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ADAPTATION TO CLIMATE CHANGE

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Securing Water, Energy, Food & Ecosystems in the Júcar River Basin District, Spain

Shaping ecosystems and protecting resources supporting Climate Adaptation

In the heart of Spain's Júcar River Basin District, a stakeholder engagement initiative addressed the complex relationships within the Water-Energy-Food-Ecosystem (WEFE) Nexus, developing tools, methods and collaborative frameworks to create climate-resilient systems.

Key Learnings

- **Science as a Compass**: A dedicated data observatory supports informed decision-making by collecting and analysing environmental information. Integrating tools like the water footprint methodology into Water Plans sets new standards for evidence-based climate strategies.
- **Collaboration as a Catalyst**: Diverse stakeholders, like farmers, authorities, and researchers, collaboratively developed practical solutions while considering local circumstances and ensuring long-term commitment. Training young leaders and assuring locally developed solutions align with regional, national and global targets ensures knowledge transfer, provides the tools to overcome global challenges, and facilitates solution replication.
- **From vision to action**: Moving from "Nexus thinking" to "Nexus action" allowed turning ideas into tangible and replicable solutions. Interdisciplinary collaboration and community empowerment led to successful transformations. Involving locals in the search for adaptation solutions strengthened trust and ensured regional implementation.

About the region

The Júcar River basin District (Figure 1), located in the Mediterranean region in South-Eastern Spain, covers over 42,000 km² and is home to more than five million residents. With 500mm average annual precipitation, the basin depends on surface and groundwater, inter-basin transfers, desalination and wastewater treatment to meet the water demand for agriculture, urban uses, industry, and the energy sector. The Júcar River Basin Authority under Spain's Ministry of Ecological Transition oversees water management and implements the EU Water Framework Directive. The Júcar Basin spans five autonomous communities and seven provinces. Mountains, coastal areas and wetlands characterise the landscape, with the Mancha Oriental aquifer connecting to the Júcar River in the West, and the l'Albufera de València providing a Ramsar site, meaning a protected wetland of international importance.

Climate Hazards

Extreme Heat, Droughts, Flooding, Water Scarcity

Sector

Water Management, Agriculture, Energy,

Biodiversity protection

Key system

Water Management, Ecosystem and Nature

Based Solutions, Land use and Food systems

Figure 1. Jucar River Basin District. Image Credit: REXUS.

Climate Threats

The Júcar River Basin faces several challenges due to climate change, such as droughts, extreme temperatures, water scarcity and heavy rain. Combined with population growth, unsustainable water management practices and competing demands for natural resources, climate change is leading to erosion, reduced soil health and biodiversity loss. Water scarcity and irregular rainfall threaten agriculture, urban water supply, and energy production, making effective water resource management essential to ensure food, water, and energy security while preserving the ecosystem. In October 2024, the Dana Floods showed the devastating impact heavy rains can have on the region's ecosystems, infrastructure and communities. Projections estimate that climate change will severely reduce water availability, making immediate action essential.

A clear roadmap with preventive measures, integrating science, society, and policy, and increasing coordination and financial capacities can support climate resilience. To achieve this, opportunities for adaptation exist via EU-aligned strategies, conservation, and innovation. The image below shows the

natural landscape of the Júcar River, showing the natural landscape of the region (**Error! Reference s ource not found.**).

Figure 2: The Jucar River. Image Credit: REXUS.

What is the "WEFE Nexus"?

The Water-Energy-Food-Ecosystem (WEFE) Nexus is an approach that examines the connection between water, energy, food, and ecosystems. Considering these links can support designing solutions that simultaneously meet water needs, support agriculture, protect nature, and be energy efficient. This means measures such as water-saving irrigation, restoring riverbanks for flood prevention, and coordinated planning across sectors to meet climate adaptation requirements. In practice, the WEFE Nexus leads to smarter and more resilient ways to manage resources under climate change.

Jucar Basin Applications: Adaptation Approaches and Mechanisms

The Water-Energy-Food-Ecosystem (WEFE) Nexus provides an integrated approach to managing interconnected resources, which is especially relevant for water-stressed regions such as the Jucar Basin in Spain.

WATER FOOTPRINT AND WATER ACCOUNTING

In recent years, remote sensing techniques have facilitated identifying water stress. Targeted water management approaches use this information to monitor crop conditions and optimise irrigation practices, helping to assess agricultural water requirements. Data on domestic and industrial consumption feed into water use databases and support the development of accurate environmental water footprint indicators. The “Water Footprint” considers water metrics such as green water from rainwater use (Figure 3), blue water for irrigation (Figure 4) and grey water, defined as water required to dilute pollutants to meet water

quality standards. Remote sensing contributes to calculating the water footprint by providing spatially explicit information on land use patterns, vegetation growth, and crop yields.

