage will depend on achievements on a hemispheric scale, while for biodiversity still regional scale measures are understood to be beneficial. As emissions and plant response depend also on climate, climate change will require adaptation measures to be taken. The higher the expectations on environmental protection, the more costly the additional abatement needed to perform such climate adaptation will be.

5. Milestones achieved:

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6. Deviations and reasons:

This deliverable was originally planned as a joint activity with WP18 but has been widened instead to provide stand-alone documents covering the full extent of relevant policy recommendations from Component 5.

7. Publications:

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8. Meetings:

- ÉCLAIRE Component 5 final workshop, IIASA, Laxenburg (Austria), June 29-30, 2015
- ÉCLAIRE 5th General Assembly, Edinburgh, September 1-4, 2015

9. List of Documents/Annexes:

ECLAIRE policy messages

ECLAIRE policy messages

1. Response strategies to prevent ecosystems damage due to air pollution

Vegetation damage has been a proven effect of air pollution for a long time. In order to tackle the problem within the Convention on Long-Range Transport on Air Pollution (LRTAP), and specifically its Working Group on Effects, bodies like the "Coordinating Centre for Effects", the "ICP Modelling and Mapping" and the "ICP Vegetation" as well as the "ICP Forests" have been set up. These allowed a co-ordinated, Europe-wide research on demonstrated and potential effects observed, and together with the Center on Integrated Assessment Modelling the development of adequate strategies for air pollution policies.

In short, several levels of vegetation damage have been established as relevant. For crops, the main contribution to damage has been the impact of ozone, which was also quantified in terms of economic losses. The flux of this trace gas through stomata of leaves during a plant's growing season has been parameterized as the Phytotoxical Ozone Dose above a flux threshold of 3 nmol/m²/s (POD3), a metric that also considers nighttime-, drought- and temperature-related stomata closures. A like threat exists to forest vegetation, albeit at lower threshold levels: POD1 for forests considers fluxes already above 1 nmol/m²/s. Both metrics replace the previously used concentration-based critical-level parameters "Accumulation over threshold" (AOT).

Other relevant effects refer to the influence of air pollution on soils. Deposition of acidifying compounds, specifically sulfates, nitrates and ammonia (undergoing microbial conversion to nitrates) has been established to cause short-term as well as long-term damage to vegetation, with a recovery period in the range of several decades only. The "critical loads" have been defined as the amount of deposition certain soils are able to withstand without negative effects to plants, with alkaline soils (e.g. limestone) in general less strongly affected. Deposition of air pollutants on agricultural soils obviously is irrelevant, as anthropogenic practices supply soils much more directly (fertilization, liming) in order to correct for any impacts that might impair soil fertility.

The ECLAIRE project aimed to provide updated information on vegetation impacts by adding specific nitrogen-related impacts to the portfolio of issues to be covered. Targeted studies on the interaction between ozone damage, nitrogen impacts on biodiversity and on the potential alleviation of ozone damage by adding nitrogen were performed. All of these activities focused on re-evaluating current policy responses and recommendations on abatement measures. As climate change may affect several of the relationships contributing to any of the impacts discussed, ECLAIRE also addressed the question if these policy recommendations might be considered robust and also valid under climate change conditions, or if there might be situations of measures turning to become disadvantageous in the future.

2. Role for Nitrogen compounds in carbon sequestration:

As in agriculture, additional nitrogen available boosts growth also in forests. Especially in boreal forests, which constitute a significant fraction of forested area in Europe and in the EU, increased anthropogenic air pollution will allow forests to grow more quickly, contributing to enhanced wood production. This assessment is, however, not valid under all circumstances and everywhere. For the more densely populated parts of Europe, where also emissions and deposition of nitrogen compounds (oxidized and reduced nitrogen) occur at a larger rate, continuous long-term deposition has led to demonstrated decreases of forest growth. Studies in Switzerland and in Belgium (Kint et al., 2012) have shown such negative impacts in biomass accumulation, which in at least the latter case have been attributed to the need of growing forest biomass to extract phosphorous from soil, which in the long term resulted in P deficiency in soils currently impeding growth. Also other causes for impeded growth have been discussed, such as ammonia accumulation having negative impacts on nutrient balances, mycorrhiza composition and ground vegetation (Bobbink and Hettelingh, 2011).

