UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas

Non-conventional resources in water management in agriculture: challenges and opportunities

DOCTORAL THESIS

Submitted for the degree of Doctor by:

Cintya Villacorta Ranera
M.Eng. Agricultural Engineering
M.Sc. Agricultural, Food and Natural Resource Economics

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Dr. Irene Blanco Gutiérrez

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A mi familia

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“Nada en la vida debe ser temido, solamente comprendido. Ahora es el momento de comprender más, para temer menos.” Marie Curie

Cuando estaba en el instituto, mi profesor de Biología me dijo que algún día sería como Marie Curie. Con el tiempo he comprendido lo vasto que es el mundo y lo difícil que resulta dejar una huella en él. Sin embargo, sigo convencida de que cada pequeño gesto puede contribuir a mejorarlo, aunque sea un poco. Inspirada por las palabras y el ejemplo de Marie Curie, he afrontado esta tesis doctoral con curiosidad, perseverancia y pasión por aprender, incluso cuando el camino ha sido complejo. Por ello, quiero expresar mi más sincero agradecimiento a todas las personas que me han acompañado en este proceso.

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Abstract

Growing pressure on water resources is challenging the sustainability of conventional groundwater and surface water supplies in many semi-arid regions worldwide. As agricultural systems adapt to these constraints, non-conventional water resources (NCW), particularly reclaimed and desalinated water, are increasingly considered strategic components of future irrigation portfolios. Understanding the barriers, opportunities and governance conditions that shape their adoption is therefore critical for developing resilient agricultural water-management strategies.

Against this backdrop, the overall objective of this thesis is to analyse the challenges and opportunities associated with the adoption of NCW in Spanish agriculture. The study focuses on the Region of Murcia and the Campo de Cartagena Irrigation Community (CRCC), one of Europe's most productive yet water-stressed agricultural areas, and a longstanding pioneer in the use of NCW. Four specific objectives guide the research: (i) identifying and systematising barriers that limit the expansion of reclaimed water; (ii) examining social perceptions and sources of disagreement surrounding its use; (iii) analysing how socio-economic, regulatory and technological drivers influence NCW adoption from stakeholders' perspectives; and (iv) quantifying the capacity of NCW to mitigate reductions in conventional water supplies.

To address these objectives, the thesis combines four complementary methodological approaches: a systematic literature review and cross-impact analysis to map and classify barriers related to reclaimed water use; Q methodology to uncover social perspectives on reclaimed water; a participatory Fuzzy Cognitive Map (FCM) to model stakeholder-informed water-management dynamics and simulate future scenarios; and a farm-based agro-economic positive mathematical programming (PMP) model to evaluate irrigation-system responses to changes in water availability, supply composition and water prices.

The literature review and cross-impact analysis show that, although reclaimed water use in Spain is expanding, supported by technological advances and regulatory improvements, its adoption remains constrained by socio-economic, technical, environmental, legal and institutional barriers. High costs, administrative complexity, limited coordination, concerns about environmental impacts and persistent scepticism among some users continue to hinder wider uptake, underscoring the need for more coherent and targeted support measures.

The Q-methodology results reveal three dominant social discourses: (i) reclaimed water as a means to secure agricultural supply; (ii) as a resource with potential for improvement; and (iii) as a source of environmental concern. While all discourses agree that consumers lack adequate information about the quality and benefits of reclaimed water, they diverge on issues such as cost allocation and perceived environmental risks. These findings point to the need for clearer communication, improved cost-sharing mechanisms and targeted environmental safeguards.

The FCM analysis shows that NCW adoption depends on a tightly interconnected set of factors, largely concentrated in the economic-technical dimension. Scenario simulations reveal that integrating renewable energy, strengthening technical capacity and expanding desalination production can enhance NCW uptake and reduce environmental pressures, whereas phasing out desalination subsidies substantially weakens system performance. Across all scenarios, the implementation of the Segura River Basin Management Plan (RBMP) further increases the strategic importance of NCW.

The agro-economic modelling demonstrates that reduced water availability from conventional resources, particularly the Tagus–Segura Water Transfer (TST), leads to marked declines in profitability, irrigated area and employment in the CRCC, reflecting the system's high dependence on external resources. However, the simulations indicate that a balanced portfolio of mitigation strategies, combining desalinated water, reclaimed water, groundwater, subsidies and cost-reducing innovations, can offset much of these losses. These measures help stabilise farm income and maintain cultivated area, although their effectiveness remains conditioned by economic trade-offs, environmental constraints and the long-term sustainability of each source.

Overall, the thesis shows that NCW can play a strategic role in strengthening water security and supporting agricultural livelihoods under growing scarcity. However, their effective integration requires coherent governance, coordinated policies, economic incentives and socially legitimate decision-making. The results provide practical insights for designing resilient and diversified water strategies in southeastern Spain and offer a reference for other regions facing similar challenges.

Resumen

La creciente presión sobre los recursos hídricos está poniendo a prueba la sostenibilidad de los suministros convencionales de aguas subterráneas y superficiales en muchas regiones semiáridas del mundo. A medida que los sistemas agrícolas se adaptan a estas limitaciones, los recursos hídricos no convencionales (RHNC), especialmente agua regenerada y desalada, se consideran componentes cada vez más estratégicos de las futuras carteras de riego. Por tanto, comprender las barreras, oportunidades y condiciones de gobernanza que determinan su adopción es crucial para desarrollar estrategias resilientes de gestión del agua en la agricultura.

En este contexto, el objetivo general de esta tesis es analizar los retos y oportunidades asociados con la adopción de los RHNC en la agricultura española. El estudio se centra en la Región de Murcia y en la Comunidad de Regantes del Campo de Cartagena (CRCC), ambas son zonas agrícolas muy productivas de Europa, aunque con estrés hídrico, y pioneras desde hace mucho tiempo en el uso de RHNC. La investigación se organiza en torno a cuatro objetivos específicos: (i) identificar y sistematizar las barreras que limitan la expansión del agua regenerada; (ii) examinar las percepciones sociales y las fuentes de desacuerdo en torno a su uso; (iii) analizar como los impulsores socioeconómicos, regulatorios y tecnológicos influyen en la adopción de los RHNC desde las perspectivas de partes interesadas; y (iv) cuantificar la capacidad de los RHNC para mitigar las reducciones en los suministros de recursos hídricos convencionales.

Para abordar estos objetivos, la tesis combina cuatro enfoques metodológicos complementarios: una revisión sistemática de la literatura y análisis de impacto-cruzado para mapear y clasificar las barreras relacionadas con el uso del agua regenerada; la metodología Q para descubrir las perspectivas sociales en torno al agua regenerada; un Mapa Cognitivo Difuso (FCM) participativo para modelizar la dinámica de gestión del agua según las partes interesadas y simular escenarios futuros; y un modelo agro-económico de Programación Matemática Positiva (PMP) a escala de explotación para evaluar las respuestas del sistema de riego a cambios en la disponibilidad de agua, composición del suministro hídrico y precios del agua.

La revisión bibliográfica y el análisis de impacto-cruzado muestran que, si bien el uso de agua regenerada en España está en expansión, impulsado por los avances tecnológicos y mejoras regulatorias, su adopción continúa restringida por barreras socioeconómicas, técnicas, ambientales, legales e institucionales. Los altos costes,

la complejidad administrativa, la escasa coordinación, la preocupación por los impactos ambientales y el escepticismo persistente entre algunos usuarios siguen frenando una adopción más amplia, lo que subraya la necesidad de medidas de apoyo más coherentes y focalizadas.

Los resultados de la metodología Q revelan tres discursos sociales predominantes: (i) el agua regenerada como vía para asegurar el abastecimiento agrícola; (ii) como recurso con potencial de mejora; y (iii) como fuente de preocupación medioambiental. Aunque todos los discursos coinciden en que los consumidores carecen de información adecuada sobre la calidad y los beneficios del agua regenerada, difieren en cuestiones como el reparto de costes y los riesgos ambientales percibidos. Estos hallazgos evidencian la necesidad de una comunicación más clara, mecanismos de reparto de costes mejorados y salvaguardas ambientales específicas.

El análisis FCM muestra que la adopción de RHNC depende de un conjunto de factores estrechamente interconectados, principalmente concentrados en la dimensión económico-técnica. Las simulaciones de escenarios revelan que la integración de energías renovables, el refuerzo de la capacidad técnica y la ampliación de la producción desaladora pueden incrementar la adopción de RHNC y reducir la presión ambiental, mientras que la supresión de subvenciones a la desalación debilita sustancialmente el rendimiento del sistema. En todos los escenarios, la implementación del Plan Hidrológico de la Demarcación del Segura refuerza aún más la importancia estratégica de los RHNC.

La modelización agroeconómica señala que la reducción de la disponibilidad de agua convencional, especialmente el Trasvase Tajo-Segura (TST), provoca reducciones significativas de la rentabilidad, la superficie regada y el empleo en la CRCC, evidenciando la alta dependencia del sistema respecto a recursos externos. Sin embargo, las simulaciones sugieren que una cartera equilibrada de estrategias de mitigación, que combine agua desalada, agua regenerada, aguas subterráneas, subvenciones e innovaciones para reducir costes, permite compensar buena parte de estas pérdidas. Estas medidas contribuyen a estabilizar las rentas agrarias y a mantener la superficie cultivada, aunque su eficacia está condicionada por las compensaciones económicas, las restricciones ambientales y la sostenibilidad de cada fuente a largo plazo.

En conjunto, la tesis demuestra que los RHNC pueden desempeñar un papel estratégico en el fortalecimiento de la seguridad hídrica y el mantenimiento de los medios de vida agrícolas ante una escasez creciente. No obstante, su integración efectiva requiere una gobernanza coherente, políticas coordinadas, incentivos económicos y toma de decisiones socialmente legítima. Los resultados aportan recomendaciones útiles para diseñar estrategias hídricas resilientes y diversificadas en el sureste español, y ofrecen una referencia para otras regiones que enfrentan retos similares.

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Abbreviations and Acronyms

AEDyR	Asociación Española de Desalación y Reutilización
AGUA	Actions for Water Management and Use Programme
CEIGRAM	Centro de Investigación para la Gestión de Riesgos Agrarios y Ambientales
CRCC	Campo de Cartagena Irrigation Community
EPA	Environmental Protection Agency
ESAMUR	Regional Entity for Sanitation and Wastewater Treatment
ETSIAAB	Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas
EU	European Union
FCM	Fuzzy Cognitive Maps
FEADER	European Agricultural Fund for Rural Development
GDP	Gross Domestic Product
IWRA	International Water Resources Association
MAPA	Ministerio de Agricultura, Pesca y Alimentación
NCW	Non-conventional water resources
PERTE	Strategic Projects for Economic Recovery and Transformation
PMP	Positive Mathematical Programming
PTRP	Recovery, Transformation, and Resilience Plan
RBMP	River Basin Management Plan
RECLAMO	La contribución de la reutilización del agua a la gestión eficiente y sostenible del agua para el riego
RHNC	Recursos hídricos no convencionales
SWOT	Strengths, Weaknesses, Opportunities, and Threat
TST	Tagus-Segura Water Transfer
UCLA	University of California, Los Angeles

UPM	Universidad Politécnica de Madrid
WFD	Water Framework Directive
WRF	Water Reuse Facility
WWTP	Wastewater Treatment Plants

1. Introduction

1.1. Research context

This thesis began in March 2022, after receiving a predoctoral scholarship contract under the internal program of the Universidad Politécnica de Madrid (UPM). The research spanned four years and was carried out at the Department of Agricultural Economics, Statistics and Business Management, which belongs to the School of Agricultural, Food and Biosystems Engineering (ETSIAAB) from UPM, as well as at the Research Centre for the Management of Agricultural and Environmental Risks (CEIGRAM), also part of ETSIAAB.

The thesis was conducted within the framework of the Spanish research project funded by the Ministry of Science and Innovation (Ref. PID2019-104340RA-I00): "The contribution of water reuse to efficient and sustainable water management for irrigation" (RECLAMO). The project was coordinated by a multidisciplinary team from CEIGRAM, led by Professor Irene Blanco. It aimed to analyse the role of reclaimed water in agricultural irrigation as a promising alternative to address increasing water scarcity. The project focused on two representative case studies: the Segura River Basin (Region of Murcia), a European leader in water reuse practices due to chronic water deficits, and the Upper Guadiana Basin (La Mancha), characterized by aquifer overexploitation and limited experience with agricultural water reuse. These contrasting regions provided valuable insights into the challenges and opportunities of reclaimed water use, thereby enhancing the general applicability of the findings.

During the final months of the thesis development, the research was also conducted within the framework of the European SudWaMa project (SUDoe SUstainable Water Management, 2025–2028), funded by the Interreg SUDOE program. Coordinated by a multidisciplinary consortium of partners from France, Spain, and Portugal, the project addresses regulatory barriers, infrastructure investment needs, and introduces innovative solutions for the reuse of rainwater, greywater, and wastewater in urban environments. The project includes the implementation and evaluation of circular water management systems at several pilot sites, incorporating cost-benefit analyses and participatory actions to actively engage end-users.

Throughout the course of the thesis, the research was further strengthened by the award of a competitive mentorship under the International Water Resources Association (IWRA) initiative, as well as by two international research stays. Through this mentorship, a collaboration was stablished with Professor Gabriel Eckstein of Texas A&M University, whose expertise on barriers to reclaimed water use proved particularly valuable. This collaboration substantially informed the sections entitled "Analysis of barriers and challenges to the expansion of reclaimed water use in Spanish agriculture."

The first international research stay, funded by UPM's internal research program, took place at the Sustainability Research Institute, School of Earth and Environment, University of Leeds (United Kingdom), from September to December 2023, under the supervision of Dr. Paula Novo. This work significantly contributed to the analysis of social perspectives on the use of reclaimed water in agriculture, the results of which are presented in the sections entitled "Social perspectives of reclaimed water in agriculture."

The second stay, supported by UPM's Research Mobility Program for North American Universities, was carried out at the Department of Civil and Environmental Engineering, Institute of the Environment and Sustainability, University of California, Los Angeles (UCLA), from January to July 2024, under the supervision of Dr. Alvar Escriva-Bou. This stay made it possible to refine and enhance the modelling approach used in the research to study the role of Non-conventional Water Resources (NCW) in mitigating the reduction of traditional water resources, as presented in the sections entitled "Assessing NCW as an alternative to traditional water resources."

1.2. Problem description

The growing pressure on conventional water resources, mainly surface and groundwater, has intensified in recent decades due to the combined effects of climate change, the expansion of irrigated agriculture, and the sustained increase in urban and industrial demand. These dynamics have shaped a scenario of water scarcity and recurrent water stress, particularly severe in semi-arid regions, where agriculture faces serious limitations in ensuring both food security and ecosystem sustainability.

In this context, diversifying water supply sources becomes essential, with NCW playing an increasingly important role. NCW include resources that extend or enhance natural freshwater availability through treatment or technological processes, such as reuse of treated wastewater (reclaimed water), desalinated seawater and brackish water, fog collection, cloud seeding, micro-catchment rainwater harvesting, etc. (Smakhtin et al., 2001). Among these, the most relevant for large-scale agricultural supply are reclaimed water and desalinated water (Williams et al., 2023).

Spain is recognised as a global leader in both wastewater reuse and desalination. In the case of reuse, the country has promoted its application in agriculture for decades, supported by a solid regulatory framework at European and national levels. However, the implementation of reuse faces limitations that challenge its consolidation as a widespread solution. The main challenges include: i) the variability of its net contribution to the hydrological system, which is significant in coastal areas but debatable in inland regions; ii) the technical requirements stemming from its physicochemical and microbiological characteristics, which demand advanced treatments, specific distribution networks, and strict sanitary control; iii) regulatory complexity, characterized by a more restrictive framework than that governing other sources; and iv) social barriers linked to negative perceptions of reclaimed water use in irrigation. In addition, there is a lack of comprehensive assessments that simultaneously address the technical, economic, environmental, social, and regulatory dimensions, while also accounting for territorial heterogeneity between coastal and inland areas. These limitations hinder the consolidation of reuse as a fully integrated strategic resource into water planning.

At the same time, the expansion of desalination has been constrained by its high cost due to elevated energy requirements, and the lack of specific regulations, which complicate its integration into irrigation systems. Nevertheless, driven by recent drought episodes and technological advances that have reduced production costs, desalination has gained prominence in arid coastal areas, such as in Spain.

In this regard, it is essential to move towards an integrated approach that incorporates both reuse and desalination into water planning, overcoming partial or fragmented perspectives. Although the international agenda increasingly recognises the relevance of NCW, significant gaps remain in understanding how reclaimed and desalinated water can be jointly considered within irrigated agriculture, including their potential complementarities and trade-offs. At the same time, evidence is still limited on their actual contribution to agricultural systems, the barriers that hinder their adoption, and the opportunities they offer for strengthening water security. Addressing these gaps is crucial to advancing the sustainability of agriculture in semi-arid regions and to consolidating NCW as a key pillar of future water management.

1.3. Objectives

The general objective of the thesis is to analyse the challenges and opportunities for effectively integrating NCW, particularly reclaimed water and desalinated water, into agricultural irrigation in a context of increasing water scarcity, with a focus on the southeastern Mediterranean region of Spain.

The specific objectives include:

A. Objective 1: Identifying the major barriers hindering the widespread adoption of the reclaimed water use in agriculture in Spain and propose possible mitigation strategies.

B. Objective 2: Understanding the diversity of social perspectives that contextualize the use of reclaimed water in agriculture in Spain, identifying main points of agreement and disagreement.

C. Objective 3: Analysing the current and future role of NCW, from the perspectives of stakeholders in the Region of Murcia.

D. Objective 4: Evaluating the use of NCW to mitigate the impacts of reduced conventional water resources in Campo de Cartagena Irrigation Community (CRCC) (Region of Murcia).

1.4. Related publications

This thesis is composed of four articles, each of which is linked to the specific objectives described in the previous section, following the same order of presentation. In addition, the research findings have been presented at various conferences and seminars. The details of these works are provided below:

Articles:

Villacorta-Ranera, C., Eckstein, G., & Blanco-Gutiérrez, I. (2025). Challenges and prospects of reclaimed water reuse in Spanish agriculture. *Water International*, *50* (6), 514–534. https://doi.org/10.1080/02508060.2025.2485856

Villacorta-Ranera, C., Blanco-Gutiérrez, I., & Novo, P. (2025). Disentangling social perspectives on the use of reclaimed water in agriculture using Q methodology. *Journal of Environmental Management, 381*, 125264. https://doi.org/10.1016/j.jenvman.2025.125264

Villacorta-Ranera, C., Blanco-Gutiérrez, I., Esteve, P. & Ballesteros-Olza, M. A Stakeholder-Based Assessment of Non-Conventional Water Resources for Agricultural Irrigation in Semi-Arid Mediterranean Regions. *Water Resources Management.* (Under review). (WARM-D-25-03550)

Villacorta-Ranera, C., Blanco-Gutiérrez, I., Escriva-Bou, A., & Esteve, P. Adapting Irrigated Agriculture to Water Transfer Reductions: Challenges and Strategies in Southeastern Spain. *Agricultural Water Management.* (Under review). (AGWAT-D-25-02065)

Conferences:

Villacorta-Ranera, C., Blanco-Gutiérrez, I. (2023). Use of Conventional and Unconventional Water Resources: Implications for Agriculture in Murcia, Spain. 1st EELISA Scientific Student Competition. Pisa (Italy). May 2023.

Villacorta-Ranera, C., Blanco-Gutiérrez, I., Gómez-Ramos, A., & Esteve, P. (2023). The use of non-conventional water resources for agricultural for irrigation in the Segura basin in Spain. 12th World Congress on Water Resources and Environment (EWRA 2023). Managing Water-Energy-Land-Food under Climatic, Environmental and Social Instability. Thessaloniki (Greece). June 2023.

Villacorta-Ranera, C., Blanco-Gutiérrez, I., Gómez-Ramos, A., & Esteve, P. (2023). Analysis of the use of non-conventional water resources in agriculture in southeastern Spain. XIV Congreso de Economía Agroalimentaria. Zaragoza (España). September 2023.