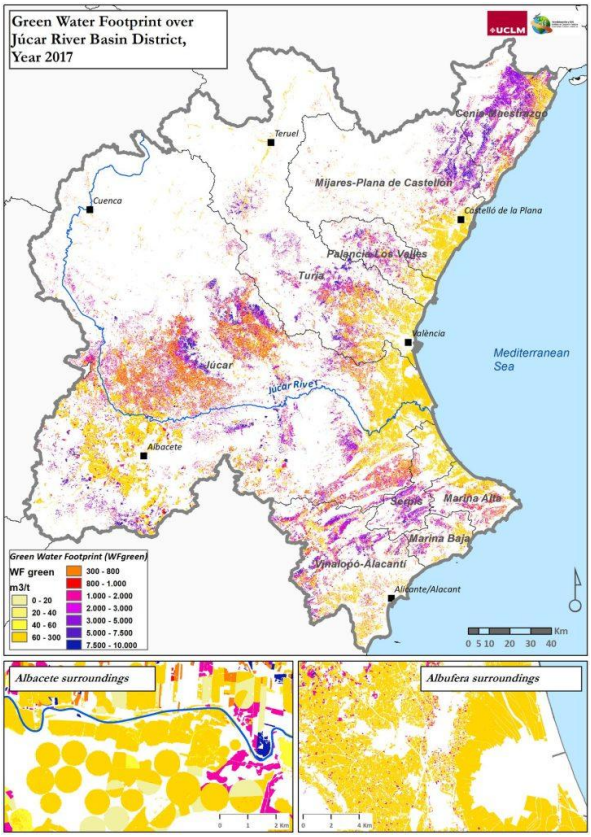

Figure 3. Green Water Footprint (rainwater use) over Júcar River Basin District. Image Credit: REXUS.

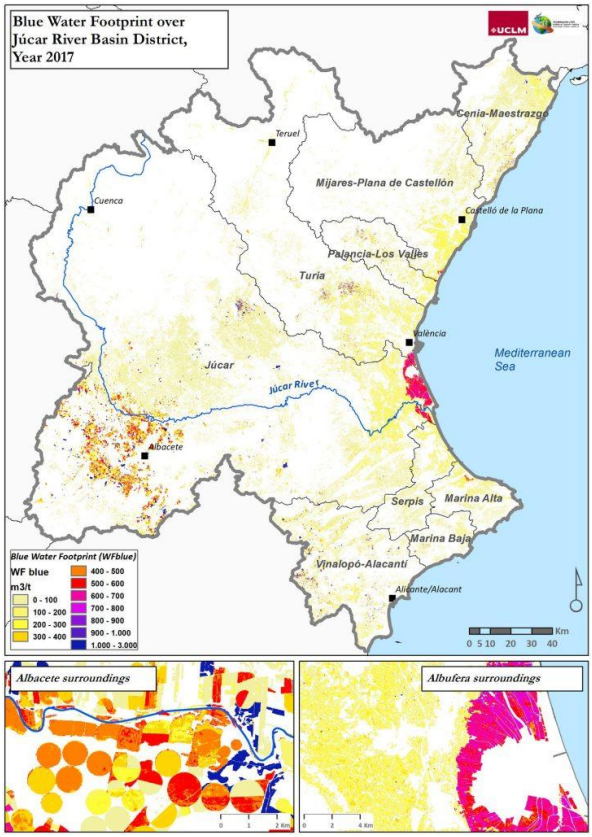

Figure 4. Blue Water Footprint (irrigation) over Júcar River Basin District. Image Credit: REXUS.

While the 'agricultural water footprint' provides an indicator of the green, blue, and grey water consumed in crop production, 'agricultural water accounting' refers to the systematic quantification of actual water inflows, withdrawals, consumption, and return flows within a basin. In practice, footprint data can inform accounting processes, but water accounting has a broader scope as it connects these indicators with basin-scale allocation, planning, and management.

Agricultural water accounting in the Júcar Basin allows precise quantification of the water demands of different crops in the Júcar Basin. Assessing needs at various scales, from individual plots to entire irrigation districts, integrating water accounting with water footprint analysis, and embedding these methods into the Júcar Basin Hydrological Plan, 3rd period 2022-2027, has promoted data-driven and climate-resilient water management. This integration allows water managers to align allocations more closely with actual crop demands and adapt to climate variability. Close collaboration between the project team and the Júcar River Basin Authority, local water user associations such as the "Junta Central de Regantes de la Mancha Oriental (JCRMO)", and municipal water managers enabled fruitful outcomes in joint workshops, technical meetings, and field demonstrations. These collaborations improved water allocation accuracy, reduced over-extraction, and fostered stakeholder trust and knowledge exchange. The results have informed decision-making, supporting the adoption of efficient irrigation practices and the prioritisation of water allocations during drought events. Incorporating these considerations into basin management plans has strengthened the region's resilience to ongoing climate challenges.