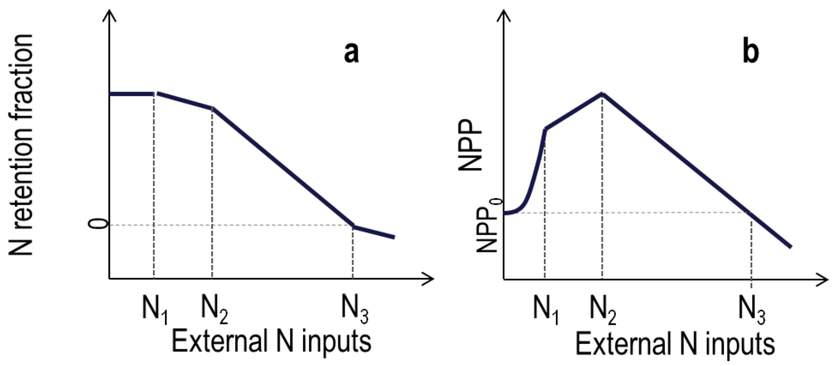

Figure 1: Schematized nonlinear responses of (a) nitrogen retention efficiency and (b) net primary production (NPP) to external of N inputs to forests (de Vries et al., 2014). N_1 indicates a change point at which nitrogen retention efficiency starts to decrease and the NPP increase levels off. N_2 indicates a change point at which forest ecosystem start to become saturated in nitrogen and NPP declines with further nitrogen addition. N_3 indicates a change point at which forest ecosystems are completely N saturated and NPP is below the value at no addition.

Fig. 1 (from de Vries et al., 2014) displays the response of N retained and of biomass growth as a function of atmospheric deposition of nitrogen. At levels below N_1 nitrogen is effectively absorbed by biomass, and not released to the environment, while significant growth advances become evident. Above that level nitrogen starts to leak and possibly affects other environmental pools. Growth still increases but arrives at a maximum level N_2, beyond which addition of nitrogen leads to a decline of growth, at least at first still much higher than in an unaffected “natural” system.

As argued by a consensus report (annex to ECLAIRE deliverable D20.7), the level of nitrogen deposition at which growth is impaired (N_2) can experimentally be found as low as 15 kg N/ha and year, at least on a long term. Using a precautionary principle, this lower end of the range should be chosen to establish a threshold that should not be exceeded in order to not impede on forest growth. That level, however, must not be understood as conflicting with any possibly lower thresholds implemented to protect other ecosystem-relevant parameters. Again as indicated in Fig. 1, the system leaks nitrogen even before arriving at point N_2. This release may give rise to soil acidification and/or to eutrophication, and limits set to mitigate such damage may not be compromised by possibly less stringent requirements to protect forest growth.

3. Ozone

GAINS scenarios run in ECLAIRE show that there is only limited potential of emission reductions to further reduce vegetation exposure to ozone. While significant improvements have been seen in the past, due to reductions of emissions of NOx e.g. by introducing the 3-way catalyst in gasoline-driven vehicles, or reducing emissions of Volatile Organic Compounds from the use of solvents in industry, the technical potential for further improvements beyond the current legislation already implemented (including reductions in NOx from diesel engines promised but not fully delivered yet by car manufacturers) and effective by 2030 is quite limited. Main reasons are the rather small sensitivity of POD values on changes in emissions, and the considerable effects of hemispheric background concentrations on the European conditions.