Villacorta Ranera, C., Blanco Gutiérrez, I., and Novo Nunez, P. (2024). Disentangling social perspectives on the use of reclaimed water in agriculture using Q methodology. EGU General Assembly 2024. Vienna (Austria). April 2024. https://doi.org/10.5194/egusphere-egu24-605

Villacorta-Ranera, C., Blanco-Gutierrez, I., Escriva-Bou, A., & Esteve, P. (2024). Adapting to Water Scarcity: The Role of Non-Conventional Water Resources in the Segura River Basin of Southern Spain. American Geophysical Union's (AGU) 2024 annual meeting. Washington D.C. (United States of America), Decembre 2024. https://agu.confex.com/agu/agu24/meetingapp.cgi/Paper/1758365

Villacorta-Ranera, C., Blanco-Gutiérrez, I. (2025). Analysis of barriers to reclaimed water reuse in Spanish agriculture: a comprehensive review and implementation prospects. 3rd EELISA Scientific Student Competition. Bucharest (Romania). June 2025.

Villacorta-Ranera, C., Blanco-Gutiérrez, I., & Novo, P. (2025). Social perspectives on reclaimed water for irrigation in Spain: insights from Q methodology. XV Congreso de Economía Agroalimentaria. Granada (España). September 2025.

Seminars:

Villacorta-Ranera, C., Blanco-Gutiérrez, I. (2023). Análisis económico del uso de los recursos hídricos convencionales y no convencionales para riego agrícola en la cuenca del Segura. VI Seminario de Investigación UPM Water. La importancia del agua. Madrid (España). Enero 2023.

Villacorta-Ranera, C., Blanco-Gutiérrez, I., & Novo, P. (2023). Disentangling social perspectives on the use of reclaimed water in agriculture using Q methodology. Seminary in the group Econopol (Research Group of Economics and Policy), in the Sustainability Research Institute and in the School of Earth and Environment of the University of Leeds. December 2023.

Villacorta-Ranera, C., Blanco-Gutiérrez, I., & Escriva-Bou, A. (2024). Analysis of the use of non-conventional water resources in agriculture in southeastern Spain. Seminary in Integrating the Human Dimension in Water Systems research group offered at the UCLA Samueli School of Engineering and the Department of Civil and Environmental Engineering at the University of California Los Angeles. June 2024.

Villacorta-Ranera, C., Eckstein, G., & Blanco-Gutiérrez, I. (2025). Análisis de Barreras para la Reutilización del Agua Regenerada en la Agricultura Español. VIII Seminario de Investigación UPM Water Canal de Isabel II. Nuevos desafíos en el sector del agua. Madrid (España). Abril 2025.

1.5. Structure of the document

This thesis is divided into six chapters. Chapter 1 includes the introduction, which presents the general context of the research, the problem description and the objectives. This section also presents the main publications which the thesis is based and outlines the overall organization of the document.

Chapter 2 reviews the state of the art on the role of NCW, particularly reclaimed and desalinated water, as strategic alternatives to growing water demand and the increasing pressures on traditional source. It discusses their characteristics, opportunities and barriers across social, technical, economic, environmental, and legal dimensions. The chapter then examines their use in Spain, focusing on two illustrative cases: the Region of Murcia, a pioneer in NCW adoption, and the CRCC, known for its advanced multi-source water management. Finally, the chapter outlines the thesis's contribution to the literature by identifying key research gaps.

Chapter 3 outlines the methodological approaches employed, which integrate complementary tools to analyse the barriers, social perceptions, and potential future scenarios related to the use of reclaimed and desalinated water in Spanish agriculture. Each section of this chapter corresponds to a specific objective, following the same order of presentation, as do the two subsequent chapter (results and discussion). First, a systematic literature review was conducted, followed by a cross-impact analysis to identify key barriers to the use of reclaimed water in agriculture. Second, Q methodology is employed to analyse the diverse social perspectives regarding the use of reclaimed water in agriculture. Third, a participatory Fuzzy Cognitive Maps (FCM) model is developed to examine the factors shaping the current and future state of NCW in the Region of Murcia. Finally, a farm-based Positive Mathematical Programming (PMP) model is employed to assess the impact of reductions in Tagus-Segura water transfer (TST) on irrigated agriculture in the CRCC, as well as to evaluate alternative scenarios of availability and pricing for both conventional and NCW.

Chapter 4 presents the results obtained in addressing each of the specific objectives. First, it identifies and ranks the barriers that hinder the use of reclaimed water in Spanish agriculture and proposes mitigation measures to address them. It then distinguishes three prevailing social discourses on reclaimed water use, revealing both areas of consensus and notable divergences. Following this, the interdependencies and dynamics of the NCW management system in the

Region of Murcia are represented, together with simulated future scenarios. Finally, a strategic economic analysis of the Campo de Cartagena Irrigation Community is presented, evaluating the impact of reduced water transfers and exploring compensatory alternatives.

Chapter 5 develops the discussion, integrating the research findings and contrasting them with the existing scientific literature.

Finally, Chapter 6 offers the conclusions, summarizing the main findings, acknowledging its limitations, and proposing future lines of research.

2. State of the art

2.1. The use of NCW in agriculture

The rising water demand, exacerbated by climate change, is exerting growing pressure on conventional water resources (Liu et al., 2023). These include surface water (rivers, lakes and reservoirs) and groundwater, which have historically served as the foundation of the water supply. Their availability is directly dependent on precipitation and runoff, rendering them highly vulnerable to climatic variability (Liu et al., 2017).

In response to this situation, many countries have begun exploring and adopting NCW as a strategic alternative to ensure water guarantee (Shemer et al., 2023). These resources generally require prior treatment or transformation processes. Among which, seawater or brackish water desalination and the reuse of treated wastewater (reclaimed water) are particularly prominent. Unlike conventional resources, both options have the advantage of not depending directly on climatic availability, affording greater stability in contexts of water scarcity (Ricart et al., 2021).

The reclaimed water consists of giving a second use to municipal or industrial wastewater after an additional treatment beyond the conventional one carried out in Wastewater Treatment Plants (WWTP) (Santos et al., 2023).

Its use is primarily for non-potable or indirect purposes, most countries currently prohibit its direct potable use (Shemer et al., 2023). Despite this, several pioneering initiatives have emerged in this field. Namibia is an international benchmark, having produced reclaimed water for human consumption under extreme scarcity conditions since 1968 (Nkhoma et al., 2021). In the United States, California has developed one of the world's most advanced regulatory frameworks, permitting a wide range of applications for reclaimed water, although direct potable reuse has only recently begun to be permitted under strict conditions (Abbaszadegan et al., 2025). In Singapore, a significant share of its potable water supply comes from reclaimed water treated trhough advanced technologies (NEWater), enabling safe indirect reuse for human consumption (Lefebvre, 2018).

Globally, however, agricultural accounts for the largest share of reclaimed water use, at 32% of the total volume reused, followed by irrigation of green areas and landscaping (20%) and industrial uses (19%). Less common uses include environmental and recreational purposes, non-potable urban applications, aquifer recharge, and indirect potable reuse (Expósito et al., 2024). The relative distribution of these uses varies across countries and regions, depending on their climatic, economic, and regulatory contexts. Key users include the United States, China, Israel, Australia, several Gulf countries, and some Mediterranean European Union (EU) countries (Gupta, 2024) (Figure 1).

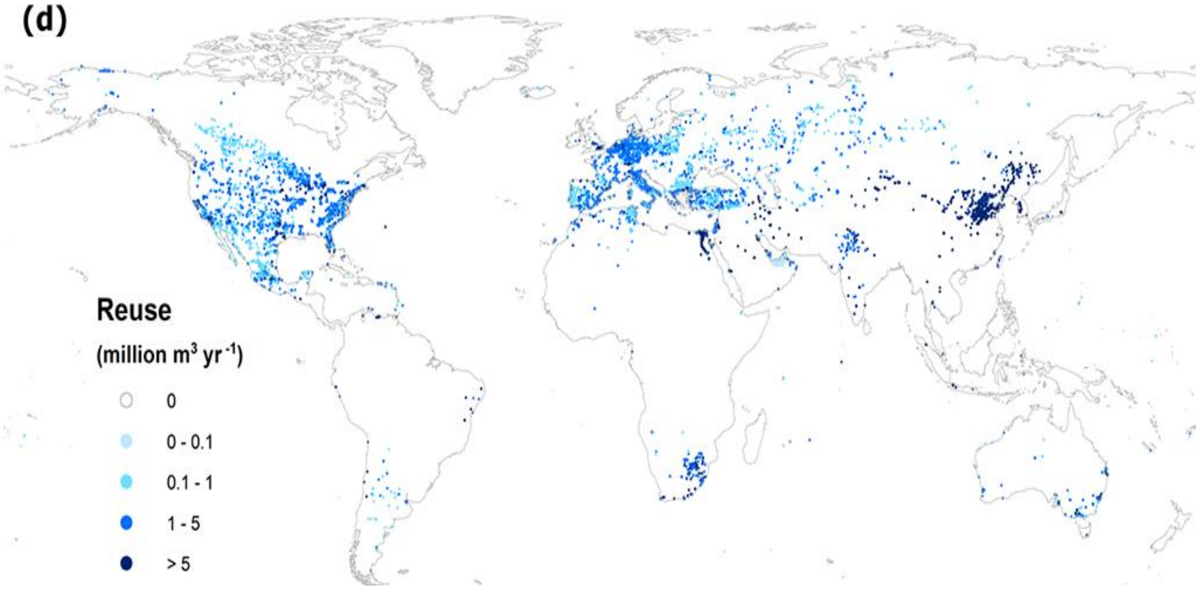


Figure 1. Global distribution of urban wastewater reuse (million m^3/year).

Source: Jones et al. (2021)

Desalination, in turn, involves producing fresh water from seawater or brackish water through physical and chemical processes that remove salt and other dissolved minerals (Voutchkov, 2022). Unlike reclaimed water, its main use is urban supply (59%), followed by industrial (36%) and, to a lesser extent, agricultural uses (2%) (Eke et al., 2020).

Desalination is most widely used in arid and semi-arid regions with limited freshwater availability and direct access to the sea. The highest concentration of global desalination capacity is found in the Gulf countries, particularly Saudi Arabia, the United Arab Emirates, Kuwait, and Qatar, which together account for more than 60% of worldwide production (Voutchkov, 2022). In the Mediterranean, desalination has become an increasingly important component of water supply strategies in countries such as Israel, Cyprus, Malta, Italy, and several regions of Spain (Efthimiou et al., 2025). Beyond these areas, many island states and coastal regions in the Caribbean and the Pacific also rely heavily on desalinated water as a key element of their water security strategies (Forde et al., 2024). In the United States, its use has been steadily increasing for municipal and industrial purposes (Xu et al., 2022) (Figure 2).

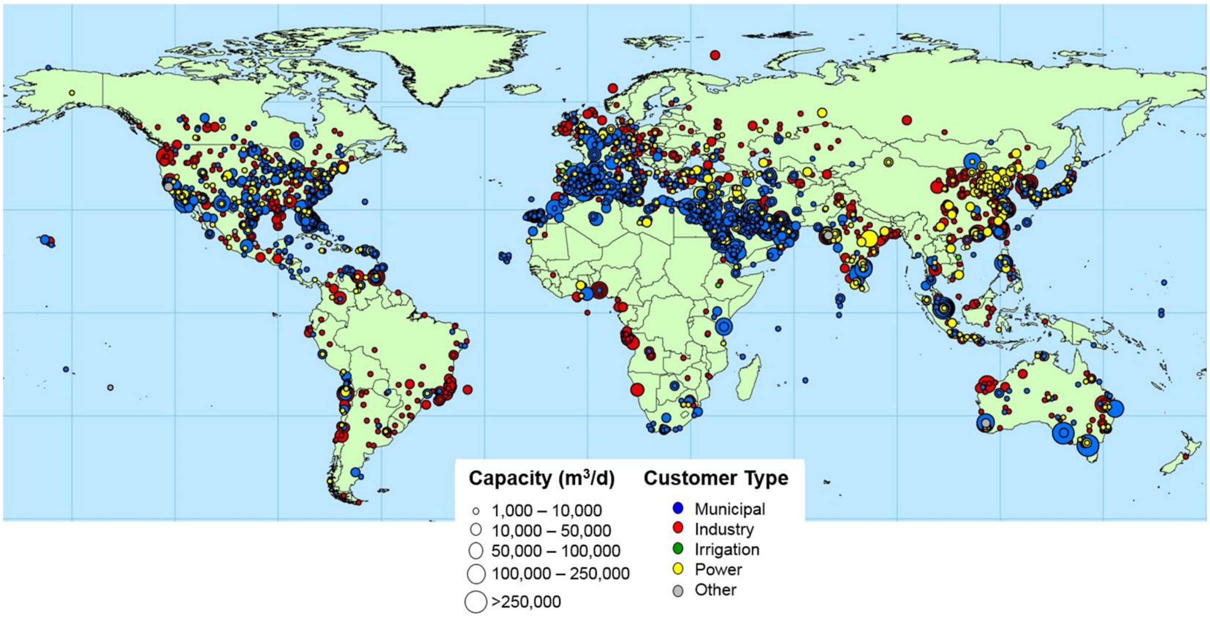


Figure 2. Global distribution of operational desalination facilities and capacities (>1000 m^3/day) by sector user of produced water.

Source: Jones et al. (2019)

As pressures on conventional resources intensify and NCW gain prominence, attention has increasingly shifted to agriculture, the sector with the highest water demand (Qin et al., 2019). In many regions of Africa, Asia, and Latin America, agriculture accounts for over 80% of total water consumption (Hejazi et al., 2023). In contrast, the European average 36%, though this figure rises sharply in Mediterranean countries where it can reach 75% (European Environment Agency, 2016). Agricultural water demand is expected to continue rising due to population growth and the need to increase food production, thereby intensifying pressure on conventional resources (Eekhout et al., 2024).

In this context, integrating NCW into agriculture emerges as a strategic pathway to reduce dependence on traditional sources and ensure the sustainability of irrigation. Nevertheless, the large-scale adoption of these resources poses significant technical, economic, and social challenges, particularly regarding water quality, social acceptance, and the financial viability of production and distribution systems. Overcoming these barriers is crucial to consolidating NCW's role in the transition towards more sustainable, and climate-resilient water management models (Ricart & Rico, 2019).

2.2. Opportunities and barriers to NCW adoption

Among the main opportunities, growing social concern over droughts and climate change is driving the search for alternative water sources beyond conventional resources (Morote et al., 2019). This trend is further supported institutionally through the development of new legislation promoting these sources (Berti Suman et al., 2023). Another significant opportunity lies in the use of NCW in agriculture, which benefits from low dependence on climatic variability, thereby providing a stable and predictable supply and reducing vulnerability to droughts (Amali et al., 2021). In addition, NCW increase effective water availability, particularly in coastal areas, where desalination provides a virtually unlimited source of seawater and reclaimed water allows the recovery of effluents that would otherwise be discharged into the sea (Berbel et al., 2023).

In terms of user acceptance, desalinated water generally enjoys greater farmer willingness due to its potential to improve the quality of irrigation blends (Aznar-Sánchez et al., 2021). Nevertheless, perceptions of reclaimed water have also evolved positively, primarily due to its agronomic benefits, such as nutrient contributions that reduce dependence on chemical fertilizers (Ofori et al., 2021).

Nevertheless, the expansion of NCW in agriculture still faces significant barriers. The primary constraint for both resources is their high costs, compounded by substantial infrastructure and maintenance investments, rendering them less competitive than conventional sources (Hurtado & Berbel, 2024; Amali et al., 2021). Additionally, the high production costs are largely due to the substantial energy requirements, especially in the case of desalinated water (Yazdandoost et al., 2021).

For reclaimed water, the administrative and technical complexity involved in its management is also significant, as it requires compliance with strict quality standards, continuous monitoring, coordination among multiple institutions, and the development of dedicated distribution and control infrastructure (Ballesteros-Olza et al., 2025).

From an environmental perspective, the barriers differ by NCW type. Reclaimed water carries risks from potential presence of emerging pollutants, heavy metals, salts, and pathogens, which can compromise soil and crop health (Aznar-Crespo et al., 2019). Additionally, in inland areas, the use of reclaimed water in agriculture raises concerns about potential impacts on river ecological flows, as diverting treated wastewater for reuse can reduce downstream return flows (Ballesteros-Olza et al., 2022). In contrast, the primary limitations of desalinated water are its high boron concentrations, which can be phytotoxic, and the challenging discharge of brine into receiving ecosystems, posing a significant environmental threat (Gómez Martínez & Pérez Martín, 2023). Furthermore, due to its high energy consumption, its production generates substantial CO_2 emissions (Cruz-Pérez et al., 2022).

These environmental and health risks reinforce a social perception of reclaimed water that is still often negative. This perception is also strongly influenced by what the literature refers to as the “yuck factor,” an instinctive feeling of disgust associated with the idea of consuming or using water that was once wastewater (Ricart et al., 2019). In the case of desalinated water, negative social perception primarily arises from the visual pollution caused by desalination plants (Hussein Abouzied, 2023). This, combined with a lack of specialized technical advice, hindering the adoption and consolidation of NCW as viable alternatives for agricultural irrigation (López-Serrano et al., 2022). Nevertheless, in recent years, NCW have received increasing support, reflected in the technological advancement of production processes and the progressive development of a more robust regulatory framework that ensures greater legal and operational security (Efthimiou et al., 2025).

Table 1 summarises the main opportunities and barriers associated with the use of reclaimed water and desalinated water in agriculture. The following sections expand on these aspects in greater detail, examining them through the key social, technical, economic, environmental, and legal–regulatory dimensions that shape their effective implementation.

Table 1. Summary of Opportunities and Barriers to Adopting Non-Conventional Water Resources in Agriculture.

Opportunities	Barriers
Growing social concern over droughts and climate change and new legislation supporting the development of NCW	High production and infrastructure costs → lower competitiveness compared to conventional sources
Low dependence on climate variability → stable and predictable supply	High energy consumption in desalinated water production
Complement to the hydrological cycle, particularly in coastal regions	Administrative and technical complexity in managing reclaimed water
Growing social acceptance	Social limitations: • Persistent "yuck" factor toward reclaimed water • Limited specialized technical advice • Visual pollution caused by desalination plants
Quality of NCW: • Desalinated water improves the quality of irrigation blends • Reclaimed water has agronomic benefits, such as nutrient contributions	Environmental impacts: • Reclaimed water: emerging contaminants, heavy metals, salts, and pathogens • Desalinated water: excess boron (phytotoxicity), discharge of brine into receiving bodies and high CO_2 emissions

Source: Own elaboration

2.2.1. Social perception

As noted, the growing scarcity of water is influencing the social perception of NCW in agriculture, with particular focus on desalinated and reclaimed water, has undergone a gradual evolution towards greater acceptance. Nonetheless, significant obstacles persist, demanding continued attention from both academic research and public management (Efthimiou et al., 2025). The scientific literature on these attitudes has not only revealed notable differences among the various stakeholders within the use of NCW in agriculture. Table 2 presents some of the methodologies employed for this purpose:

Table 2. Methodologies Applied to the Study of Social Perceptions of NCW in Agriculture.

Methodology	Type of NCW	Country/Region	Source
Q Methodology	NCW	EEUU	(Brannstrom et al., 2022)
Qualitative interviews	Desalinated water	Australia, UK	(Liu et al., 2022)
	Reclaimed water	Spain	(López-Serrano et al., 2022)
FCM	Reclaimed water	Spain (Guadiana River)	(Ballesteros-Olza et al., 2022)
Strengths, Weaknesses, Opportunities, and Threat (SWOT) analysis	NCW	Spain	(Ricart et al., 2021)
	Reclaimed water	Spain	(Mesa-Pérez & Berbel, 2020)
Semi-structured interviews	Desalinated water	Spain (Alicante and Murcia)	(Ricart et al., 2020)
	Reclaimed water	Algeria	(Karef et al., 2025)
	Desalinated water	Southeast Spain	(Aznar-Sánchez et al., 2021)
Bibliometrics analysis	NCW	Global	(Xu et al., 2024)
	Desalinated water	Global	(Chowdhury et al., 2024)
Literature review	NCW	Spain	(Ricart et al., 2021)
	Reclaimed water	Global	(Ricart et al., 2019)
	NCW	Mediterranean basin	(Efthimiou et al., 2025)
	Reclaimed water	Latin America	(Félix-López et al., 2023)

Source: Own elaboration

In the case of reclaimed water, social reluctance is primarily driven by concerns over its origin and quality particularly regarding its use for irrigating agricultural products (Santos et al., 2023).

Farmers generally maintain a positive perception of reclaimed water, based on successful prior experiences, supply guarantee, and the nutrient inputs that reduce the reliance on chemical fertilizers (Karef et al., 2025). In contrast, consumer perception tends to be more negative, mainly influenced by knowledge gap and the so-called "yuck factor," an emotional aversion rooted in the association with wastewater. This perception is further reinforced both by cultural risk biases and distrust in its safety, despite the availability of scientific evidence and regulatory frameworks that ensure its safe use (Ricart et al., 2019).