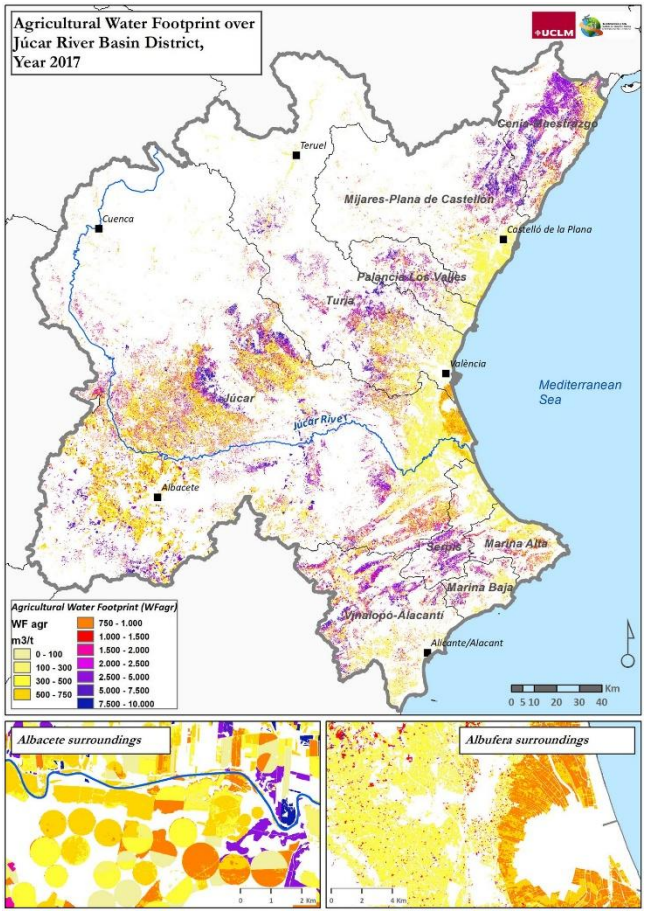

Figure 5. Agricultural Water Footprint over Jucar River Basin District. Image Credit: REXUS.

PARTICIPATORY SYSTEM DYNAMICS MODELLING FOR POLICYMAKERS

In the Júcar River Basin, a participatory system dynamics modelling framework has marked a significant shift in understanding and addressing complex watershed challenges. Over the past three years, the project team, under CNR-IRSA's lead, has developed the framework, using Casual Loop Diagrams (Figure 6) to visualise cause-and-effect relationships and support the transition from nexus thinking to Nexus action. Systems thinking encourages viewing the basin as an interconnected asset, where changes in one area affect the entire system. Encouraging stakeholders to co-create these diagrams captures valuable on-the-ground insights. The diagrams show how policy, climate, and local practices interact to shape outcomes across the basin.

The approach identifies challenges and sectoral conflicts and pinpoints policy leverage points (Table 1). Tackling unauthorised groundwater extraction is a prime example: even minor changes, such as improved monitoring or community-led reporting, can have a strong impact. The measures can restore balance to groundwater levels, enhancing ecosystem health, and ensuring long-term water security for all users. Computer simulations (scenario modelling) help stakeholders understand the potential impacts of their decisions on other sectors, supporting holistic thinking and maximising overall benefits.

Rather than relying solely on top-down technical assessments, Participatory System Dynamics Modelling brings together diverse stakeholders, such as farmers, urban water users, environmental groups, industry

representatives, and public agencies, to collectively map the complex interconnections that define the region's water, energy, food, and ecosystem Nexus. Stakeholder engagement fosters collaboration, builds trust and ensures topic relevance while addressing stakeholder needs and reducing potential conflicts.

Figure 6. Project collaboration in the Jucar Basin: Creating CLDs, identifying resources and risks, and teamwork. Image Credit: REXUS.