Fig. 2 presents these results in detail. Data derive from a number of different studies and are explained in detail in ECLAIRE deliverable D20.7. In addition to POD values, the figure also includes the SOMO35 metric (Sum of

Ozone Means Over 35 ppb), which is considered relevant for human health protection. All data are given relative to the year 2010 and in relation to the hemispheric background situation. It becomes evident that the ozone flux endpoints (POD1 or POD3) become virtually undistinguishable on a relative scale, and also that it is a very insensitive parameter, compared to e.g. SOMO35: strong changes in input (emissions) will result only in little effective variation. Nevertheless, a clear decrease can be demonstrated between 1990 and 2010, despite of the increasing hemispheric background and (economic) activity numbers which would have triggered further increase towards the "hypothetical 2010" markers. Further improvements may be expected under "current legislation" for the year 2030. Using the technological optimum of emission abatement measures implemented in GAINS, in 2030 the Maximum Technically Feasible Reductions (MTFR) may be achievable. This technological optimum, which comes at considerable abatement costs, shows rather little difference from the expected 2030 situation – much less than what has been achieved between the "hypothetical" and the actual 2010 results. Note that the EU Commission's Clean Air proposal for human health protection (see Amann et al., 2014, for details) comes up with clearly lower ambitions, which would result only in a quarter of the MTFR achievements. Returning to the 1990's hemispheric ozone background would allow arriving at twice the positive effects on reducing ozone damage to vegetation compared to the Commission proposal.

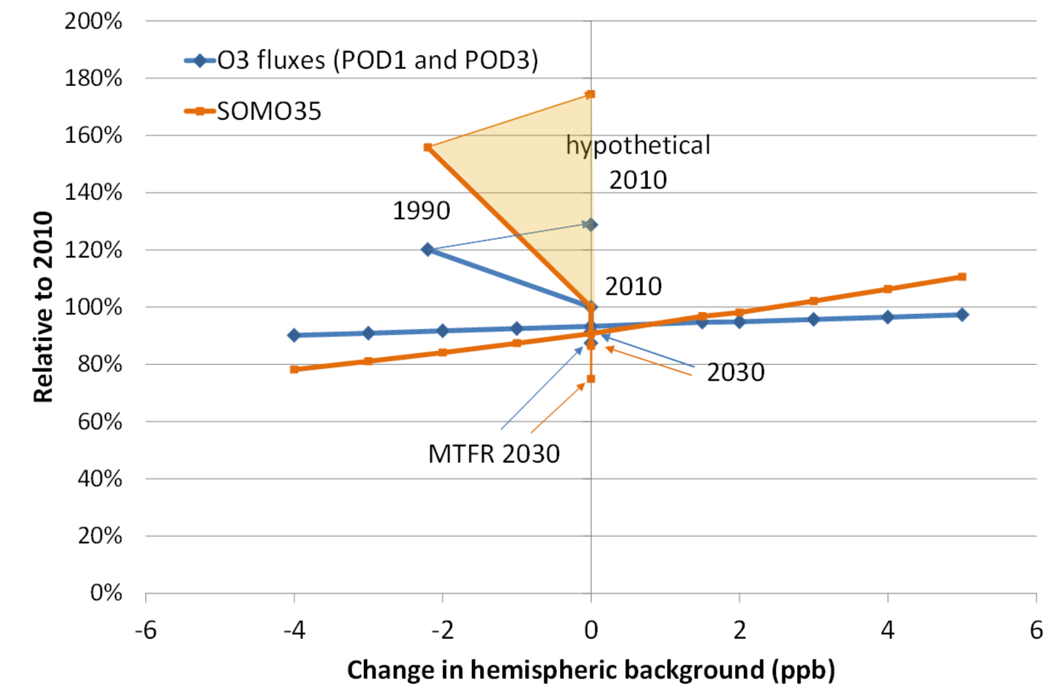

Figure 2: Developments of relative POD and SOMO35 (human health-related) changes in the past (starting from a lower hemispheric background) and expectations under current legislation as well as potential for the year 2030.