In summary, the perception of reclaimed water in agriculture is shaped by a combination of determinants. These include: the demand for stringent quality standards and effective regulatory oversight (Ramm & Smol, 2023), farmers' capacity to manage associated agronomic risks with its irrigation use (Ballesteros-Olza et al., 2022), social concerns regarding its origin (Ricart et al., 2021), as well as the recognized economic and sustainability benefits from input cost savings in inputs and supply guarantee (Hurtado & Berbel, 2024).

Concurrently, recent trends show growing public acceptance of agricultural uses of reclaimed water, a shift largely attributed to awareness campaigns and the consolidation of specific regulations (Félix-López et al., 2023).

Social acceptance of desalinated water social reluctance is primarily driven by concerns over higher in water-stressed regions, where conventional sources are insufficient or limited (Martínez-Alvarez et al., 2023). While overall social perception is positive reservations persist concerning environmental impacts, particularly those linked to the operation of desalination plants, including visual pollution (Hussein Abouzied, 2023) and brine discharge effects on receiving ecosystems (Bali & Ghanem, 2025). From a sectoral perspective, farmers value the quality of desalinated water particularly when blended with other sources (Aznar-Sánchez et al., 2021), yet the high cost remains a significant barrier to its widespread agriculture adoption (Hurtado & Berbel, 2024).

Collectively, the perception of NCW is defined by a tension between the recognized need to diversify water sources and build drought resilience, and the persistence of historical prejudices, knowledge gaps, and environmental concerns. This dynamic underscores the critical importance of enhancing scientific communication and strengthening institutional support to integrate NCW into sustainable water management strategies.

2.2.2. Technical considerations

The origin of reclaimed water lies in treated urban wastewater at WWTP. Although all wastewater undergoes preliminary treatment before discharge into the natural environment, not all can be considered reclaimed water (Santos et al., 2023). Optimal reuse necessitates additional tertiary treatment, performed either within the WWTP itself or at a dedicated Water Reuse Facility (WRF). The conventional wastewater treatment process typically includes screening, grit removal, biological treatment, and nutrient elimination. At this stage, tertiary treatment is introduced, which may involve membrane filtration, ozonation, or ultraviolet radiation disinfection among other technologies, aiming to ensure water quality and safety for reuse, particularly in agricultural irrigation (Kesari et al., 2021).

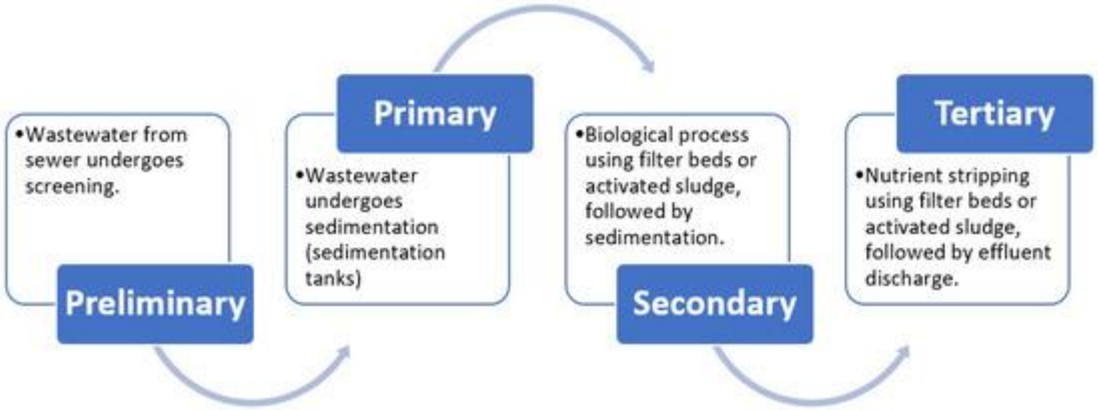


Figure 3. Stages of wastewater treatment, from preliminary to tertiary treatment.

Source: Silva (2023)

In recent years, technological innovations have improved the efficiency of these processes. Advances such as membrane bioreactors, bioelectrochemical systems, and nanotechnology, enabling enhanced removal of emerging contaminants such as organic compounds, micropollutants, and pathogens (Shah et al., 2022; Verma et al., 2024). Additionally, the deployment of digital continuous monitoring systems and advanced risk management frameworks has strengthened quality control and minimized the risk of cross-contamination within distribution networks (Hernández-Cuenca et al., 2025). Moreover, emerging legislation has further support the normalization and standardization of the reclaimed water, facilitating its broader adoption and consolidating its role as a strategic water source (Berti Suman et al., 2023; Thilmany et al., 2024).

Desalinated water, in turn, is produced in desalination plants through the removal of salts present in brackish water or primarily seawater (Voutchkov, 2022). This process (Figure 4) consists of an initial phase (pre-treatment) aimed at preparing the water to protect the membranes, removing suspended solids, particles, and organisms through filtration, flocculation, and flotation (Kavitha et al., 2019). The main desalination phase is carried out using different technologies, with the most widespread technology being reverse osmosis, which has undergone significant advances in recent years aimed at improving energy efficiency and reducing costs (Shabib et al., 2025). This process involves applying high pressure to force saline water through semipermeable membranes, which retain salts and other impurities producing high-quality water suitable for human consumption, agricultural, and industrial use. Finally, post-treatment includes remineralization and pH adjustment to ensure water quality for its final use, as well as microbiological control and removal of residual contaminants (Poirier et al., 2023).

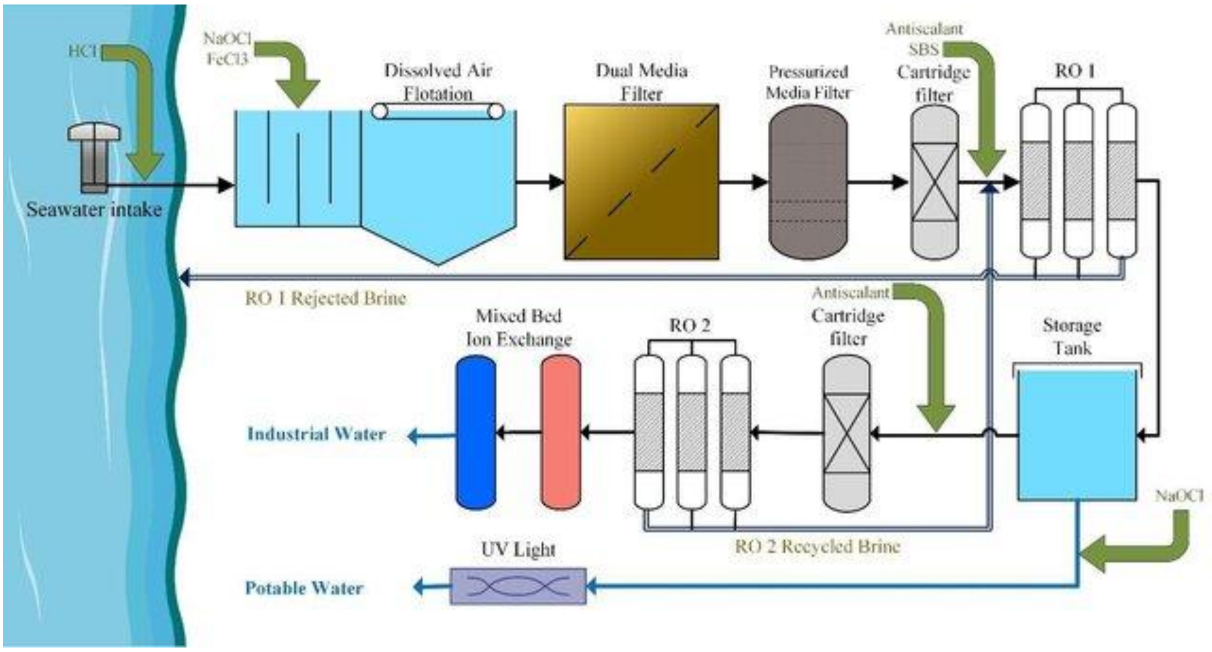


Figure 4. Desalination and plant diagram.

Source: Fayyaz et al. (2023)

Among the most notable technical advancements are the development of next-generation membranes with greater permeability and lower pressure requirements, as well as the incorporation of highly efficient energy-recovery systems that have substantially reduced electrical consumption, thereby improving the sustainability and competitiveness of desalination (Schunke et al., 2020). In addition, post-treatment processes are applied to adjust pH and mitigate the aggressiveness of desalinated water, facilitating its blending with other water sources and optimizing its use across various applications, and minimizing potential environmental impacts (Birnhack et al., 2011). Desalinated water production has also benefited from innovative integrations such as hybrid or dual plants that combine power generation and desalination, thereby reducing operational costs and environmental footprint (Salsabila et al., 2025).

From a technical perspective, the effective use of NCW in agriculture requires the development of dedicated infrastructure for storage, transport, and distribution (Gómez-Ramos et al., 2024). This includes the construction of separate conveyance networks, pumping systems, storage reservoirs, and monitoring and control equipment to ensure that water reaches farms with the appropriate quality and reliability (Ricart et al., 2021). These technical requirements are often substantial, as NCW typically cannot be integrated into existing potable or irrigation networks without specific adaptations.

In summary, technical advancements have enhanced the efficiency, quality, and sustainability of both reclaimed and desalinated water. These improvements firmly position them as viable and strategic alternatives for water management in contexts of increasing scarcity and climatic variability.

2.2.3. Economic considerations

The treatment processes required for NCW substantially increase their costs, posing a significant barrier to farmers interested in their use, especially for low-value-added crops (Pistocchi et al., 2017). This constraint is further exacerbated by the high initial investments needed to develop treatment facilities, transport systems, and distribution infrastructure (Shemer et al., 2023).

The production costs for desalinated water typically range from €0.5 to €1.0/m^3 and can be lower (0.3 to 0.5 €/m^3) for brackish water. These costs include infrastructure amortization, operation, and maintenance. A dominant factor is energy consumption, which alone accounts for 40% to 60% of the total price, due to the high electricity demand of reverse osmosis pumping processes (Feo-García et al., 2024; Gómez-Ramos et al., 2024).

Reclaimed water typically has lower production costs of around 0.45 €/m^3. However, its final price is influenced by the need for additional infrastructure for advanced treatment, distribution, and transport, which increases overall costs. In all cases, investment in reclamation facilities and distribution networks constitutes a significant component of the final cost (Expósito et al., 2024).

Various strategies have been implemented to mitigate these costs. However, NCW generally remain more expensive than conventional sources. On average, the price of surface water is around 0.02 €/m^3, while groundwater typically costs about 0.09 €/m^3. In regions facing severe water scarcity, subsidies and financing mechanisms are commonly applied to support NCW development. These instruments lower the price paid by the end user, transferring the remaining cost to society (Ricart et al., 2021).

Another relevant measure is the integration of renewable energies, particularly photovoltaic solar energy, into desalination plants. This strategy reduces reliance on conventional energy sources and directly lowers production costs (Menon et al., 2023). Concurrently, ongoing infrastructure optimization and the adoption of technological innovations remain key factors for improving efficiency and facilitating the expanded agricultural use of these NCW.

In summary, the adoption of both desalinated and reclaimed water is challenged by significant economic barriers, primarily high energy and infrastructure costs. Advances in technology, the integration of renewable energy, and the use of subsidies and financing mechanisms are key strategies to help reduce these costs and facilitate the sustainable incorporation of these resources into water management.

2.2.4. Environmental impact

From an environmental perspective, the incorporation of desalinated and reclaimed water into agricultural systems presents a range of potential benefits and impacts that require careful assessment to ensure their sustainable use.

Among the benefits of both resources is that they reduce pressure on conventional freshwater sources by substituting part of the demand that would otherwise come from rivers, reservoirs, or aquifers, helping to mitigate overexploitation and aid the recovery of degraded water bodies (Quon & Jiang, 2023). They also offer greater resilience against drought and climate variability because they depend less on precipitation, providing a more reliable water source that improves the environmental stability of agricultural systems (Ricart et al., 2021).

In the case of reclaimed water, clear advantages include undergoing advanced treatment processes (often including tertiary or even quaternary stages) that produce effluents of higher quality than conventional wastewater treatment plant discharges, reducing pollutant loads and improving downstream water quality (Fayyaz et al., 2023). It is also a potential resource for nutrient recycling, as it usually contains residual nutrients (e.g., nitrogen and phosphorus), which can reduce the need for synthetic fertilizers and associated environmental impacts (Santos et al., 2023). Among ecological risks are the presence of nutrients, heavy metals, persistent organic pollutants, pharmaceuticals, and endocrine disruptors, which can accumulate in soil, alter microbial biodiversity, and affect both crops and groundwater (Fito & Van Hulle, 2021). Prolonged irrigation with reclaimed water can modify key ecological processes and, in some cases, pose risks to human health due to potential bioaccumulation of contaminants within the food chain (García-Valverde et al., 2023). Nonetheless, controlled application can also provide agronomic benefits by supplying essential nutrients that improve soil fertility and reduce dependence on chemical fertilizers (Christou et al., 2024). Hydrologically, the use of reclaimed water in inland areas may compromise river ecological flows, diminish self-purification capacity and disrupt the balance of aquatic ecosystems (Ballesteros-Olza et al., 2022).

In the case of desalinated water, its quality enables its use in multiple sectors such as urban supply, agriculture, and industry (Khondoker et al., 2023). Moreover, its use in agriculture allows for the improvement of water blending quality (Martínez-Álvarez et al., 2023). As for impacts, primary concerns arise from its high energy consumption, which is typically dependent on fossil fuel sources, resulting in significant greenhouse gas emissions and contributing to climate change (Moreno-Silva et al., 2025). Additionally, desalination affects marine ecosystems: water intake can trap and harm microscopic organisms (plankton, larvae), while the discharge of concentrated brine alters local salinity, negatively impacting sensitive marine species (Sirota et al., 2024). Moreover, the use of chemicals for pretreatment and biological control in desalination plants, if not properly managed, can introduce contaminants into aquatic environments (Abushaban et al., 2021). The construction of desalination infrastructure also involves land transformation and potential degradation of natural habitats (Hussein Abouzied, 2023). Finally, desalinated water may contain residual sodium and boron, which affect soil quality and structure when used for irrigation, posing risks of salinization and fertility loss if control measures are not implemented (Liu et al., 2022).

In summary, both desalinated and reclaimed water represent strategic solutions to water scarcity, yet each presents specific environmental impacts related to energy consumption, contamination, and ecological effects. Proper monitoring, regulation, and adaptive management of these resources are fundamental to ensuring their integration into a sustainable long-term water management strategy.

2.2.5. Legal and regulatory aspects

The growing interest in NCW has prompted many countries to establish legal and regulatory frameworks, adapted to their environmental, economic, and social contexts.

In the United States, NCW is regulated at both the federal and state levels. The primary legal framework is the Clean Water Act, which governs discharges and pollution of surface waters and indirectly promotes the reuse and advanced treatment of wastewater (Rich et al., 2023). Additionally, specific state regulations address water reuse and desalination, with the Environmental Protection Agency (EPA) establishing quality and safety criteria for the use of reclaimed water, particularly in agriculture and urban applications (Markland et al., 2017).

China promotes wastewater reuse and desalination through policies that incentivize investment and technological development. Its legislative framework prioritizes quality and safety standards as well as the integration of NCW into national water planning (Zhu et al., 2019). Specific regulations govern reuse across agricultural irrigation, industry, and large urban centers, mandating the use of advanced treatment technologies and robust environmental monitoring (Zhu & Dou, 2018).

Israel is a world leader in reclaimed water for agricultural irrigation, with a long-standing, stringent regulatory system. The country has maintained specific legislation since the 1970s and has established a robust institutional framework that facilitates both public and private sector participation (Sneegas et al., 2022). Desalination is regulated through concession systems and state oversight of quality and discharge, forming a cornerstone of the nation’s water security strategy (OECD, 2020).

Australia has established a comprehensive legislative framework for reclaimed water and desalinated water as part of its drought adaptation efforts. National and state regulations govern the production, use, and quality of recycled and desalinated water. The country promotes the integration of NCW systems into urban and industrial water supplies, underpinned by mandates for health and environmental risk assessments (Samnakay et al., 2024).

In Persian Gulf countries, regulatory frameworks prioritize desalination and water reclamation. Legislation typically establishes quality standards and provides incentives for the adoption of desalination technologies. At the same time, reclaimed water is strictly regulated, particularly in the municipal and agricultural sectors, where environmental monitoring is intensifying and restrictions are tightening. Regional cooperation agreements emphasize the equitable use of shared resources and environmental protection (Cochrane & Al-Hababi, 2023).

At the European level, desalination is not governed by a single specific legal framework, but it is integrated into broader regulations on water management and environmental protection. The Water Framework Directive (WFD) (European Commission, 2000) establishes principles that indirectly affect its management, such as the protection of the public water domain, hydrological planning, and environmental impact assessment. Consequently, the development of NCW, such as desalinated water, is directly framed within the EU's overarching water sustainability objectives.

Regarding reclaimed water, Regulation (EU) 2020/741 (European Parliament, 2020) establishes the first harmonized EU-wide legal framework for water reuse, with an initial focus on agricultural irrigation. It sets minimum quality standards, mandates risk management requirements and plans, and outlines key transparency obligations and authorization criteria for reuse projects, all aligned with sustainability and public health protection objectives. The regulation aims to foster the expansion of water reuse across the EU and to bolster public acceptance and confidence in agricultural products irrigated with reclaimed water. The regulation classifies reclaimed water according to its quality and the intended agricultural use (Table 3).

Table 3. Classes of reclaimed water quality and permitted agricultural use and irrigation method.

Minimum reclaimed water quality class	**Crop category**	**Irrigation method**
A	All food crops consumed raw where the edible part is in direct contact with reclaimed water and root crops consumed raw	All irrigation methods
B	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	All irrigation methods
C	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	Drip irrigation or other irrigation method that avoids direct contact with the edible part of the crop
D	Industrial, energy and seeded crops	All irrigation methods

Source: European Parliament (2020)

The regulation also establishes minimum quality requirements for reclaimed water (Table 4).

Table 4. Reclaimed water quality requirements for agricultural irrigation.

Reclaimed water quality class	**Indicative technology target**	**Quality requirements**				
		***E. coli* (number/ 100 ml)**	**BOD$_5$ (mg/l)**	**TSS (mg/l)**	**Turbidity (NTU)**	**Other**
A	Secondary treatment, filtration, and disinfection	≤ 10	≤ 10	≤ 10	≤ 5	Legionella spp.: < 1 000 cfu/l where there is a risk of aerosolisation Intestinal nematodes (helminth eggs): ≤ 1 egg/l for irrigation of p
B	Secondary treatment, and disinfection	≤ 100	In accordance with Directive 91/271/EEC (Annex I, Table 1)	In accordance with Directive 91/271/EEC (Annex I, Table 1)	–	
C	Secondary treatment, and disinfection	≤ 1 000			–	
D	Secondary treatment, and disinfection	≤ 10 000			–	

Source: European Parliament (2020)

Additionally, Regulation (EU) 2020/741 establishes the obligation to implement a risk management plan, a systematic process designed to ensure the safe use of reclaimed water for agricultural purposes. Its main objective is to identify, assess, and control potential risks associated with the reuse of treated water, protecting human health and the environment.

The risk management plan is structured into modules that describe the reuse system, analyse potential hazards and exposed populations, establish monitoring programs to assess water, soil, and crop quality, and define coordination and emergency protocols. The plan also promotes active participation from all stakeholders (operators, competent authorities, and end users). It integrates preventive measures and control barriers throughout all stages of the process, from treatment to water application.

The relevance of this plan lies in its proactive capacity to anticipate and mitigate risks to public health and the environment. By doing so, it ensures the long-term sustainability and social acceptance of water reuse practices, especially amid challenges posed by climate change and escalating water scarcity.

Similarly, Directive (EU) 2024/3019 of the European Parliament and of the Council has introduced new requirements for the treatment and monitoring of urban wastewater (European Parliament & Council of the European Union, 2024). This directive strengthens standards for treatment and discharge control and establishes a closer regulatory connection between wastewater management and its reuse potential. Its provisions directly influence the quality and safety of reclaimed water and indirectly affect desalination by conditioning brine discharge and its interactions with sanitation systems.

Moreover, the EU Water Resilience Strategy (European Commission, 2025) recognises the diversification of water sources as essential to addressing growing water scarcity, highlighting water reuse and desalination as key NCW. It promotes the safe use of reclaimed water, particularly in agriculture and industry, and anticipates a possible expansion of the Water Reuse Regulation (EU) 2020/741 (European Parliament, 2020). The Strategy also acknowledges the role of desalination in coastal regions, while stressing the need to ensure its environmental and economic sustainability. Overall, it supports the integration of NCW within a “Water Efficiency First” approach, while allowing Member States flexibility in their implementation.