The mapping exercise depicted interconnections within the WEFE Nexus and revealed gaps, such as underrepresented energy-related questions. The exercise involved participatory workshops in which stakeholders and experts jointly developed causal maps linking water availability, agricultural practices, hydropower production, ecosystem services, and food security. The process highlighted the strong influence of irrigation efficiency on groundwater quality and ecosystem health, while also revealing that energy linkages – such as electricity demand for pumping or the use of renewables in irrigation – are insufficiently addressed in existing assessments. Expert input and targeted literature searches were used to refine and complement these missing elements. The exercise enabled stakeholders to understand

interconnections and develop better-suited policies for the basin. Improving water quality and supporting ecosystem services involves stricter groundwater monitoring using smart meters and remote sensing and promoting Nature-based Solutions like constructed wetlands. Encouraging sustainable farming practices, such as cover cropping, crop rotation, no-till methods, and organic farming, also helps protect soil and maintain healthy wetlands. These policies foster cross-sectoral collaboration and adaptive management, addressing immediate challenges and long-term resilience in the Júcar Basin.

Table 1: water, energy, food, and ecosystem nexus challenges at the Júcar River Basin and associated leverage points.

Nexus Challenges	Leverage Points
Soil degradation and desertification	• Protection of the natural soil cover • Sustainable agricultural practices • Territory control • Farmers' environmental awareness
Júcar baseflow	• Innovative irrigation system • Institutional reputation (i.e., when water institutions are trusted, stakeholders are more likely to follow water allocation rules, monitoring protocols, and conservation measures, which reduce illegal or excessive groundwater pumping) • Farmers' environmental awareness
Albufera wetland state	• Sustainable agricultural practices • Return flow • Protecting agricultural practices
Unauthorised groundwater abstraction	• Innovative irrigation system • Farmers' income • Farmers' environmental awareness
Energy production (focus on finding alternative energy sources and efficiency)	• Innovative irrigation system • Alternative energy sources

The Participatory System Dynamics Modelling assessment combines scientific and local knowledge to map complex intersectoral relations. Casual Loop Analysis combined with Graph Theory, which creates and shows a network of points and lines, reveals challenges and leverage points to design effective policies, encouraging long-term adaptation and tailored actions.

While these advances have laid the groundwork for more adaptive and inclusive governance, the journey is ongoing. The next steps involve making these approaches even more accessible and useful for stakeholders. Further developing quantitative system dynamics models, simulating the impacts of different policy decisions, ensures the insights gained from participatory modelling translate into real-world action.

Testimonials from Key Stakeholders

"The nexus assessment allows us to achieve a sustainable transition, by meeting demands as well as achieving environmental objectives, with more coordination between the different levels of competence and the different sectors.",

Laura Tanco, River Basin Authority

"Scientific tools like REXUS give policymakers confidence and direction. Organisations and public administrations must utilise these tools to offer the necessary support. Often, the general public may not see this directly, but without research, we would be adrift.",

Herminio Molina, Farmer and Former president of Irrigators board

The adaptation actions brought together local, regional and national stakeholders – including municipalities of Palma de Gandia and Albacete, Regional Governments (Valencia and Castilla La Mancha), the river basin authority (CHJ), irrigation communities (Junta Central de Regantes de la Mancha Oriental, FENACORE), the Ministry of Agriculture, Fisheries and Food (MAPA), the Ministry for the Ecological Transition (MITECO), agricultural cooperatives, farmers, energy providers and NGOs.

The project team facilitated participatory workshops and technical meetings, developed decision-support tools, and co-designed adaptation measures tailored to the basin´s unique risks. A key outcome is the implementation of the REXUS Water Footprint in the Basin 3rd cycle Hydrological Plan.

Summary

In Spain's Júcar River Basin, a collaborative initiative applied the Water-Energy-Food-Ecosystems (WEFE) Nexus approach to tackle climate threats like drought, flooding, and water scarcity. Combining scientific approaches like water footprint analysis, remote sensing, and participatory system dynamics modelling with stakeholder engagement enabled informed, inclusive decision-making and locally tailored adaptation solutions. Key outcomes included improved water accounting while integrating innovative methods into the regional Water Plan, and boosted greater trust among farmers, policymakers, and researchers. Innovative irrigation systems improve water use efficiency and reduce the energy needed for pumping and distribution. Combining these systems with renewable energy technologies reduces fossil fuel dependence and enables more efficient local energy production as well as the integration of renewables into farm operations. This supports sustainable energy generation and more stable energy use patterns in agriculture. Alternative energy use emphasises the shift towards renewables, which efficient water use underpins by aligning water and energy needs, smoothing demand peaks and allowing for tailored adoption of energy solutions suited to local climate and resources. This transition from "Nexus thinking" to "Nexus action" positioned the basin as a replicable model for climate-resilient, sustainable resource governance.

Further information

The work presented in this adaptation story is part of the REXUS project.

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- Videos: https://www.youtube.com/@rexusproject; https://youtu.be/52-qzS4Qrhk

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