In consequence, further reductions of emissions from European sources are unlikely to be effective in reducing plant exposure to ozone by 2030. Instead, improvement of the hemispheric background situation (much of it via reducing CH_4 emissions) seems to be able to further reduce ozone damage to plants in Europe, while simultaneously improving the air quality situation in India, China or in North America. Here the hemispheric interactions allow to establish positive results across the continents, if air pollution measures are properly implemented.

4. Ozone and nitrogen interaction

Both ozone (in terms of entering stomata and becoming disruptive in the physiological processes) and deposited nitrogen (in form of N concentrations found in leaves) are deeply entangled in the photosynthesis process and thus the key plant activity governing biomass formation and plant growth. The mechanisms have been investigated in ECLAIRE and the status is described in ECLAIRE deliverable D12.3, which uses the An-gsto

DO3SE model to parameterize the underlying relationships. That activity aimed at establishing revised dose-response relationship between ozone and net annual biomass increments in forests considering N impacts.

In essence, the interaction may be regarded in two contrasting ways. Ozone can be seen to impede the fertilizer effect of N, but likewise the addition of N can be considered a way to alleviate ozone damage. Both views just represent a different aspect of the same facts. The dose-response relationships presented in ECLAIRE deliverable D12.3 (their Fig. 13) demonstrate that, under any level of available N, POD will have a consistent and rather constant negative effect on biomass increments. Stark differences are to be seen between different plants (deciduous vs. coniferous trees). Moreover, at higher levels of N deposition (again, depending on tree species: a generalized level would be around 2000 moles per ha and year or ~30kg/ha N) leaf N concentrations (and hence effects on photosynthesis) will level off as a function of deposition. Hence the beneficial effects of adding N to compensate negative impacts of O3 will be lost at such high deposition rates.

5. Ecosystems services

Work in ECLAIRE demonstrated that, while effects of air pollution on ecosystems are evident, quantification in monetary terms (as an input to cost-benefit analysis) proved to be challenging. While for some services provision of data is straightforward (e.g., the relationship of forest productivity as a function of temperature change, CO2- and N-fertilization is an ECLAIRE output – ECLAIRE deliverable D15.4), other possible services can be identified only without robust quantification. Neglecting these relationships would imply to set the effects to zero, which is clearly unreasonable. Therefore ECLAIRE deliverable D18.2 as well as Maas (2014) attempt to overcome these issues.

The following elements have been investigated in these studies:

- Marketed ecosystem services
- Willingness-to-pay for non-marketed services
- Restoration costs
- Elimination costs
- Legal requirement approach on conservation
- Nitrogen Use Efficiency approach

While only the first and the last bullets provide actual market based figures (in the case of the last bullet, via the amount of fertilizer saved under improved N use efficiency), a comparison of three independent approaches (restoration costs, willingness-to-pay and elimination costs) converged at a common value – at a benefit/cost ratio that was considered to be markedly lower for biodiversity protection than for health protection.

Further to the economic valuation of ecosystems, a decision has already been taken by society in protecting certain nature areas, the “Natura 2000” areas. Legal obligations exist demanding “no net loss of biodiversity” from these areas in the EU28. Based on this legislation, a firm and consistent guidance to air pollution impacts can be developed. This requires to establish “biodiversity” as an endpoint in the GAINS system, using atmospheric emissions and abatement strategies as an input. The underlying assumptions and strategies have i.a. been reported in ECLAIRE deliverable D19.4.

6. Eclaire optimization scenario and biodiversity benefits from health-related measures

Using the “biodiversity” approach, an optimization scenario (“illustrative ECLAIRE scenario”) has been developed. This allows to take a look of advantages from proposed health related air pollution abatement with respect to biodiversity. The “cost curve” presented in Fig. 3 describes the cost of abatement measures (above the CLE costs) needed to arrive at a given target. In this metric, the target is a certain percentage of the difference between the "current legislation" (CLE) at 0 and the "maximum feasible reduction" (MFR) scenario at 100, taken from the total cumulated threshold exceedance of all protected areas in EU28. The scenario has been described in all details in ECLAIRE deliverable D20.7.