2.3. NCW in Spain: case study

Spain represents a paradigmatic case in Europe regarding water resource management, due to the notable water scarcity in the Mediterranean region, which directly constrains its socioeconomic development (Fornés et al., 2021). The country is defined by limited water availability and an uneven spatial distribution of conventional resources, leading to recurrent imbalances between urban, agricultural, and environmental supply and demand (Ricart et al., 2021).

As shown in Figure 5, agriculture represents the main water-consuming sector in Spain, accounting for 78% of total use, far exceeding domestic (17%) and industrial (4%) consumption (MITECO, 2022).

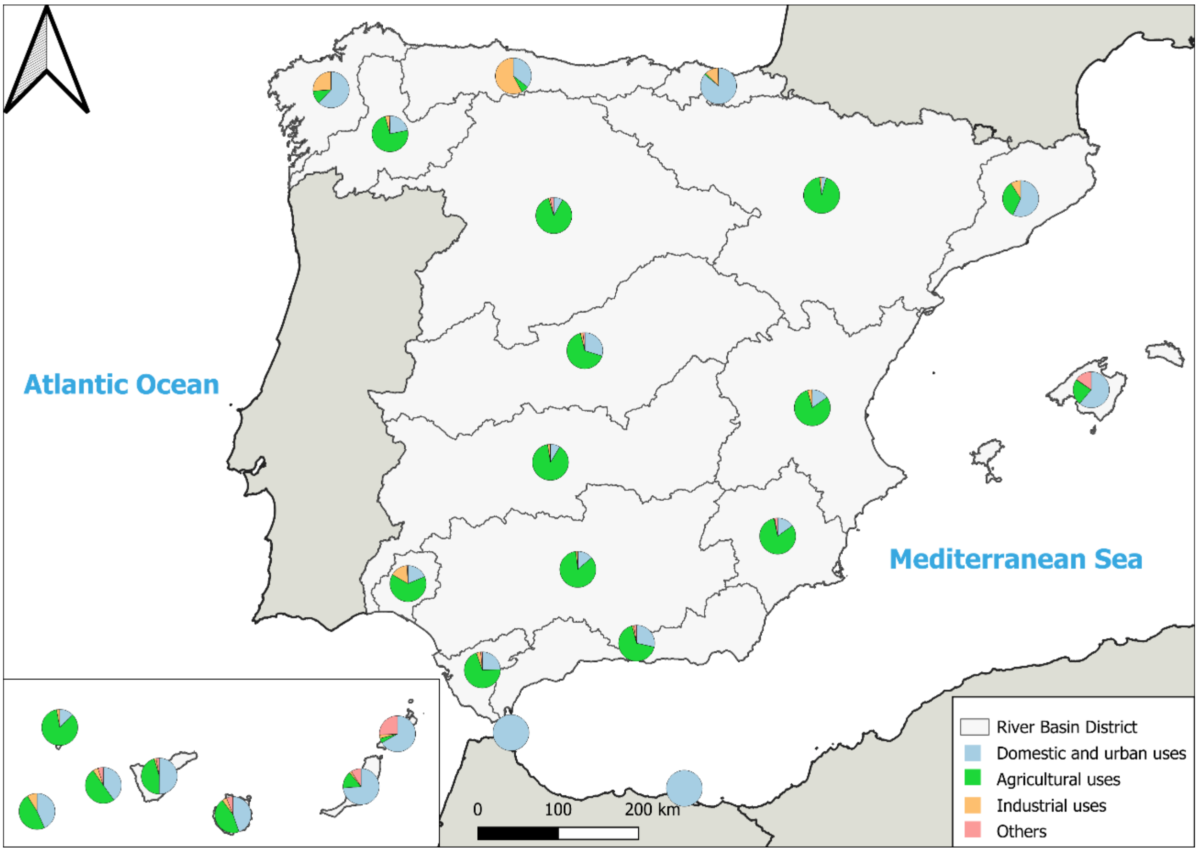


Figure 5. Main uses of water by river basin in Spain.

Source: Own elaboration based on data from MITECO (2022)

These water demands are mainly supplied by conventional resources, particularly surface water, followed by groundwater, which are mostly concentrated in the river basins of the northern and central Spain (Figure 6). The geographical distribution of these resources creates a markedly uneven scenario: while the Atlantic and Cantabrian basins concentrate most of the available surface water, the Mediterranean basins of the southeast (Segura, Júcar, Sur and eastern Guadiana) face a water deficit, exacerbated by high agricultural pressure on a limited natural base (Gómez-Ramos et al., 2024). In this context, deficit regions have sought to diversify their water supply sources through the use of NCW, mainly desalinated and reclaimed water. In the case of Spain, NCW represent barely 3% of the total water used (1% reuse, 2% desalination), but they are strategic for diversifying supply and alleviating pressure on traditional sources, especially in coastal regions with high water scarcity (MITECO, 2022). The two archipelagos and the autonomous cities stand out for their intensive use of desalinated water, whereas the Mediterranean basins have shown greater development in the use of reclaimed water. Particularly noteworthy is the Segura River Basin, which exhibits a high diversification of resources, with NCW accounting for nearly 20% of total water consumption (MITECO, 2022).

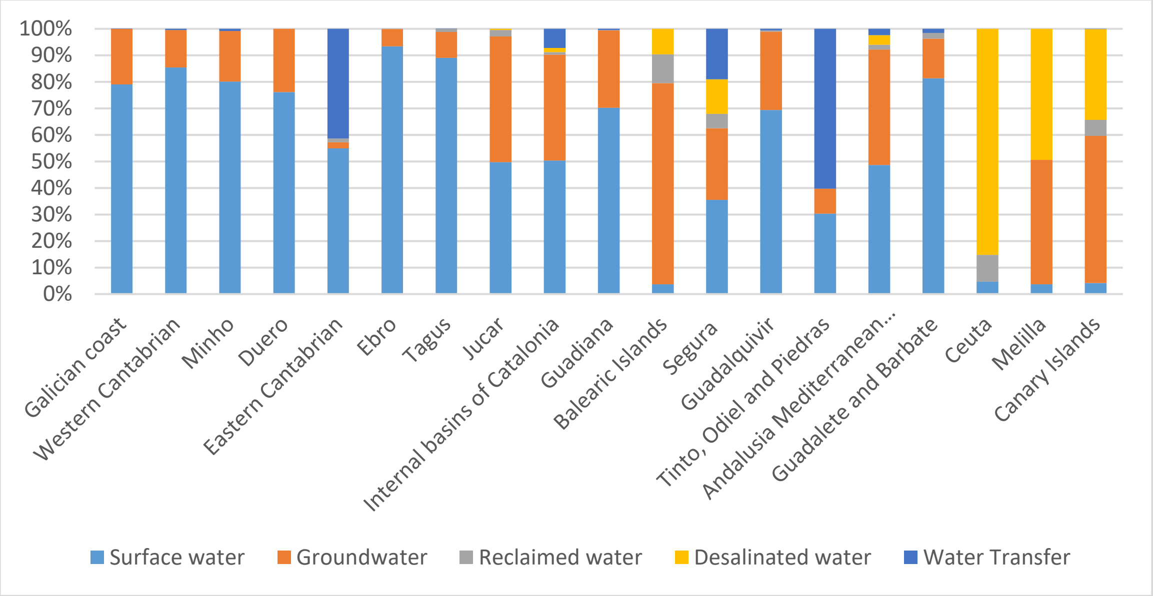


Figure 6. Distribution of water resources by source and region in Spain.

Source: Own elaboration based on data from MITECO (2022)

Spain ranks at the forefront of water reuse in EU, accounting for more than half of the European total volume of reclaimed water (533 hm^3/year), equivalent to 9.5% of the treated wastewater in the country in 2022, compared with a European average below 3% (INE, 2024). The country has approximately 2,000 WWTP, of which around 27% are equipped with regeneration systems. Currently, 69% of reused water is allocated to agriculture. In comparison, the remainder is distributed among industrial uses (20%), irrigation of gardens and recreational areas (11%), sewer cleaning and street washing (1%), and other applications such as aquifer recharge (2%) (Figure 7). Direct use for human consumption is prohibited; however, during prolonged droughts, indirect reuse solutions have been implemented to support supply.

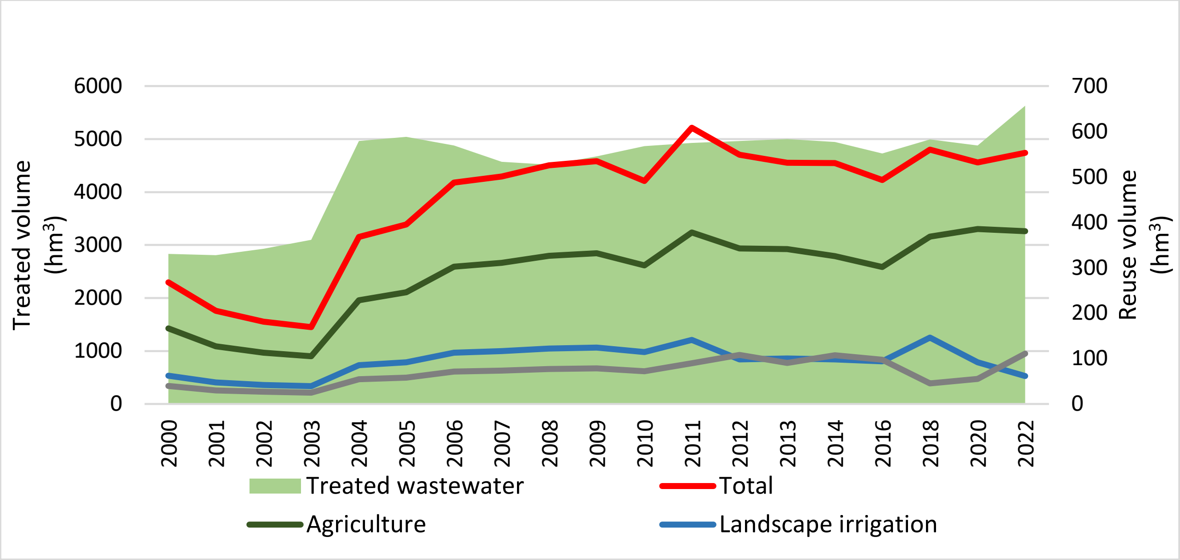


Figure 7. Evolution of reclaimed water production in Spain.

Source: Elaboration by authors based on INE (2024)

During the 2020–2021 hydrological year, the volume of reclaimed water consumed reached $310\ \text{hm}^3$, with the highest concentrations observed in the Segura and Júcar river basins (Figure 8).

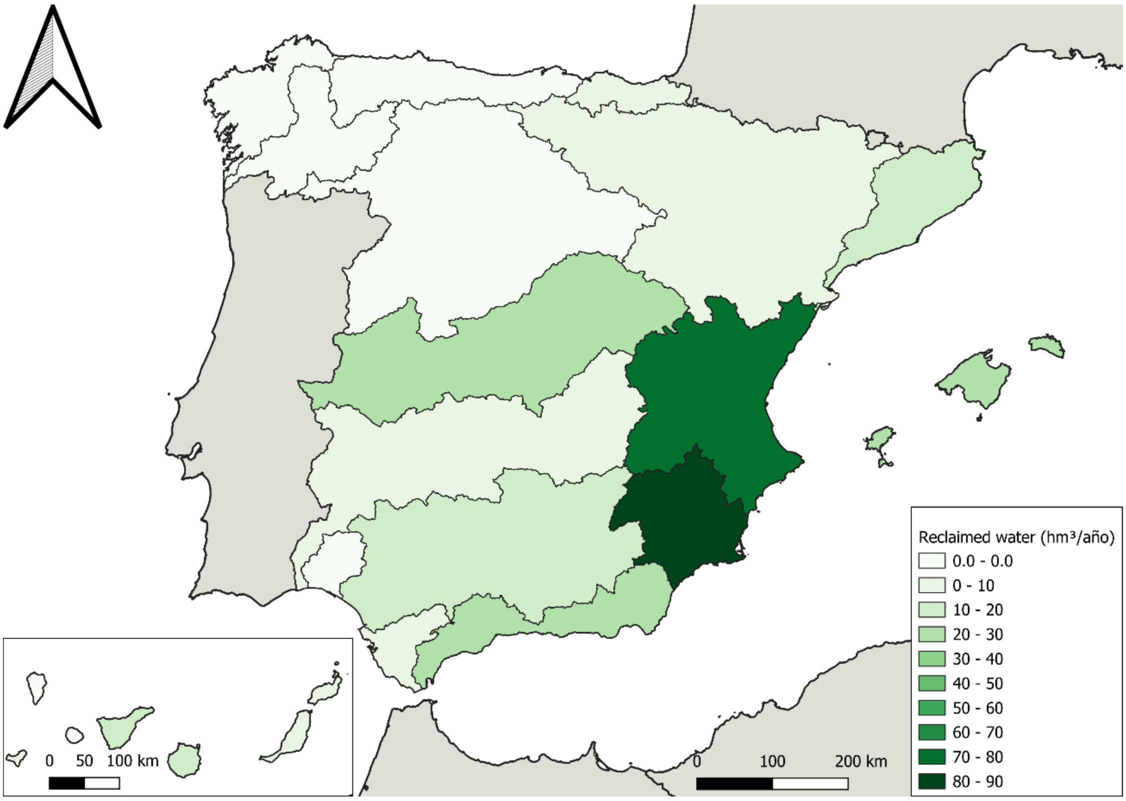


Figure 8. Spatial Distribution of Reclaimed Water Volume in Spain (hm^3/year)

Source: Own elaboration based on data from MITECO (2022)

Water reuse in Spain began in the mid-20th century, primarily for agricultural irrigation along the Mediterranean coast and the archipelagos, using basic treatments methods and without specific planning or regulation. From the 1990s onwards, technological advances and stricter environmental requirements spurred the development of a regulatory framework. The Water Law (Real Decreto Legislativo 1/2001, 2001) recognized reuse as a consumptive use, while Royal Decree 1620/2007 (Real Decreto 1620/2007, 2007) established, for the first time, quality standards, authorized uses, and control mechanisms. Subsequently, programs such as the Actions for Water Management and Use Programme (AGUA) (2004) (Real Decreto-Ley 2/2004, 2004) and the National Reuse Plan (2012) (MAGRAMA, 2012) promoted the construction of modern treatment infrastructures and distribution networks, particularly in the Mediterranean region.

In the last decade, growing pressure on conventional water resources has accelerated the adoption of water reuse, supported by the DSEAR Plan (2014–2023) (MITECO, 2014) and Royal Decree 1085/2024 (Real Decreto 1085/2024, 2024), in alignment with Regulation (EU) 2020/741 (European Parliament, 2020), which introduced improvements in reclaimed water quality, traceability, and risk management. Royal Decree-Law 4/2023 (Real Decreto-Ley 4/2023, 2023) set the target of achieving 1,000 hm^3/year of reused water by 2027, nearly doubling the current volume. Reaching this goal will require expanding and modernizing infrastructure, improving wastewater treatment (particularly in small and medium-sized municipalities) enhancing energy efficiency, advancing the digitalization of monitoring systems, and ensuring compliance with updated quality standards (Gómez-Ramos et al., 2024; Pérez de las Heras, 2023).

Funding for these initiatives comes from a combination of European sources, such as European Agricultural Fund for Rural Development (FEADER), alongside with resources from the Recovery, Transformation, and Resilience Plan (PRTR) (including Strategic Projects for Economic Recovery and Transformation (PERTE) programs) (Orden TED/934/2022, 2022) and contributions from national and regional administrations. Among the most significant initiatives is the Plan for the Improvement of Efficiency and Sustainability in Irrigation (2021–2026) (MAPA, 2021), which allocates approximately €62 million to targeted reclaimed water reuse projects (Lipińska & Cazorla González, 2023; Zuluaga-Guerra et al., 2023).

Meanwhile, desalination was introduced in the Canary Islands during the 1960s via small thermal plants aimed at mitigating the overexploitation of island aquifers. A major shift occurred from the 1980s onwards, with reverse osmosis technology emerging as the predominant option, due to its superior energy efficiency and lower operating costs (AEDyR, 2018); it now constitutes over 95% of installed capacity. In the Iberian Peninsula, desalination expanded in the 1990s, driven by urban and tourism growth along the Mediterranean coast. Royal Decree 1327/1995 (Real Decreto 1327/1995, 1995) established the regulatory framework for public and private facilities, distinguishing between the desalination of inland brackish water (subject to concession under the hydraulic public domain) and seawater desalination, which does not require a prior concession but does necessitate authorizations for discharges and for occupying the public maritime-terrestrial domain (Coastal Law) (Ley 22/1988, de Costas, 1988).

A major turning point occurred with the AGUA plan (2004–2011), which partially replaced the Ebro River transfer planned in the 2001 National Hydrological Plan with an ambitious initiative to construct of seawater and brackish water desalination plants (Cabrera et al., 2019). In recent years, several measures have sought enhance system efficiency and reduce production costs, including the implementation of subsidized tariffs (in force until 2026 and renewable) and the approval of Royal Decree-Law 6/2022, which recognizes electricity generation as a strategic sector. Additionally, the Supreme Court has established a dual concession system to regulate both the production and use of desalinated water, introducing administrative complexity and potentially limiting private-sector participation.

Spain currently operates approximately 765 desalination plants, with 360 for seawater and 405 for brackish water, classified by capacity (Table 5).

Table 5. Typology of desalination plants by capacity and water source.

Capacity	**Production range (m^3/day)**	**Desalination plants**		
		Total	**Seawater**	**Brackish Water**
Large	250.000 - 10.000	99	68	31
Medium	10.000 – 500	450	207	243
Small	500 - 100	216	85	131

Source: own elaboration based on data from AEDyR (2019)

The total annual consumption of desalinated seawater amounts to 483 hm^3, with 55% allocated to urban supply, 25% to agricultural irrigation, 15% to industrial uses, and the remainder to tourism activities. Its use is primarily concentrated in the Segura River Basin (211 hm³) and the Canary Islands (166 hm³), with smaller volumes in Andalusia, the Balearic Islands, Catalonia, Júcar, Ceuta, and Melilla (MITECO, 2022) (Figure 9).

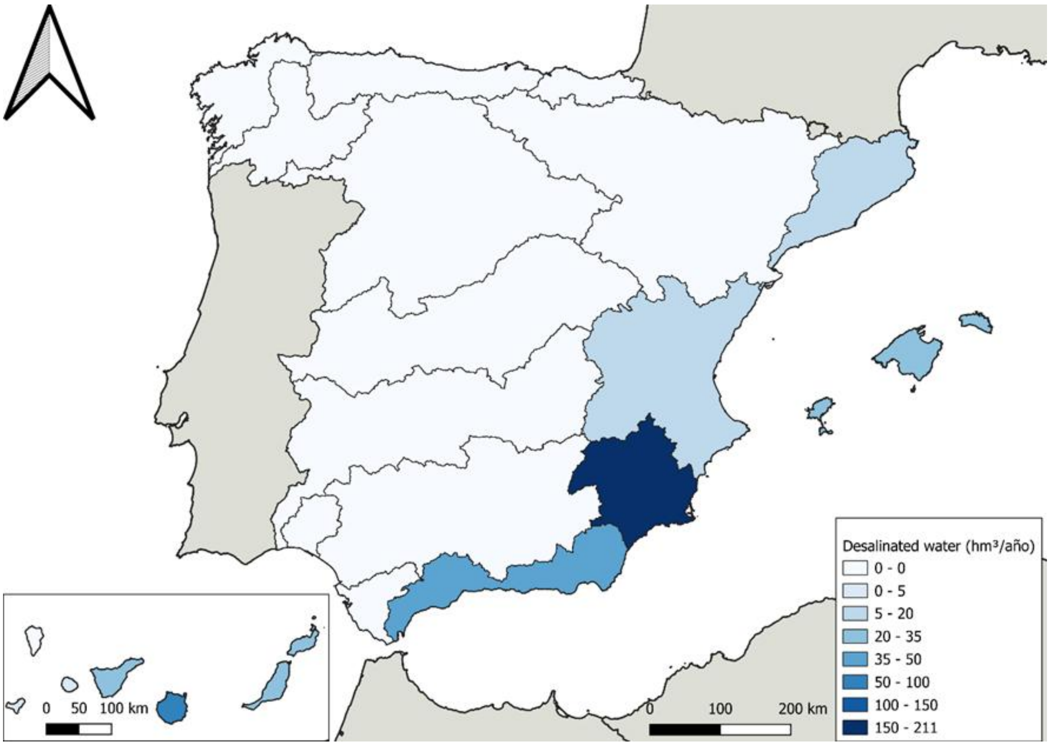


Figure 9. Spatial Distribution of Desalinated Water Volume in Spain (hm³/year)

Source: Own elaboration based on data from MITECO (2022)

The largest desalination plants are predominantly located along the Mediterranean coast (Table 6), while brackish-water desalination facilities are more common in the central part of the country (Table 7). Overall, the total installed capacity exceeds 5 million cubic meters per day (equivalent to 1,825 hm³ per year), positioning Spain as the world's fourth-largest desalination producer and the leading country in Europe (Zarzo, 2020).

Table 6. Main Seawater Desalination Plants in Spain.

Desalination plant	Location	Capacity (m³/day)	Population served
Torrevieja	Alicante	240,000	140,000
Águilas Guadalentín	Águilas	210,000	130,000
El Prat	Barcelona	200,000	4.5 million
Valdelentisco	Cartagena	137,500	60,000
Carboneras	Almería	120,000	200,000

Source: own elaboration based on data from AEDyR (2024)

Table 7. Main Brackish Water Desalination Plants in Spain.

Brackish water desalination plant	Location	Capacity (m³/day)
Sant Joan Despí	Barcelona	206,000
Abrera	Barcelona	200,000
El Atabal	Málaga	165,000
Almoguera	Madrid	123,840
Cancarix–Hellín Irrigation	Albacete	54,794

Source: Own elaboration based on data from (AEDyR, 2024b)

Although Spain currently has no specific national target for desalination expansion, the third cycle of hydrological planning proposes investments of nearly 800 million euros to construct new plants and expand or modernize existing facilities, with focus on the Levante region (Segura River Basin) and the Canary Islands. Within this framework, the Plan for the Improvement of Efficiency and Sustainability in Irrigation (2021–2026) allocates 124.2 million euros to desalination projects and an additional 30 million euros to brackish water initiatives.

2.3.1. Case study: Region of Murcia

Within this framework, the Region of Murcia is considered in this thesis as an emblematic case study for analysing the current and future role of NCW. It is in located in southeastern Spain (Figure 10) and is characterized by a semi-arid Mediterranean climate, with an average annual temperature of 18 °C and an average annual precipitation of only 300 mm (Gil-Meseguer et al., 2024).

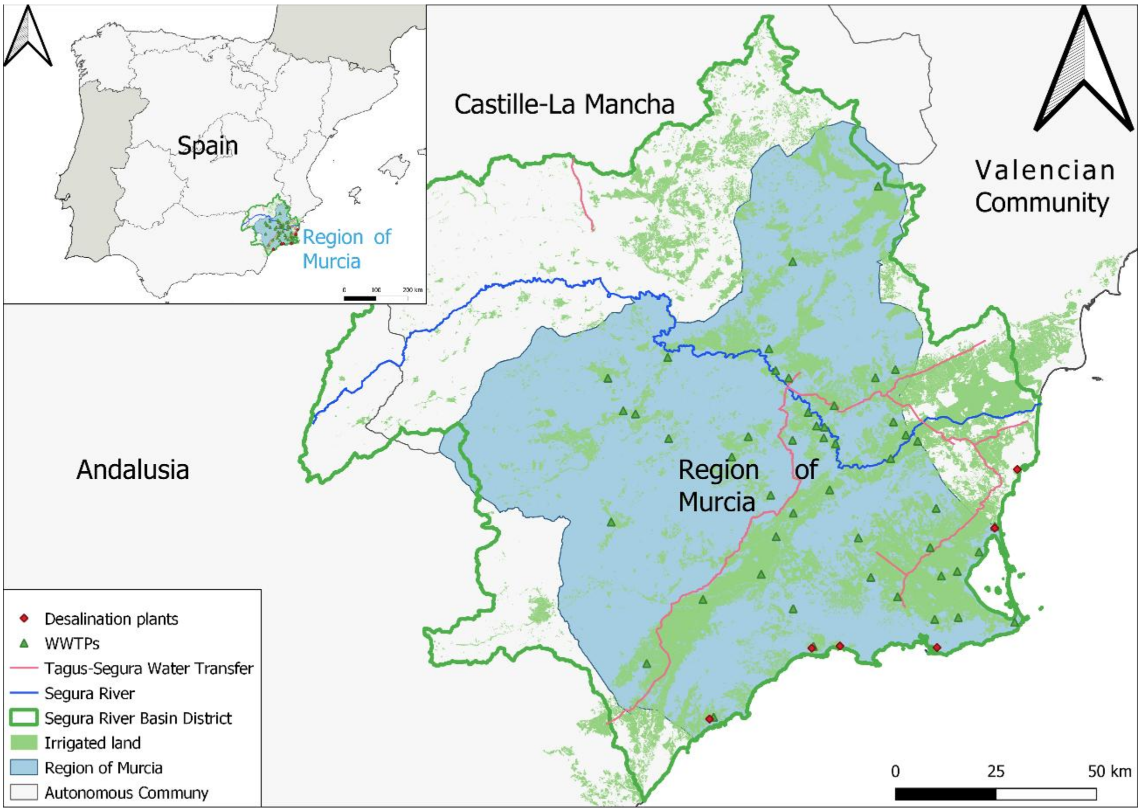


Figure 10. Location of the case study: Region de Murcia (Spain).
Source: Own elaboration.

Agriculture is a key pillar for the regional economy, contributing 4.2% to regional Gross Domestic Product (GDP), 9.5% to employment, and 26.4% to exports (CREM, 2025a), largely driven by irrigated fruit and vegetable production (MAPA, 2025). Irrigated land covers 164,294 hectares (45% of the cultivated area) and is characterized by an intensive, technologically advanced model (CREM, 2025b; Ricart et al., 2021). As the main consumer of blue water (80%), the sector is highly dependent on water availability, raising concerns amid declining resources and growing competition from other uses, particularly tourism (CHS, 2022a).

The Region of Murcia faces a structural water deficit managed through a combination of reservoirs, intra- and inter-basin transfers, intensive groundwater abstraction, and the growing use of NCW (Gómez-Ramos et al., 2024). Surface water comes from the Segura River and the Tagus–Segura Water Transfer (TST) (a 300 km channel that transports water from the Upper Tagus River Basin to the Segura Basin) (Morote et al., 2020). Groundwater is particularly in coastal areas where other resources are scarce (CHS, 2022a).

Over the past two decades, the region has become a pioneer in the use of NCW, particularly reclaimed and desalinated water. With the support of the regional public entity ESAMUR (Entidad de Saneamiento y Depuración de Aguas Residuales), Murcia leads Europe in wastewater reuse, reusing more than 90% of treated effluents (Simón & Oller, 2024). Given the poor status of many water bodies and the complexity of the regional water system, Murcia adopted stricter treatment standards than other Spanish regions, leading to 90% of its WWTPs being equipped with tertiary treatments.

Desalinated seawater has also become a key resource, both as a complement to and in blending with other waters. Seven seawater desalination plants currently supply 613,300 m^3/day (Gómez-Ramos et al., 2024), with Valdelentisco and Torrevieja playing particularly important roles in securing regional water availability (Bernabé Crespo et al., 2019).

Given their strategic importance, NCW sources receive economic support. Reclaimed water is subsidized through sanitary fees paid by urban users, covering wastewater treatment costs (Gómez-Ramos et al., 2024). For desalinated water, Order TED/157/2023 guarantees price reductions until 2026 (extendable to 2033).

Looking ahead, conventional water availability is expected to decline due to reduced surface flows, groundwater depletion and decreasing TST volumes associated with new environmental flow requirements and climate change impacts in the donor basin. In this context, NCW is set to play an increasingly central role, motivating strategies such as expanding desalination capacity, constructing new facilities, developing renewable-energy-powered desalination, and improving water regeneration processes. Therefore, various measures are being implemented to promote greater use of these resources in the agricultural sector.

2.3.2. Case study: Campo de Cartagena Irrigation Community

The second case study, aimed at providing a data-driven evaluation of the feasibility, trade-offs, and limitations of relying on NCW to mitigate the impacts of reduced inter-basin transfers, focuses on the Campo de Cartagena Irrigation Community (CRCC). Established in 1952, the CRCC currently brings together about 9,700 members and covers some 42,255 irrigable hectares (García Castellanos et al., 2024; MAPA, 2024b). Its territorial scope comprises eight municipalities, seven belonging to Murcia and one to the Valencian Community (García Castellanos et al., 2024) (Figure 11).

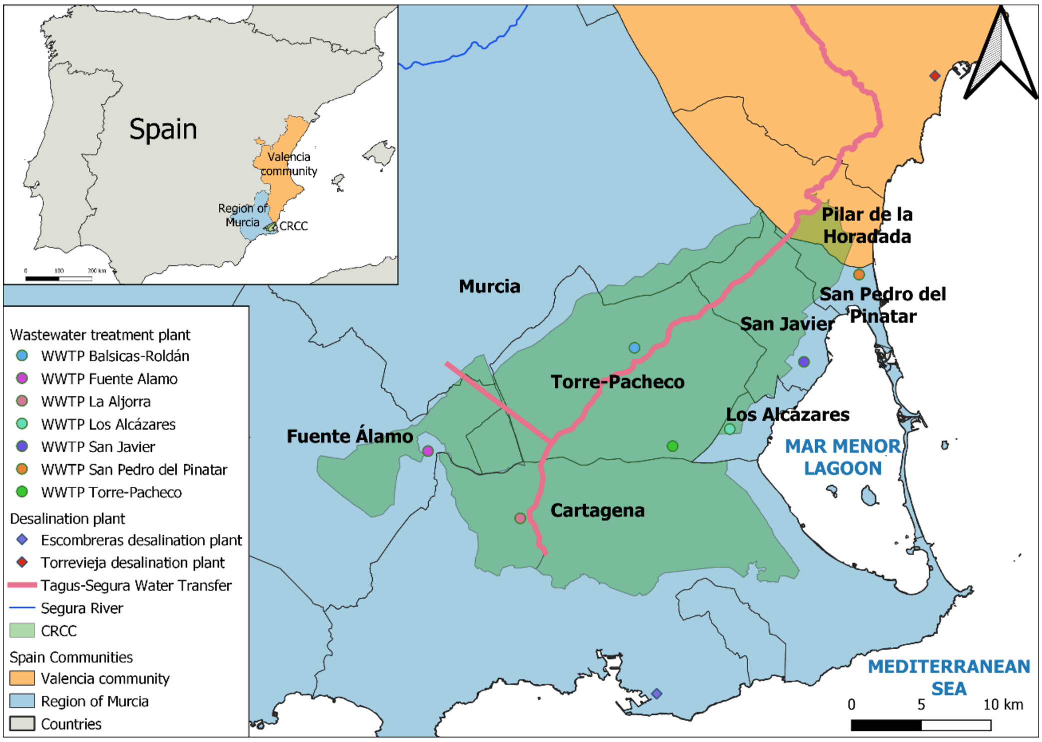


Figure 11. Location of the CRCC.

Source: Own elaboration.

In 2022, agricultural production associated with the CRCC was estimated at 346 million euros, representing more than 15% of regional agricultural output and around 1% of the national total (CHS, 2022a; MAPA, 2022a). The predominant crops are vegetables (artichoke, cauliflower, lettuce, melon, and pepper), which account for 53% of irrigated land. Citrus fruits represent 22%, while the remainder corresponds to woody crops and fallow land.

Given the region's low natural water availability, irrigation is an indispensable condition for the viability of the sector. Between 2018 and 2020, average agricultural water demand stood at 114 hm^3 per year, with variations depending on rainfall levels. To meet these needs, the community operates a diversified and integrated system that combines the TST, surface water, seawater and brackish water desalination, reclaimed water, and emergency wells during droughts. These sources are mixed in a common canal prior to distribution, enabling a flexible and integrated management model, unique within the Segura Basin.

As shown in Figure 12, the TST has historically been the most important water source for the CRCC, with an average contribution of 48.5 hm^3, equivalent to 42.5% of supply between 2018 and 2020. However, its contribution varies greatly from year to year: during the 2016–2017 drought, practically no water was transferred. By contrast, seawater desalination gained importance, providing 13.3% of supply during the same period. Other sources, though smaller in volume, were equally crucial: surface water (2.4%), reclaimed water (5.3%), brackish desalination (1.1%), and water obtained from rights transfers or drought wells (2%) (2018–2020).

The remaining 33.5% of water allocations was covered by groundwater resources, outside the management of the CRCC (MAPA (2024) and Soto García (2020)). These unregulated resources come from aquifers under critical conditions due to overexploitation, nitrate pollution, and high salinity derived from seawater intrusion (Alcolea et al., 2019). Their hydrological connection with the Mar Menor, a coastal saltwater lagoon, exacerbates the problem, since agricultural runoff has intensified eutrophication processes and anoxic episodes (Álvarez-Rogel et al., 2020). For this reason, the current Segura RBMP incorporates measures aimed at strengthening controls and reducing withdrawals from this source before 2027 (CHS, 2022e).

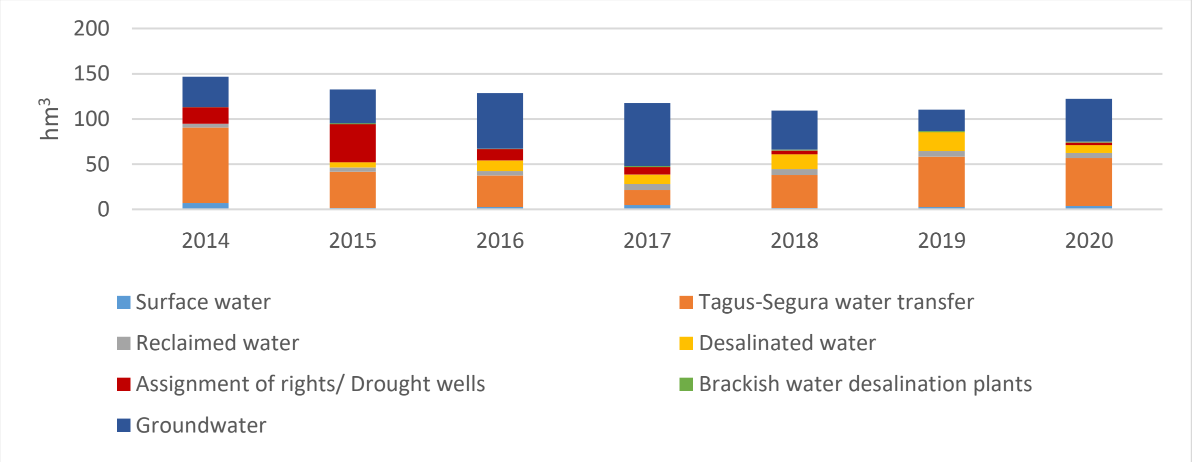


Figure 12. Water irrigation is used by sources (2014-2020) for the CRCC.

Source: Own elaboration based on data provided by the CRCC.

Regarding reclaimed water, growth potential is very limited, since six of the seven WWTP serving the community already reuse the entirety of their flows. Only the San Javier WWTP operates at 80% due to quality issues. In contrast, desalinated water offers greater room for expansion, with two public desalination plants within the CRCC's scope. Of particular note is the Torrevieja desalination plant, whose capacity increase from 80 to 100 hm³ is expected by 2027. Furthermore, the Segura RBMP foresees new desalination facilities (CHS, 2022a).

Although NCW still entail high production costs, their viability is supported by public funding mechanisms. Reclaimed water is financed through the sanitation fees paid by urban users and established by the ESAMUR, while the State subsidizes part of the operating costs of desalinated water (Gómez-Ramos et al., 2024).

the new Plan integrates measures designed to promote the expansion of NCW as a strategy to mitigate the impacts associated with the reduction of conventional water resources.

Table 8 shows the average prices for farmers of the different water sources used by the CRCC between 2018 and 2020. Thanks to financial support mechanisms, both desalinated and reclaimed water are offered at prices well below their real production costs (€0.70/m³ and €0.44/m³, respectively).

Nevertheless, the high dependence on the TST remains a critical issue for the CRCC. The new Segura RBMP projects a 40% reduction in transferred volumes by 2027 (CHS, 2022a). This would lower the average 48.5 hm³ (2018–2020) to about 29.3 hm³. This outlook, coupled with pressure on aquifers, environmental impacts, and the effects of climate change, poses major uncertainties for water security and agricultural production. For this, the new Plan integrates measures designed to promote the expansion of NCW as a strategy to mitigate the impacts associated with the reduction of conventional water resources.

Table 8. Price of CRCC water sources.

Water sources	**Price (€/m3)**
Surface water	0.03
TST	0.16
Reclaimed water	0.085
Desalinated water	0.58
Assignment of rights/ drought wells	0.14
Brackish water desalination plants	0.1
Groundwater	0.4

Source: Own elaboration based on data provided by Soto García (2020), Soto García (2015), Custodio (2018) and Custodio et al. (2019)

In this context, the CRCC represents a valuable case for analysing the response of irrigation systems to reductions in transferred resources. At the same time, it underscores the strategic importance of NCW to offset these reductions, and of economic instruments to mitigate and redistribute the environmental and socio-economic impacts associated with this shift in water availability.

2.4. Contribution of the thesis to literature

NCW have become increasingly relevant in Spanish and Mediterranean water planning due to growing water scarcity and the rising pressure on conventional resources. Despite this strategic importance, their widespread adoption, particularly in agriculture, its main end user, has advanced far more slowly than anticipated.

In the case of reclaimed water, the literature consistently identifies persistent socio-economic, technical and environmental barriers that continue to hinder its integration into irrigation systems (Mesa-Pérez & Berbel, 2020; Santos et al., 2023; Simón & Oller, 2024). Similar constraints have been documented at the European scale, where high treatment costs, institutional fragmentation and limited social acceptance remain major obstacles (Yalin et al., 2023), contributing to the marked underutilisation of treated wastewater (Fabregat, 2025). Quantitative studies reinforce this diagnosis. agroeconomic modelling and cost–benefit analysis show that reclaimed water could be a viable complementary supply source with marginal effects on farm income, yet uptake remains constrained by high treatment and distribution costs (Hristov et al., 2021).

In Spain, econometric and cost analysis likewise point to institutional, economic and infrastructural factors as key determinants restricting reuse volumes (Bolinches et al., 2022; Expósito, Díaz-Cano, et al., 2024; Gallego-Valero et al., 2019). Interviews with irrigation communities and expert surveys in semi-arid basins such as the Segura further indicate that concerns about emerging pollutants and regulatory uncertainty weaken confidence in the expansion of wastewater reuse (Gómez-Ramos et al., 2024; Jodar-Abellan et al., 2024). However, despite these contributions, there is still no comprehensive empirical assessment that systematically examines, classifies and prioritises the barriers limiting reclaimed-water expansion in Spain.

This thesis addresses this gap through an extensive literature review that identifies and maps barriers across contexts and regions. Building on this review, and through expert consultation and cross-impact analysis, the thesis develops a structured classification of barriers, identifies the most influential and proposes targeted mitigation strategies. This integrated approach advances current knowledge on the constraints affecting reclaimed-water adoption and supports the development of more effective policies and practices for its expansion in Spain.

In parallel, several studies have explored stakeholder perceptions of the use of reclaimed water in agriculture. Many of them, however, emphasise aggregated or consensus-based views rather than capturing the nuanced diversity of individual perspectives. For instance, Ballesteros-Olza et al. (2022) applied a stakeholder-based FCM to present a consensus view of the current state of reclaimed water reuse. Similarly, Mesa-Pérez et al. (2020) employed a SWOT analysis to identify the perceived the strengths, weaknesses, opportunities, and threats associated with its use. Other contributions, such as those by Ricart et al. (2019, 2022), focused on specific stakeholder groups, such as farmers and consumers, addressing environmental and health risks concerns. Likewise, Zabala et al. (2019), and Moya-Fernández et al. (2021) conducted surveys to explore consumer perspectives, assessing perceived impacts, willingness to pay, and acceptance of reclaimed water for consumption. While these studies offer valuable insights, they often fail to fully capture the broader diversity of views within the sector.

To address this limitation, this thesis seeks to better represent the range of subjective viewpoints on reclaimed water use in agriculture in Spain. Gaining a comprehensive understanding of these perspectives is crucial for identifying synergies and mitigating potential conflicts, thereby informing more effective policy decision-making. To this end, this study applies Q methodology, a tool designed to identify subjective viewpoints and construct shared narratives on complex topics. Originally developed in the field of psychology, this approach has gained widespread recognition in the environmental social sciences due to their suitability to understand perspectives on multifaceted and often polarising issues (Watts & Stenner, 2012; Zabala et al., 2018). The analysis makes it possible to elucidate areas of consensus and divergence among stakeholders, critical elements for informed, coherent and socially robust policy design, contributing to a deeper and more nuanced understanding of the social dimensions shaping reclaimed water use in Spanish agriculture.