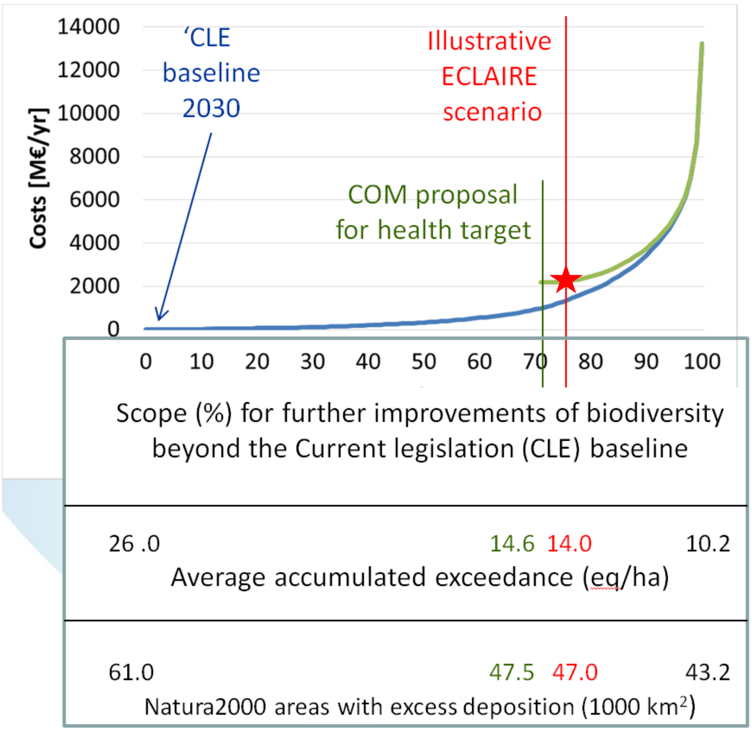

Figure 3: GAINS cost curve for optimizing starting from baseline (blue) vs. from the commission proposal on human health protection. The illustrative ECLAIRE scenario developed here is marked by the red asterisk

As shown in Fig. 3, just implementing the health related commission proposal (in the version as described by Amann et al., 2015) will take care of 71.2% of the maximum achievable by technical measures. No specific consideration on biodiversity needs to be taken as emission abatement measures are largely the same. Note that originally this commission proposal has been defined to take care of 67% of the potential to mitigate the "Years of life lost" parameter.

In order to demonstrate the effect of a marginal change, the ECLAIRE scenario optimizes abatement measures at a level that just slightly exceeds those of the commission proposal, while maintaining the health target of 67% it simultaneously increases the biodiversity gap closure to 75%. The average accumulated exceedance (per ha of protected area) decreases, from the CLE case roughly to one half, while the area exceeded decreases somewhat less, by only a quarter. Compared to what had been achieved already in the commission proposal, the decrease extends to about 4% of exceedance (and 1% of area). In order to achieve these improvements, additional costs extend to just 23 M€ or 1.1% of the costs assigned to the commission proposal (additional to those already spent for the CLE scenario).

Starting from the health target as included in the commission proposal not only allows to have a considerable share of possible measures achieved already. It furthermore allows taking advantage of a piece of a cost curve of rather gentle slope – where a limited set of further measures indeed proves very cost-effective.

7. Impacts of a future climate

Several of the relationships described by GAINS are affected by climate, most prominently by ambient temperature and by humidity/precipitation. With an increasing understanding of the future climate impacts in 2050 and in a more distant future (here termed the "nominal 2100 scenario"), it becomes relevant to shed light also on the effects a changed climate may have on vegetation response to air pollution.