While reclaimed water has received considerable attention, desalination has simultaneously become a cornerstone of Spanish water policy, especially in regions facing chronic water deficits. Technological advances and declining production costs have supported its rapid expansion, and many irrigation communities now combine desalinated water with other sources. Nevertheless, when multiple sources coexist, farmers' decisions are mediated by a complex network of economic, technical, environmental and institutional factors. Existing research rarely captures this complexity. The prevailing tendency has been to analyse barriers and drivers separately, offering only a fragmented understanding of the conditions that shape NCW uptake (Aleisa & Al-Haddad, 2024; Morote et al., 2019; Palma et al., 2024; Ricart et al., 2021). Likewise, most contributions examine desalination and water reuse separately, disregarding the principles of integrated water resources management and failing to capture the complementarities and trade-offs between them (Bernabé Crespo et al., 2019; Silva, 2023). Others cluster them together under the general category of NCW, without fully exploring the substantial differences they present in terms of cost, environmental impact, social acceptance, or technical feasibility (Hurtado et al., 2024; Zuluaga-Guerra et al., 2023). Furthermore, perception studies tend to focus on specific groups, mainly farmers (Ricart et al., 2022) or consumers (Zabala et al., 2019), without considering the full range of stakeholder views in agricultural water management (Gómez-Ramos et al., 2024). Altogether, these gaps underscore the need for integrated analyses that jointly examine desalination and reclaimed water reuse, consider their multiple interdependencies, and incorporate a broader spectrum of stakeholder views.

Responding to this need, the thesis analyses the current and future role of desalinated and reclaimed water, by identifying the triggers, barriers and impacts, and interactions that shape their adoption. A differentiated FCM approach is applied to map causal relationships, capture perceived dynamics, and simulate alternative management and policy scenarios, providing a systems perspective rarely used in this field. The analysis incorporates the views of a broad range of key stakeholders, including public administration, farmer associations, water companies, environmental organizations and NCW experts, thereby complementing existing research with a more holistic and practice-grounded perspective.

The FCM analysis is applied to the Region of Murcia, in southeastern Spain, a territory characterized by structural water scarcity, high dependence on irrigated agriculture, and a long-standing reliance on NCW (Morote et al., 2020). While previous research has analyzed the effects of NCW irrigation on crops and soils (Acosta et al., 2025), and its use in irrigation communities (Ballesteros-Olza et al., 2025; Gómez-Ramos et al., 2024), no study has explicitly mapped the network of interacting factors shaping NCW adoption or explored how these dynamics may evolve under future conditions. By simulating stakeholder-defined scenarios, including NCW expansion, cost-recovery measures, investment in renewable energy and capacity-building initiatives, the thesis provides an integrated, stakeholder-informed and context-specific assessment of how NCW could strengthen water-supply reliability and agricultural sustainability.

The potential of NCW to offset future reductions in conventional water resources has likewise received little attention. This gap is particularly evident in southeastern Spain, where climate change and recent policy reforms are expected to sharply reduce the availability of traditional sources such as inter-basin transfers. The TST, a cornerstone of regional water supply has been extensively analysed in terms of governance and socio-political conflict (Bourguignon et al., 2024; Hernández-Mora et al., 2014; Melgarejo-Moreno et al., 2019; Morote et al., 2020), its economic contributions to agricultural production and employment (Buendía-Azorín et al., 2025; PricewaterhouseCoopers, 2020), its financial viability, and pricing structures (García-López et al., 2022, 2023), environmental impacts (Fazelpoor et al., 2021; Ibor et al., 2011; San-Martín et al., 2020), and vulnerability to climate change (Cañizares et al., 2022; Pellicer-Martínez & Martínez-Paz, 2018; Senent-Aparicio et al., 2021).

However, far fewer studies have quantitatively examined the capacity of desalinated, reclaimed and groundwater resources to compensate for these anticipated reductions, despite growing policy emphasis on diversification and resilience. Existing research on NCW substitution has largely relied on qualitative approaches, such as policy analysis or expert and stakeholder consultations (Gómez-Ramos et al., 2024; Morote et al., 2017), or has focused on isolated technical aspects, including the agronomic effects of NCW irrigation (e.g. Acosta et al., 2025; De las Heras & Mañas, 2020; Martínez-Álvarez et al., 2023), its implementation in irrigation communities (Ballesteros-Olza et al., 2025; Gómez-Ramos et al., 2024) or its role in climate adaptation (Morote et al., 2019; Ricart et al., 2021). While valuable, these contributions do not provide scenario-based quantitative evidence on how NCW could buffer reductions in conventional supplies, nor do they assess the economic instruments required to support such transitions.

To address this gap, this thesis applies a farm-based agroeconomic PMP model to the CRCC, one of the most transfer-dependent and technologically advanced districts in the Segura River Basin. The model simulates farmers' behaviour under varying supply and pricing conditions and evaluates the potential of desalinated, reclaimed and groundwater resources to mitigate the impacts of reduced TST deliveries. By quantifying effects on profitability, water use, crop patterns, labour demand and water costs, the analysis provides a data-driven assessment of the feasibility, benefits and limitations of substituting conventional supplies with NCW.

Finally, by integrating structural barrier assessment, stakeholder-perception analysis and quantitative modelling, the thesis makes a multi-dimensional contribution to the literature and strengthens the foundations for more resilient and adaptive water-governance frameworks. Although the thesis focuses on Spain, an international benchmark in the use of NCW, its contributions extend beyond the national context. The analyses in the Region of Murcia and the CRCC, both emblematic of intensive irrigation systems reliant on desalinated and reclaimed water, provide a solid empirical basis for broader insights. Building on these cases, the thesis offers transferable evidence to inform diversified and climate-resilient water-governance strategies in other Mediterranean and semi-arid regions.

3. Materials and methods

3.1. Barriers to reclaimed water use in agriculture.

This section presents three differentiated but complementary methodologies, which together allowed for the identification and analysis of the main barriers that hinder the use of reclaimed water in agriculture in Spain.

Firstly, a systematic mapping was developed combining two procedures: a bibliometric analysis and a literature review focused on publications presenting barriers to the establishment of this type of project in Spain.

The bibliometric analysis, developed by Garfield (1955), employs mathematical and statistical methods to analyse the relationships and impact of scientific publications, providing a summary of advancements and trends within a particular research field (Li et al., 2022; Ricart et al., 2022). In parallel, the literature review involved a detailed content analysis that evaluated the robustness of evidence, theoretical frameworks, and future research directions (Clark et al., 2022; Silva, 2023). To conduct this comprehensive review, we followed the detailed steps outlined in the subsequent subsections.

3.1.1. Protocol

To ensure the reproducibility of the review process, the systematic literature review (SLR) adhered to the sequential workflow outlined in the Preferred

Reporting Items for Systematic Reviews and Meta-Analyses checklist (PRISMA) (Page et al., 2021), thereby minimizing potential bias and enhancing transparency and replicability (Page et al., 2023). This protocol elucidates the bibliographic corpus selection, data extraction criteria, subsequent analysis, and interpretation of results (Krstikj et al., 2022). Figure 13 provides a concise overview of the protocol implemented in this study.

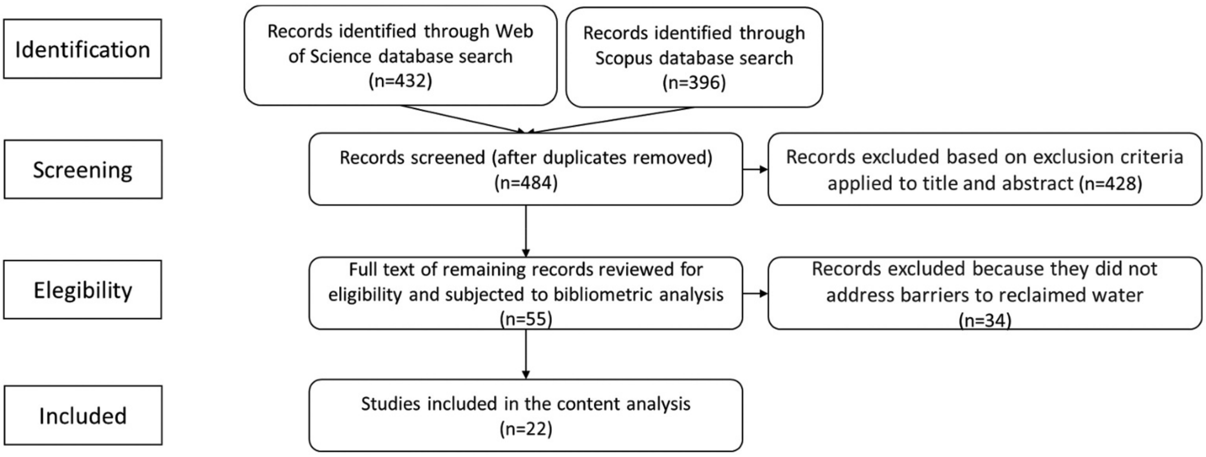


Figure 13. PRISMA flowchart of the systematic literature review protocol for the data retrieval and analysis process.

Source: Own elaboration.

As seen in Figure 13, the review process commenced with the identification phase, during which searches were performed in accordance with the research objectives, employing predefined inclusion and exclusion criteria. Subsequently, duplicate papers were removed. In the screening phase, titles and abstracts were thoroughly scrutinized against the exclusion criteria. Upon completing this phase, the review proceeded to the eligibility stage, wherein the full texts of the remaining 55 papers were examined. Ultimately, 22 papers addressing barriers to reclaimed water reuse projects were selected, setting the stage for an in-depth content analysis.

3.1.2. Query strings

The inclusion terms for the search encompassed all forms of reclaimed water and irrigation as depicted in the literature, which had to appear in titles, keywords, or abstracts. Additionally, results were filtered by region (Spain) and the time frame from 2008 to January 2024. The study period began in 2008 and continued to coincide with the publication of Royal Decree 1620/2007, which established the legal framework for reusing treated wastewater. This decree marked increased governmental support for NCW and their development

The search query in Web of Science was: TI = (‘reuse* water’ OR ‘reuse* wastewater’ OR ‘reclaim* water’ OR ‘reclaim* wastewater’ OR ‘regenerat* water’ OR ‘regenerat* wastewater’ OR ‘water reuse*’ OR ‘wastewater reuse*’ OR ‘water reclaim*’ OR ‘wastewater reclaim*’ OR ‘water regenerat*’ OR ‘wastewater regenerat*’ OR ‘wastewater recycl*’ OR ‘recycl* water’ OR ‘recycl* wastewater’ OR ‘repurif* water’) AND TI = (irriga*) AND AB = (Spain) AND PY = (2008–2024). The search query in Scopus was: TITLE-ABS-KEY = ‘reuse* water’ OR ‘reuse* wastewater’ OR ‘reclaim* water’ OR ‘reclaim* wastewater’ OR ‘regenerat* water’ OR ‘regenerat* wastewater’ OR ‘water reuse*’ OR ‘wastewater reuse*’ OR ‘water reclaim*’ OR ‘wastewater reclaim*’ OR ‘water regenerat*’ OR ‘wastewater regenerat*’ OR ‘wastewater recycl*’ OR ‘recycl* water’ OR ‘recycl* wastewater’ OR ‘repurif* water’ AND TITLE-ABS-KEY = ‘irriga*’ AND PUBYEAR > 2008 AND PUBYEAR < 2025 AND (LIMIT-TO (AFFILCOUNTRY, ‘Spain’)).

3.1.3. Study selection

The search conducted in February 2024 yielded a total of 836 papers from both databases. After removing duplicates and applying the exclusion criteria, 55 papers were reviewed and subjected to bibliometric analysis. Of these, only 22 specifically addressed the barriers to implementing reclaimed water reuse projects.

The exclusion criteria were as follows:

- Irrigation of plants other than agricultural crops.
- Non-agricultural irrigation (e.g., golf irrigation, groundwater recharge).
- Studies focused on treatment technologies for purification and reclamation.
- Comparative studies of purification and reclamation treatments.
- Studies on other NCW.
- Studies conducted outside of Spain.

3.1.4. Data management and analysis

The 55 reviewed papers were analysed bibliometrically to determine their geographical distribution, publication years, and content (Ricart et al., 2022).

Initially, a performance analysis was conducted to assess the volume of papers and identify regions with the most papers (Cucari et al., 2023). Subsequently, scientific mapping was used to generate relational indicators to create a spatial representation of the interactions between different elements. This was accomplished using VOSviewer software, which facilitates the creation, visualization, and exploration of network data maps, adopting a distance-based approach to visualize cluster networks (van Eck et al., 2010).

Subsequently, a literature review and in-depth analysis were conducted based on the final 22 papers to identify barriers and potential solutions. Following the initial phase of barrier identification, a team of five experts synthesized these barriers by eliminating duplicates and classifying them according to the PESTEL analysis. PESTEL facilitates the investigation of the external context influencing strategic decisions and their susceptibility to critical variables (Eierle et al., 2022). The dimensions of the PESTEL analysis encompass various aspects, including political, economic, social, technological, environmental, and legal facets. The political dimension involves the analysis of governmental policies, political stability, and international relations. The economic dimension focuses on the macroeconomic environment, including national income, investment incentives, and energy costs. The social dimension examines societal perceptions and potential impacts. The technological dimension addresses water treatment processes and technological advancements. The environmental dimension delves into pollution issues and their effects on ecosystems. Finally, the legal dimension encompasses understanding and knowledge of laws and regulations and their implications for water management.

Finally, a cross-impact analysis was conducted to identify and examine the correlations between the barriers, aiming to analyse the most influential ones. Barriers were systematically identified and organized into a matrix format to achieve this (Medina et al., 2015) showcasing their interrelationships and clarifying which barriers exert the greatest influence on the development of reclaimed water reuse projects. The matrix rows illustrate how these barriers affect the elements listed in the columns.

The cross-impact analysis was conducted through remote interviews in March and April 2024. A total of twelve experts in the use of reclaimed water in agriculture were interviewed, recognized for their extensive knowledge in the field, as evidenced by their various publications. These experts represent various public and private sector entities across different regions of Spain, including environmental and social NGOs, public administrators and research centres. During the interviews, each expert was asked to rate the rows on a scale of 0 to 3, where 0 indicated no influence, 1 denoted slight influence, 2 represented strong influence, and 3 signified very strong influence.

Upon completion of the interviews, the average ratings for each barrier were calculated across the matrices provided by the respondents. Subsequently, the active and passive sums were computed for each barrier. The active sum indicates the extent of a barrier's influence on others, while the passive sum reflects a barrier's dependence on others. This analysis allowed us to identify the most influential barriers.

3.2. Social perspectives of reclaimed water in agriculture.

This section aims to analyse the various existing social perspectives on the use of reclaimed water in agriculture. To this end, the Q methodology was employed, developed by Stephenson (1980) as a tool to capture and compare diverse perspectives on the same topic.

The Q methodology is a bridge between two methodological approaches, qualitative and quantitative, allowing the researcher to deal with the subjectivity and opinions of respondents in a systematic and in-depth way (Hampson et al., 2022). It is considered qualitative due to its focus on subjective data derived from individual values and its ability to produce meaningful insights without relying on large population samples, distinguishing it from traditional survey techniques. In addition, it incorporates quantitative elements, as data collection and analysis involve the use of statistical and mathematical techniques (Frantzi et al., 2009). This combination allows the methodology to reveal a set of social perspectives that explain participants’ perceptions and the arguments underlying them, providing a robust and comprehensive framework for exploring complex social issues.

The first step of the Q methodology consists of defining and developing the Q-set, which is a population’s set of opinions, ideas, and perceptions about an argument related to the research objective (Gholamrezai et al., 2023). In this section, we collected 101 statements. The sources from which these statements were obtained include scientific articles, press releases, reports, conference proceedings, and interviews with key stakeholders conducted within the framework of the RECLAMO project between March and July 2022 (Ballesteros-Olza et al., 2022). All sources were selected for their relevance to the perception of the use of reclaimed water in agriculture, following the line of research established in Brannstrom et al. (2022) and Phiri et al. (2023). Each of the statements were analysed by the authors to ensure all aspects of reclaimed water reuse were covered: impact on the environment and crops, health risks, prices, economic costs, water quality, emotional reactions, awareness and information, regulations, management, governance, infrastructure, and technology. Duplicates were eliminated and the statements that conveyed the most concise and clear ideas about reclaimed water were selected. Finally, a total of 36 statements were chosen and tested in five pilot interviews, resulting in easily understandable statements.

The second step involves identifying the P-set, which comprises the study's participants. Although a large sample size is not required, the group must be diverse to capture a range of perspectives (Cooper & Wardropper, 2021). Participants are intentionally selected based on their relevance to the subject area (Novo et al., 2024). In this study, the P-set included 23 representatives from key stakeholder groups related to the use of reclaimed water in agriculture in Spain. These participants were carefully selected to reflect the entire reclaimed water use chain, drawing on a thorough literature review and the authors' prior work (Ballesteros-Olza et al., 2022). The group included representatives from environmental NGOs (4), food retailers (2), consumer organisations (1), farmer associations (3), public administrators (4), private water treatment companies (3), water treatment associations (2), and experts in water reuse (4).

The third step is the Q-sort, which consists of asking participants (P-set) to rank statements according to their opinions. This step is performed on a forced distribution grid, known as a Q-grid. This grid employs a 5-point Likert scale, ranging from -5 (strongly disagree) to +5 (strongly agree) (Finchilescu & Muthal, 2019). In the present research, the rankings were carried out using the Q method software (https://qmethodsoftware.com/), through virtual interviews conducted on ZOOM, due to the geographical dispersion of the participants, from March to July 2023.

During the interviews, a preliminary classification of the statements into three categories was conducted: those with which participants agreed, those they disagreed with, and those generating neutral or mixed opinions. Subsequently, the statements were sorted based on their relative level of agreement / disagreement using the Q-grid shown in Figure 14. Columns on the left represent greater disagreement, and those on the right indicate greater agreement, while the boxes within each column have equivalent conformity values, whether positive or negative. The sorting process began with the category containing the most statements, either agreement or disagreement, and concluded with the neutral statements. Once the sorting was done, the participants were allowed to reclassify the statements if they were not satisfied with their initial sorting. Finally, respondents were asked about the classification of some statements and the reasons for this classification. Every participant provided written or verbal consent for the interviews to be recorded, transcribed, and used for analysis purposes. Throughout the study, their anonymity has been maintained.

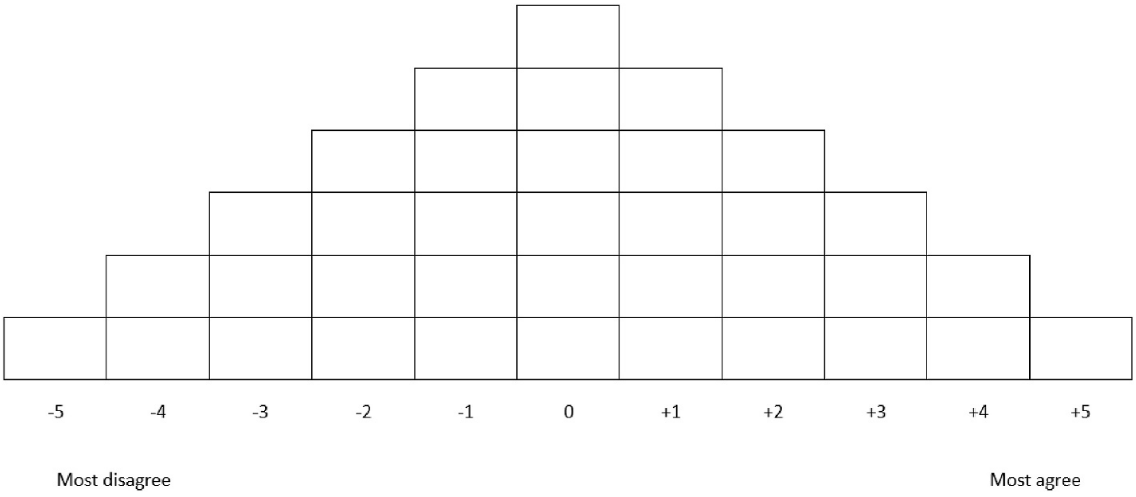


Figure 14. The Q methodology grid used for this study.

Source: Own elaboration.