In ECLAIRE, several elements of variation were considered which would have impacts on vegetation. First of all, this regards anthropogenic activities and implementation of technologies that regulate the emissions of air pollutants. Next, temperature may have a direct effect on specific emissions, especially those that result from biological processes occurring in an outdoor environment (as is quite typical for ammonia emissions). Also the extent to which new technology can be developed and implemented is not known. Finally, out of the available options to abate emissions certain sets will be chosen – as a consequence of legal requirements, of environmental policies or voluntary action. An approximation of the respective impacts is provided in Fig. 4, the background information of which is described in detail in ECLAIRE deliverables D20.6 and D20.7. This figure shows that the ammonia emissions are strongly affected by assumption on future human activity level, but even more by the selection of abatement strategies here subsumed under "management" – the difference between what we regard as "current legislation" and the "maximum feasible reduction" technologies. This allows to conclude that still the largest and part of variation of future emissions, decisive for the environmental impact in general, is in the choice of human societies. Direct temperature-related effects which would impact emissions are, in this analysis, considered to be less relevant contributors of change.

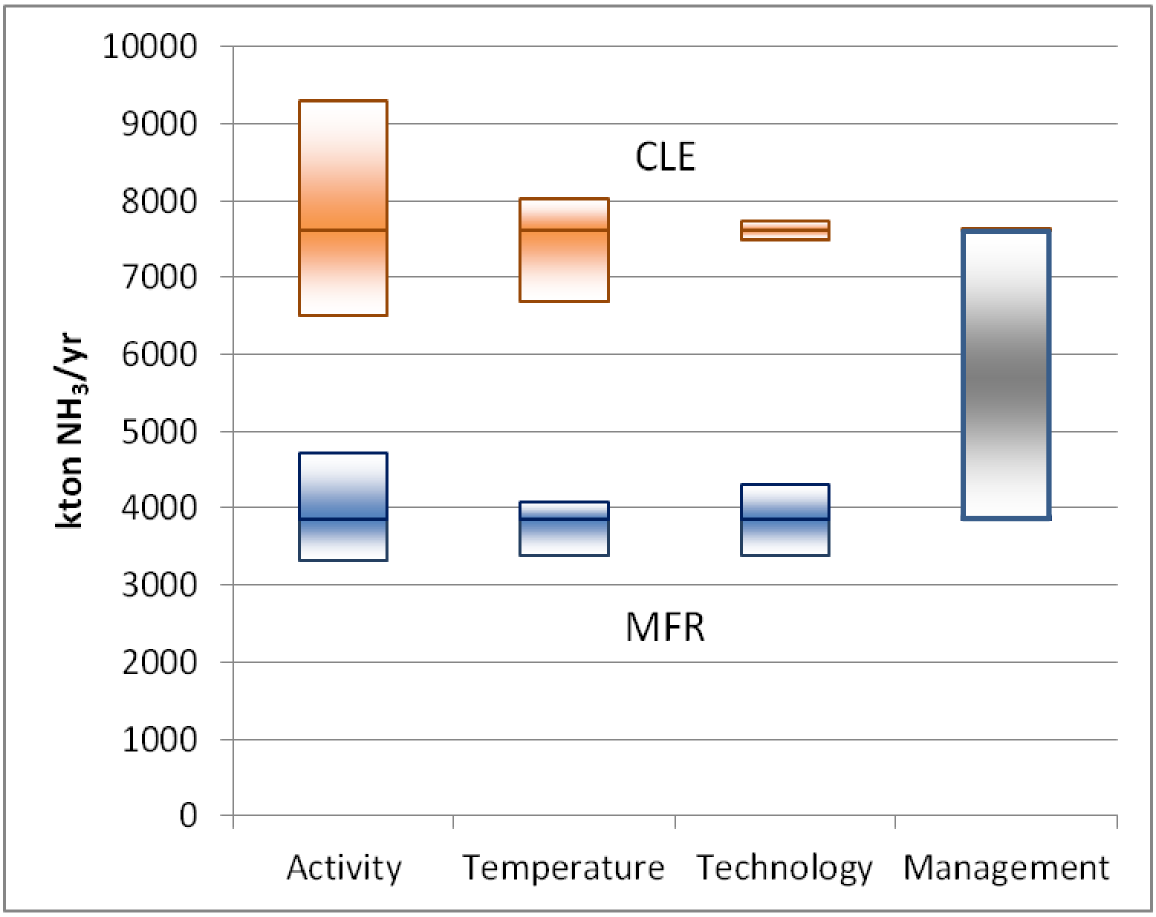

Figure 4: Emissions of NH3 and ranges of uncertainty of future emissions ("nominal 2100") as the total of 40 European countries