The last step in Q methodology involves estimating factor scores for each statement and identifying the distinctive and common statements for each discourse. For this, a factor analysis was performed in R software using the 'qmethod' package (version 1.5.5) (A. Zabala, 2014). Principal Component Analysis (PCA) was used for factor extraction, which was subjected to a variamax rotation and a Spearman correlation coefficient.

3.3. Stakeholder-based assessment of NCW for agricultural irrigation.

In order to study the current situation of NCW, in this section a FCM has been developed with the participation of stakeholders to reflect the complex relationships and interdependencies between variables that affect the management of NCW such as desalinated water and reclaimed water in the Region of Murcia, Spain.

3.3.1. Participatory development of FCM

Cognitive mapping methodologies were initially developed by Axelrod (1976) and Tolman (1948), Kosko (1986) subsequently introduced the notion of fuzziness, coining the term Fuzzy Cognitive Maps (FCM). These maps depict the components of a system and the causal relationships among them, as defined by individuals or groups (Kok, 2009). Their construction commonly relies on participatory approaches, such as structured interviews or workshops, in which the components of the system are identified and the directed links between them are established (Gray et al., 2015). Each relationship indicates the type of influence (positive or negative) that one component exerts on another. The strength of these relationships is quantified using coefficients ranging from -1 to +1: values close to -1 represent strong negative influences, values close to +1 indicate strong positive influences, and values near zero reflect weak causal relations (Nápoles et al., 2024).

This technique has demonstrated wide applicability across diverse fields-from engineering to environmental and social sciences, and water resource management (Mohamed et al., 2020; Sánchez-Barroso et al., 2023; Sarmiento et al., 2024; White et al., 2021), due to its ability to represent complex systems. The tool can integrate expert and local perspectives, synthesize quantitative and qualitative data, and effectively model feedback loops and nonlinear dependencies within a system (White et al., 2021).

This study employed a participatory FCM to capture and analyse stakeholder perceptions of the interactions affecting the current and future use of NCW in agriculture in the Region of Murcia. The map was co-created during a November 2024 workshop under the RECLAMO project (2020–2024), which provided extensive prior fieldwork and in-depth engagement with local actors. A total of 19 participants took part, representing public administrations, farmer associations, water companies, environmental associations, and NCW experts (see workshop participants in the annexes Table S1). Stakeholder groups were first identified through a literature review (Aznar-Sánchez et al., 2017; Ballesteros-Olza et al., 2022; Molina & Melgarejo, 2016; Ricart et al., 2021), and further refined using the project's accumulated local knowledge to ensure balanced sectoral representation (Ballesteros-Olza et al., 2025; Gómez-Ramos et al., 2024). To complement this process, a targeted snowballing strategy was applied to identify additional key informants with recognised expertise or influence in NCW management.

During the workshop, participants first identified the components of the system they considered most influential in the current NCW context and classified them into three dimensions (economic-technical, environmental, and socio-institutional). Second, they described the relationships between pairs of components, specifying the direction of causality (from Ci to Cj or vice versa), while indicating whether each interaction was positive (when the increase in one factor leads to the increase in the other) or negative (when the increase in one factor leads to a decrease in the other). Third, participants assessed the perceived strength of each link (wij) using a Likert scale from 1 to 5 for positive relationships and –1 to –5 for negative relationships (White et al., 2021). Following Blanco-Gutiérrez et al. (2020), these values were subsequently normalised to the conventional –1 to +1 interval to obtain the final weights.

After reaching consensus on the FCM, participants explored potential future developments to support scenario building and simulation. Stakeholders proposed alternative change scenarios and key system transformations, identifying the key drivers for each scenario.

Once the workshop outcomes were processed, the preliminary FCM was refined and validated through a series of expert consultations held via Zoom between December 2024 and January 2025. This process culminated in the construction of the adjacent matrix (W) (Table S2), with dimensions $n \times n$, where n represents the total number of components included in the FCM.

3.3.2. FCM analysis

First, the FCM's structure was examined using standard indicators: number and types of components, total relations, relations per component, density, complexity, indegree, outdegree and centrality (Table S3).

Subsequently, the FCM model was used to assess the map's dynamic behaviour and to generate exploratory predictions of its potential evolution under different conditions. This dynamic analysis provided a solid basis for scenario development (Mohamed et al., 2020). This predictive process relied on successive inference, where the adjacency matrix was multiplied by a state vector (A) of size $1 \times n$ over a defined number of iterations (k). The Kosko activation rule, as proposed by Stylios & Groumpos (2004), was implemented for this process. This allows each component's value at any iteration to depend on both its previous state and the incoming influences of other components, through the causal relationship strengths:

(Equation 1)
$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j\neq i\\ j=i}}^{N} A_j^{(k)} w_{ji}\right)$$

where $A_i^{(k+1)}$ is the value of the component C_i at iteration $k+1$, $A_i^{(k)}$ is the value of the component C_i at iteration k, $A_j^{(k)}$ is the value of the component C_j at iteration k, y w_{ji} is the weight of the causal connection between components C_j y C_i.

To ensure efficient system convergence at each cycle, a sigmoid function (equation 2) was applied, compressing the values within a bounded range. While this limits strict quantitative analysis, it enables qualitative comparisons among components and scenarios (Nápoles et al., 2024):

(Equation 2)
$$f(x) = \frac{i}{1 + e^{-\lambda x}}$$

where λ determines the slope of the function and is a positive real number, in this study, the value is set to $\lambda = 1$.

The inherent dynamics of FCM allow tracking the evolution of relationships across iterations, guiding the system towards an equilibrium or stable state (also known as the baseline scenario). From this equilibrium, alternative scenarios can be simulated to observe the system's response to specific incentives or perturbations, encompassing economic, technical, institutional, environmental, or social factors.

For the analysis, the FCMapper tool was used in conjunction with the unit vector approach described by Wildenberg et al. (2010). In this approach, the initial component values (activation vector, A_0) are set to 1. All components were defined according to their current conditions, with scarce elements represented as "lack of," enabling both dynamic and scenario-based analyses.

3.3.3. Scenario analysis

Scenario analysis provides insights into how current decisions may shape outcomes, informing robust policies, challenging assumptions, and fostering proactive responses to emerging environmental challenges (Elsawah et al., 2020). In line with this, the developed FCM was used to simulate alternative scenarios to better understand the role and potential of NCW. To this end, selected driver components, those able to influence the system by modifying its baseline value, were set to 0 or 1 (representing a decrease or increase compared to the baseline scenario, respectively), as per Blanco-Gutiérrez et al. (2020) and Reckien (2014).

Four distinct scenarios were identified by stakeholders and assessed: (i) NCW expansion; (ii) Cost recovery; (iii) Investment in renewable energy projects; and (iv) Capacity building. Table 9 summarizes each scenario, including the key components and their adjusted values, which reflect deviations from the baseline case.

Table 9. Description of the selected scenarios.

Scenario	*Description*	*Components' value changes*
NCW expansion	This scenario examines the expansion of NCW availability through the enlargement of desalination plants and the enhancement of wastewater treatment and reclamation capacity, as envisaged in the RBMP and Royal Decree 1085/2024.	"Lack of new desalination projects" and "Lack of implementation of new policies for wastewater treatment and reclaimed water" were decreased (Δ=-0.66) to 0

Cost recovery	This scenario assesses the implication of phasing out subsidies for desalinated water, as scheduled for 2026 under Order TED 157/2023. Removing these subsidies will allow progress toward full cost recovery, adjusting the final price to the actual cost of production and distribution.	"Subsidies for desalinated water" was decreased (Δ=-0.66) to 0
Investment in renewable energy projects	This scenario simulates the implementation of renewable energy projects aimed at supplying NCW infrastructures, an initiative currently promoted by the Spanish government. Integrating renewable energy is expected to reduce energy expenditures, which represent a major share of NCW production costs.	"Lack of renewable energy projects" was decreased (Δ=-0.66) to 0
Capacity building	This scenario responds to local farmers' demand for training in the use of NCW. It includes the development of technical support and education programs to enhance farmers' ability to integrate these resources effectively.	"Lack of farmer training" was decreased (Δ=-0.46) to 0.2

Source: Own elaboration

Additionally, all four scenarios were evaluated under the current allocations of the conventional water sources, and under the implementation of the recently approved Segura RBMP (CHS, 2022a), which foresees reductions in transfer volumes and aquifer withdrawals. To simulate this, the component representing the maintenance of current TST and groundwater levels decreased to 0 (from to its baseline value of 0.66), reflecting the expected reduction in water availability following the plan's enforcement.

For results analysis, the relative changes in component values were presented both individually and in aggregate. For the latter, components were classified as positive (an increase benefits the system), negative (an increase has an adverse effect), or neutral (Sarmiento et al., 2024) (see Table S4). As suggested by Blanco-Gutiérrez et al. (2020), aggregate values were calculated by subtracting the sum of relative changes in negative components from the sum of changes in positive components.

3.4. Evaluation of NCW as an alternative to traditional water sources.

Finally, in this section, a positive mathematical programming model has been developed by adapting the works of Blanco & Viladrich-Grau (2014), Medellín-Azuara et al. (2019) and Escriva-Bou et al. (2023), with specific modifications, to evaluate the impact of the TST reduction and alternative water supply scenarios on the CRCC. Mathematical programming models enable the analysis of agricultural water demand management strategies by integrating economic, agronomic, technological, and institutional constraints (Howitt, 1995).

This approach is notable for its ability to integrate extensive technical and economic information and to disaggregate results according to the available information level, such as farm types, irrigation communities, irrigated areas, or sub-basins (Calatrava & Martínez-Granados, 2012).

3.4.1. Data Collection

The data used in this section are secondary data collected from various sources (Table 10) and the data are found in Table 17, Table S6, Table S8 and Table S9.

Table 10. Different sources of the data.

Data	Source
Crop Yield, Area, and Price	CARM (2024)
Crop net water requirements	MAPA (2024a)
Labor requirements and costs	Del Villar García et al. (2020)
Basic payment	MAGRAMA (2016) and MAPA (2022)
Crop salinity thresholds	Maas & Hoffman (1977)
Water source availability	Fieldwork conducted in July 2022 and Soto García (2020)
Water source prices	Soto García (2015; 2020), Custodio (2018) and Custodio et al. (2019)
Water source salinity	Martínez-Alvarez et al. 2023; Sadhwani Alonso & Melián-Martel, 2018; Soto García, 2015, 2020))

Source: Own elaboration

3.4.2. Model

Based on the available data, a mathematical programming model was developed and calibrated using the Positive Mathematical Programming (PMP) method, following a two-step procedure.

In the first step, a conventional linear programming model was solved under calibration constraints, using the most recent data corresponding to the 2018–2020 average. In the second step, the information contained in the dual values of these constraints was used to define a nonlinear objective function. Thus, once the calibration constraints were removed, the new model reproduced with high accuracy the activity levels observed in the baseline scenario (Blanco Fonseca & Iglesias Martinez, 2005).

The objective function maximizes the net benefits of the agricultural system by optimizing the use of key production inputs (land, water, and labour) across different crops, while considering the specific constraints of each scenario (Rodríguez-Flores et al., 2022). The variables in the equations are specified by crop (c: artichoke, broccoli-cauliflower, lettuce-melon, pepper, and lemon tree), month (m), and/or water source (h: surface water, reclaimed water, water rights assignments, groundwater, TST, desalinated water, and brackish water).

The model equations are formulated as follows:

Equation 1 is the objective function and shows the profit maximization of farmers:

(Equation 1)

$$MaxZ = \sum_{c}(rto_c \times pc_c - cost_c) \times X_c + \sum_{c} PB_c \times X_c - \sum_{m} pmo \times MOA_m - \sum_{h}\sum_{m} cag_{h,m} \times CostW_{h,m}$$

Where: rto_c: yield per crop; pc_c: price per crop; $cost_c$: costs per crop; X_c: production area per crop; PB_c: basic payment (EU Common Agricultural Policy subsidy) per crop; pmo: labour cost; MOA_m: paid labour per month; $cag_{h,m}$: water consumption per month and water source; $CostW_{h,m}$: water cost per month and water source.

This maximization is subject to various constraints, including land availability (Equation 2):

(Equation 2)

$$\sum_{c} X_c \leq SAR$$

Where SAR represents the available area in the CRCC. Additionally, Lettuce and melon are planted in succession, which means growing different species in the same space but in different seasons (Poch-Massegú et al., 2014). Conversely, lemon trees, as a permanent crop, are restricted to a maximum area variation of 10%, as exceeding this threshold would require costly and complex measures, such as tree removal.

The constraint of labour (Equation 3):

(Equation 3)

$$\sum_{c} NMO_{c,m} \times X_c \leq MOA_m + dMOF_m$$

Where: $NMO_{c,m}$: labour requirements per month and crop; $dMOF_m$: availability of family labour per month.

The water constraints (Equations 4 and 5):

(Equation 4)

$$\sum_{c} NAG_{c,m} \times X_c \leq \sum_{h} cag_{h,m}$$

(Equation 5)

$$cag_{h,m} = dag_{h,m} + (dag_{h,m-1} - cag_{h,m-1})$$

Where, $NAG_{c,m}$: crop net water requirements per month and crop; $dag_{h,m}$: water availability per water source and month in the CRCC. In the Autonomous

Community of Murcia, citrus crops are typically irrigated under a deficit regime, receiving 30% less water from August to March. This strategy prioritizes critical phenological stages for these crops- flowering (March-May) and fruit development (April-August), during which 100% of the crops' water needs are met (Navarro et al., 2023). Additionally, groundwater use is not supplied by the CRCC but is managed independently by farmers. Groundwater consumption is estimated as the difference between total crop water requirements and water supplied from other sources.

Finally, the salinity constraint (Equation 6):

(Equation 6) $$\sum_h ECW_{h,m} \times cag_{h,m} \leq \sum_h 3 \times cag_{h,m}$$

Where, $ECW_{h,m}$: salinity of water by source and month. Additionally, irrigation water salinity impacts crop yield according to the Maas & Hoffman (1977) Model. To mitigate these effects, a salinity threshold of 3 dS/m is set for water mixture; exceeding this limit results in severe yield restrictions. The model is also dynamic, allowing unused water in one month to be carried over to the next.

Next, the calibration constraint equation will be added:

(Equation 7) $$X_{ct} < X0_{ct} \times (1 + \varepsilon)$$

The calibration constraint equation is included to ensure that the linear programming model reproduces the observed activity levels for the base year (X0).

Solving the linear model provides the dual values (μ) associated with the calibration constraints, which offer additional information on the cost functions. From these results, the marginal cost functions are defined according to the parameters:

- α: marginal cost intercept.
- β: marginal cost slope (activity).

(Equation 8) $$\alpha_c = cost_c - lr$$

(Equation 9) $$\beta_c = \frac{\mu_c}{X0_c}$$

Once the cost functions have been derived, the final nonlinear model is formulated, enabling the simulation of hypothetical agricultural policy scenarios:

(Equation 10)
$$MaxZNL = \sum_c rto_c \times pc_c \times X_c + \sum_c PB_c \times X_c - \sum_c X_c \times (\alpha_c + 0.5 \times \beta_c \times X_c) - \sum_m pmo \times MOA_m - \sum_h \sum_m cag_{h,m} \times CostW_{h,m}$$

This model, without the calibration constraints, accurately reproduces the activity levels observed in the baseline year and serves as the foundation for prospective analyses of agricultural and water policy alternatives.

3.4.3. Scenarios

To assess potential future alternatives, the following scenarios are defined (detailed in Table 11):

- **Baseline:** Represents the current situation, based on the average water supply and demand between 2018 and 2020.
- **Water Transfer Reduction:** Considers a 40% reduction in the TST, as indicated in the Segura RBMP (CHS, 2022a).
- **Increased Alternative Water Sources:** It is a hypothetical, though somewhat unrealistic, scenario aimed at analysing how to mitigate the effects of reducing the water transfer by allowing unlimited use of groundwater and desalinated water. In the CRCC, groundwater is an unregulated resource and, therefore, farmers use it almost without restrictions. Regarding desalinated water, it is expected that, with the expansion and development of new desalination plants, its use can also be expanded without limits. Lastly, the use of reclaimed water is increased up to the current concession limit granted to the CRCC.
- **Constrained Alternative Water Sources:** Introduces usage limits on groundwater and desalinated water, as outlined in the Segura RBMP for 2027, while retaining previous assumptions regarding water transfer and reclaimed water.
- **Desalinated Water Subsidy:** Maintains the same volumetric constraints as the previous scenario but assumes a reduction in the price of desalinated water to €0.35/m^3, following the provisions of Order TED/157/2023. This order temporarily suspends the application of the cost recovery principle (Article 111 bis of the Spanish Water Act) for ten years. The measure was

enacted in response to the severe drought affecting the country and rising energy costs driven by the war in Ukraine, aiming to promote affordable alternative water sources and ease pressure on aquifers.

- **No Subsidies for NCW:** Retains the same volumetric constraints but assumes full cost pricing for desalinated and reclaimed water. According to studies by Cabrera et al. (2019) and Gómez-Ramos et al. (2024), these prices could reach €0.70 for desalinated water and €0.44 for reclaimed water.

Table 11. Scenario characteristics.

	Availability (hm^3)				Price (€/m^3)	
Scenarios	**TST**	**Groundwater**	**Desalinated water**	**Reclaimed water**	**Desalinated water**	**Reclaimed water**
Baseline	48.5	43.6	15.2	6.0	0.58	0.08
Water transfer reduction	29.3	43.6	15.2	6.0	0.58	0.08
Increased Alternative Water Sources	29.3	unlimited	unlimited	11.2	0.58	0.08
Constrained Alternative Water Sources	29.3	43.2	45.2	11.2	0.58	0.08
Desalinated Water Subsidy	29.3	43.2	45.2	11.2	0.35	0.08
No Subsidies for NCW	29.3	43.2	45.2	11.2	0.70	0.44

Source: Own elaboration

4. Results

4.1. Barriers to reclaimed water use in agriculture.

The following three subsections present the results from both the systematic mapping and cross-impact analysis. The first section (4.1.1) examines the bibliometric characteristics of the 55 papers selected for comprehensive review. Sections 4.1.2 and 4.1.3 present the literature review results and cross-impact analysis based on the 22 papers included in the content analysis.

4.1.1. Bibliometric and thematic analysis on the use of reclaimed water in Spanish agriculture

The bibliometric analysis was conducted on the 55 papers selected in the eligibility phase of the PRISMA protocol concerning the use of reclaimed water in agriculture in Spain from 2008 to 2024. Figure 15 shows a stable publication trend, with 1 to 4 papers per year until 2019, when there was a significant increase to 11 publications. This surge is attributed to the growing focus on nonconventional water resources, prompted by the droughts during the hydrological years 2016-2017 and 2017-2018 (García-Herrera et al., 2019) and the launching of key water reuse initiatives at both European and national levels (Ricart et al., 2021). In 2019, the European Commission published a comprehensive report on the implementation of the Circular Economy Action Plan , outlining a pathway towards a circular, climate-neutral economy aimed at minimizing pressure on natural resources, freshwater, and ecosystems (Domenech & Bahn-Walkowiak, 2019). This was followed by major regulatory advancements, including EU Regulation 2020/751 and Spain's National Plan for Sanitation, Efficiency, Saving, and Reuse of Wastewater (DSEAR Plan, 2021), further reinforcing the policy framework for water reuse.

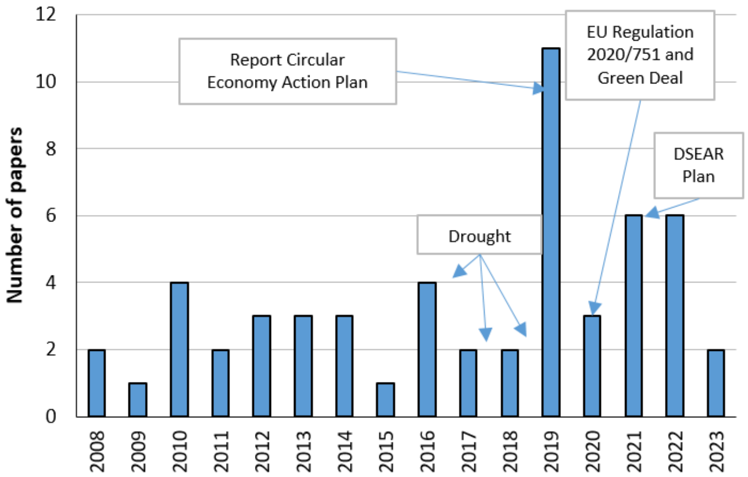


Figure 15. Evolution of Papers on the Use of Reclaimed Water in Agriculture in Spain from 2008 to 2024

Source: Own elaboration

In terms of geographic distribution (Figure 16), only 6 did not include case studies. Among the remaining papers, 3 had a global scope, 8 focused on Europe, and 5 examined Spain as a whole. At the regional level in Spain, six papers focus on Murcia, five on Catalonia, and four each for Valencia and Almeria. The Canary

Islands and Madrid were each examined in 1 paper. In terms of river basins, the Segura basin was the most studied with 5 papers, followed by the Jucar with 3, the Guadiana with 2, and the Ebro and Guadalquivir with 1 each. The geographical distribution of these studies aligns with the regions where reclaimed water reuse is most prevalent, particularly along the Mediterranean arc and the archipelagos (see Figure 8). However, in recent years, inland areas, such as Madrid and the Guadiana Basin, have also gained increasing research attention.