Beyond the emissions, also other climate-relevant effects may emerge. One aspect refers to the sensitivity of ecosystems to air pollutants. With regard to the biodiversity indicator developed in ECLAIRE, critical loads have been assessed for the conditions of a climate scenario representing 2050 as well as 2100. An overall increase in sensitivity can be demonstrated, i.e. the same level of negative effects already appears at lower levels of emissions. Information on revised atmospheric transfer and deposition patterns is not available. For biodiversity, where impacts depend on deposition of sulfur and nitrogen compounds, at least the total of such depositions may be considered stable as compounds are conserved in the atmosphere and total emissions closely match total deposition. Using available emission projections from the RCP process feeding into IPCC's AR5, for ECLAIRE deliverable D20.7 we assessed the overall deposition patterns for a "nominal 2100" case. It turns out that the underlying emission projections have been based on technologically very optimistic assumptions, and especially that all available scenarios expect the NOx reductions that are technologically feasible to be widely implemented. This leads to a methodological discrepancy between reduced and oxidized N compounds that only can be resolved once the next generation of emission data being produced for IPCC becomes available (the "SSP" scenarios are already on their way).

Future climate may impact also in another way. All else being equal, changed temperature and precipitation pattern that causes vegetation damage will increase the need to address that damage. Additional efforts here need to be regarded a climate adaptation measure. The extent of such adaptation may be assessed from Tab. 1, where we investigate impacts of an increased temperature (for a 2050 situation only) on climate change due to altered NH_3 emissions as well as due to changed vegetation impacts. Again, the detailed assumptions are provided in ECLAIRE deliverable D20.7.

Table 1: Costs to compensate increased biodiversity impacts caused by climate change

	Central case, Current climate 2030		With biodiversity indicators under climate change**)			With higher NH3 emissions due to climate change ***)		
	HS indicator (eq/ha)	Costs *)	HS indicator (eq/ha)	Additional costs to return to central case *)		HS indicator (eq/ha)	Additional costs to return to central case *)	
CLE	26.0	0	30.9	+95	0.11%	26.7	+26	0.03%
COM proposal	14.6	2189	17.7	+889	1.03%	14.9	+236	0.27%
ECLAIRE scenario	14.0	2212	16.3	+1333	1.54%	14.4	+386	0.33%

*) costs in M€/yr, on top of current legislation /% of CLE costs
**) for 2050 climate scenario (~1° higher temperature)
***) 4% increased total NH3 emissions in EU-28

In the analysis presented in Tab. 1, the impact of revised sensitivity of biodiversity as well as of increased NH3 emissions are calculated for their 2050 case, but for the matter of just determining adaptation costs anthropogenic activities and implemented technologies are kept at a 2030 CLE situation as the central case. Results indicate (i) that the effect of climate on the sensitivity of biodiversity seems larger than that of increased ammonia emissions (at least under the assumptions documented in the ECLAIRE deliverables D20.6 and D20.7) and (ii) that adaptation seems readily available at low costs in the CLE case, but may become quite costly (smaller but similar range than the measures alone) once applied on existing abatement strategies. In those cases, the cheap options have been taken already which limits further possibility of low-cost abatement. Only the additional costs under CLE are in the range of the additional costs created by the ECLAIRE scenario alone (23 M€/yr above the COM proposal).

These results point to the continued need to assess and evaluate ecosystem and biodiversity damage due to air pollution. With adaptation costs increasing strikingly with increased ambition to maintain vegetation and its functions, an abatement regime will need to be pursued actively. If adding costs involved to the overall costs of climate impacts, there is even more reason to tackle greenhouse gas emissions as the primary cause of climate change.

8. References

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