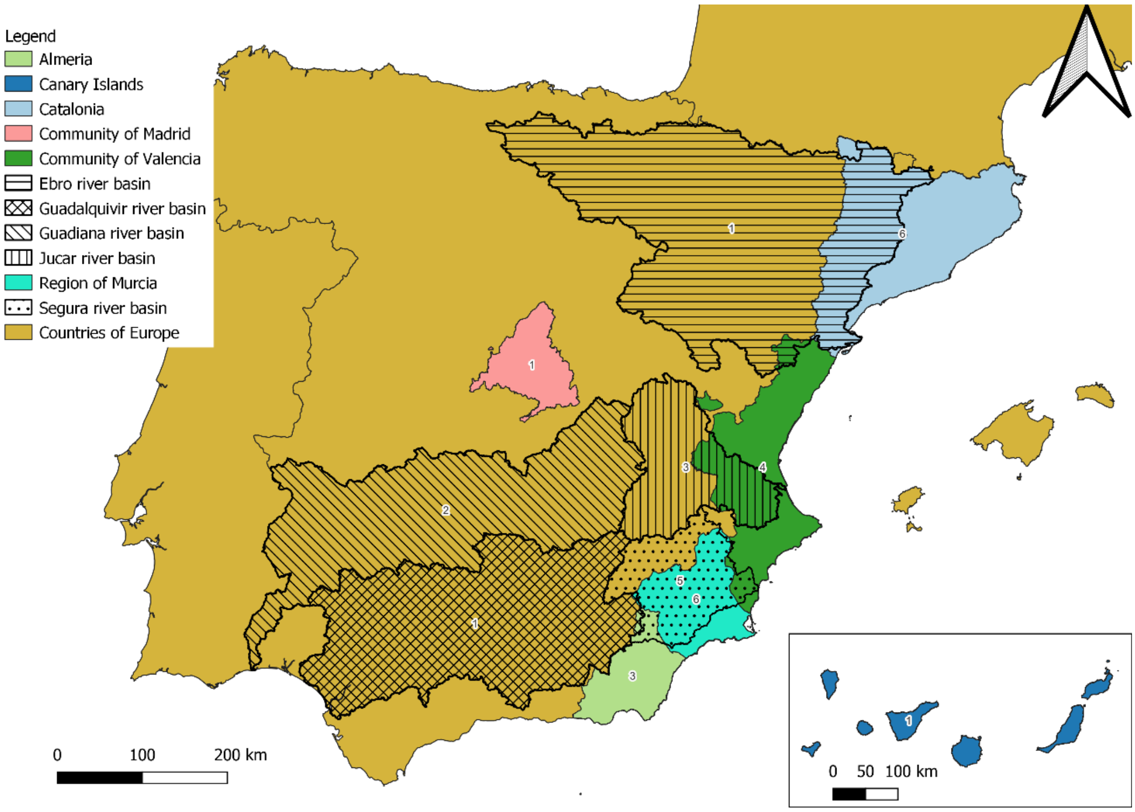


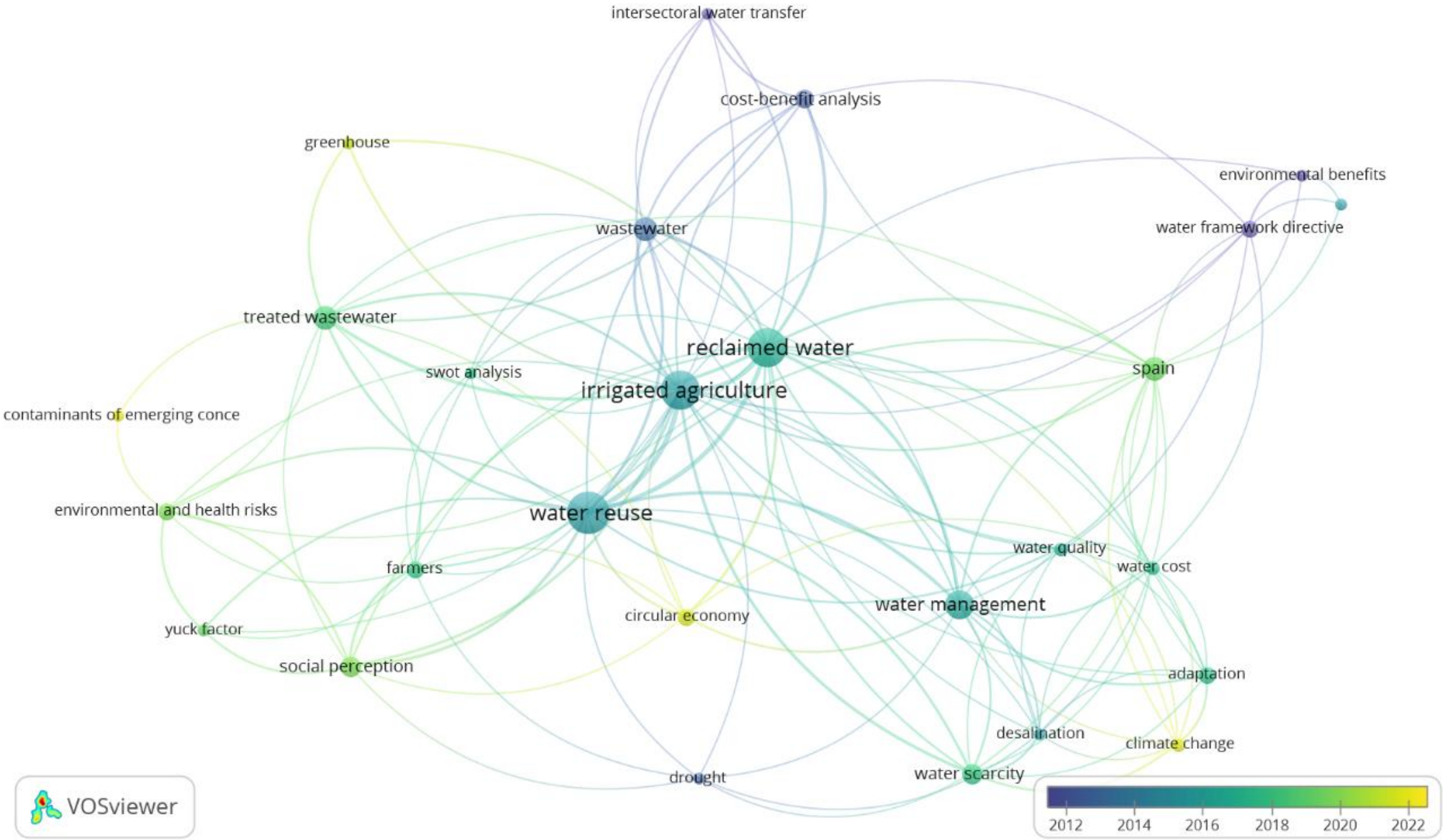
Figure 16. Geographical Distribution and Number of Papers on the Use of Reclaimed Water in Agriculture in Spain from 2007 to 2024.

Source: Own elaboration

The content analysis was conducted using VOSviewer software, resulting in a network map (Figure 17 and Figure 18) based on the occurrence of the keywords from the 55 papers analysed. Initially, 202 keywords were considered; however, after synonym cleaning using a thesaurus file, the list was refined to 171 keywords. Of these, only 27 appeared at least twice (two occurrences). Keywords with greater similarity are positioned closer together on the maps, and the size of the circles indicates the frequency of keyword appearances in the papers. Figure 17 shows the keywords' occurrence by year, while Figure 18 displays them by thematic groups.

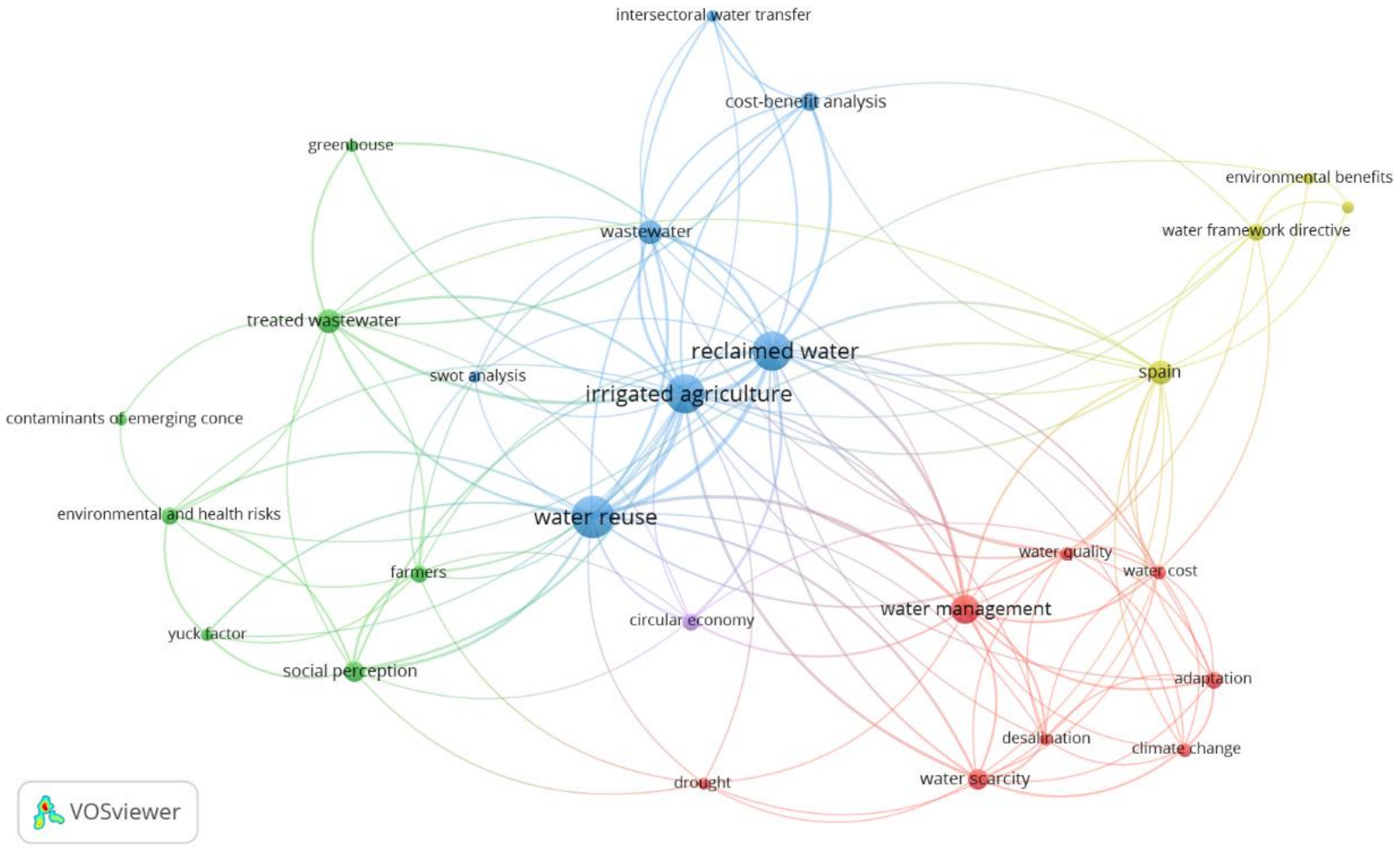
In both maps, cited keywords were: "reclaimed water," "water reuse," and "irrigated agriculture." As shown in Figure 17, earlier papers focused on the sources of reclaimed water (wastewater) and the economic and regulatory aspects of reclaimed water, which were crucial for establishing relevant policies. From 2016 onwards, the focus shifted toward the practical application and sustainable management of water, with increasing interest in how farmers can utilize reclaimed water for irrigation and manage water resources efficiently. Keywords also include adaptation, desalination, water quality, and cost. From 2020, the main keywords are associated with environmental and health risks, including the “yuck factor” and its impact on social perception. Finally, from 2022 onwards, terms such as circular economy and climate change become prominent, reflecting a growing concern for sustainability and resilience in the face of environmental challenges. Five distinct clusters were identified in terms of thematic groups (Figure 18). The blue cluster focuses on using and evaluating reclaimed water, encompassing cost-benefit, and SWOT analyses to assess its advantages and disadvantages. This cluster is linked to the green cluster, which centres on social perception and farmers' attitudes towards reclaimed water. The red cluster, also associated with the blue cluster, addresses climate change and water scarcity, emphasizing the importance of NCW such as reclaimed and desalinated water and underscores the need for effective water management strategies to adapt to these conditions. The yellow cluster indicates references to Spain and its associated regulations. Finally, the purple cluster, comprising a single keyword (circular economy), is highly interconnected with the other clusters as it integrates various aspects of water reuse.

Figure 17. Keyword Co-occurrence Analysis of Author Keywords with a Threshold of Two Occurrences by Year.



Source: Own elaboration using VOSviewer software

Figure 18. Keyword Co-occurrence Analysis of Author Keywords with a Threshold of Two Occurrences by Thematic Group.



Source: Own elaboration using VOSviewer software

4.1.2. Identification of barriers to reclaimed water in agriculture: PESTEL classification

Following the bibliometric analysis of the 55 selected papers, a detailed review was conducted to identify papers addressing barriers to water reclamation and reuse implementation. Only 22 papers discussed such barriers (Table 12). These barriers were classified using the PESTEL analysis (Political, Economic, Social, Technological, Environmental, and Legal factors) to identify the main drivers that may influence the implementation of reclaimed water reuse projects.

The barriers identified within the Political dimension indicate institutional fragmentation (Sánchez-Cerdà et al., 2020), which impedes coordination among various institutions (Ballesteros-Olza et al., 2022). Additionally, administrative procedures were found to lack agility. On a local scale, some papers mentioned difficulties in reaching agreements among irrigators within irrigation communities concerning the use of reclaimed water (Ortega-Reig et al., 2014). Another notable barrier is the need to integrate new roles mandated by the European Directive 2020/741 (Ricart et al., 2021). This role is known as the Reclaimed Water Manager, which is critical and accountable for implementing risk management plans, thereby ensuring environmental and sanitary safety in the use of reclaimed water (Jiménez-Benítez et al., 2020).

Table 12. List of papers included in the analysis.

Authors	Year	Title	PESTEL barriers					
			Political	Economic	Social	Technical	Environmental	Legal
Aznar-Crespo et al.	2019	Factors of uncertainty in the integrated management of water resources The case of water reuse		x	x	x	x	
Ballesteros-Olza et al.	2022	Using reclaimed water to cope with water scarcity- an alternative for agricultural irrigation in Spain	x	x	x	x	x	x
Bolinches et al.	2022	A method for the prioritization of water reuse projects in agriculture irrigation				x	x	
Elbana et al.	2010	Preliminary planning for reclaimed water reuse for agricultural irrigation in the province of Girona, Catalonia (Spain)		x	x		x	
Ferro et al.	2015	Conventional and New Processes for Urban Wastewater Disinfection Effect on Emerging and Resistant Microorganisms			x		x	
Gil-Meseguer et al.	2019	Recycled Sewage - A Water Resource for Dry Regions of Southeastern Spain			x	x		
Heinz et al.	2011b	Evaluating the costs and benefits of water reuse and exchange projects involving cities and farmers			x		x	
Heinz et al.	2011a	Water reclamation and intersectoral water transfer between agriculture and cities - a FAO economic wastewater study		x				
Koseoglu-Imer et al.	2023	Current challenges and future perspectives for the full circular economy of water in European countries			x			
López-Serrano et al.	2022	Farmers' Attitudes towards Irrigating Crops with Reclaimed Water in the Framework of a Circular Economy	x	x	x	x	x	x
Maestre-Valero et al.	2019	The role of reclaimed water for crop irrigation in southeast Spain			x		x	
Mesa-Pérez et al.	2020	Analysis of Barriers and Opportunities for Reclaimed Wastewater Use for Agriculture in Europe		x	x	x		
Molinos-Senante et al.	2013	Tariffs and Cost Recovery in Water Reuse		x				

Morales et al.	2014	Reclaimed wastewater as a resource for irrigation of Segura River Basin (SPAIN)		x				
Ortega-Reig et al.	2014	The integrated use of surface, ground and recycled waste water in adapting to drought in the traditional irrigation system of Valencia	x		x			
Polo	2012	Recycling and reuse of treated wastewater Challenges and perspectives - The example of the Júcar River Basin District and the Albufera Lake		x		x		x
Ricart & Rico	2019	Assessing technical and social driving factors of water reuse in agriculture- A review on risks, regulation and the yuck factor					x	
Ricart et al.	2019	Risk-Yuck Factor Nexus in Reclaimed Wastewater for Irrigation Comparing Farmers' Attitudes and Public Perception	x	x	x	x		
Ricart et al.	2021	Extending Natural Limits to Address Water Scarcity The Role of Non-Conventional Water Fluxes in Climate Change Adaptation Capacity A Review	x	x		x	x	x
Sánchez-Cerdà et al.	2020	Reuse of reclaimed water What is the direction of its evolution from a European perspective		x	x	x		x
Urkiaga et al.	2008	Development of analysis tools for social, economic and ecological effects of water reuse		x	x		x	
Yalin et al.	2023	Mitigating risks and maximizing sustainability of treated wastewater reuse for irrigation			x		x	

Source: Own elaboration

In the Economic dimension, a prominent barrier is the high cost of reclaimed water compared to conventional water resources (Berbel et al., 2023). This cost is often prohibitive for some farmers (López-Serrano et al., 2022), primarily due to the investments required in various infrastructures. These investments include connections to WWTP, intake chambers, disinfection equipment, pumping stations, discharge pipelines, automation systems, waterproofing of lakes and reservoirs, filtration stations, drainage chambers, pipelines, and electrical installations (Pérez Morales et al., 2014). Despite ongoing government economic aid, uncertainties in cost recovery pose investment risks associated with these reclaimed water reuse projects (Heinz et al., 2011), which are leading to increasingly narrow profit margins for farmers (López-Serrano et al., 2022).

In the Social dimension, the primary barrier is the lack of social acceptance (Ricart et al., 2019; Yalin et al., 2023), largely driven by health risk concerns (Maestre-Valero et al., 2019). Weak communication strategies and the absence of effective awareness campaigns further contribute to consumer reluctance to purchase products irrigated with reclaimed water (Mesa-Pérez et al., 2020). Additionally, some farmers distrust reclaimed water, perceiving it as low quality and detrimental for crop productivity (Ricart et al., 2019).

The main barriers in the Technological dimension include the need to improve existing reuse systems (Polo, 2012), as not all wastewater treatment plants are equipped with the necessary technology for effective reclamation (Sánchez-Cerdà et al., 2020). Moreover, inadequate distribution and regulatory infrastructure (e.g., canals, storage tanks) (Ricart et al., 2021), as well as deficiencies in the management and operation of wastewater treatment systems, are major challenges (Polo, 2012).

The primary barriers in the Environmental dimension include the high conductivity of reclaimed water (Aznar-Crespo et al., 2019), which can compromise the quality of the final product or soil productivity (Elbana et al., 2010), alongside the potential presence of emerging contaminants and heavy metals (Heinz et al., 2011). These barriers are closely related to the quality of reclaimed water and are influenced by the water source, treatment processes and irrigation management practices (M. Xu et al., 2016). Additionally, the use of reclaimed water can reduce return flows, potentially impacting downstream users and jeopardizing compliance with ecological flow requirements (Expósito et al., 2024). In some basins, particularly in inland areas, this may restrict the approval of water reuse projects unless appropriate compensatory measures are implemented (Ballesteros-Olza et al., 2022; Bolinches et al., 2022).

Lastly, the barriers in the Legal dimension include the complexity of regulations (Ballesteros-Olza et al., 2022), which are often overly stringent (Sánchez-Cerdà et al., 2020), and the necessity of establishing a risk management plan introduces further procedural requirements, extending the time, and costs involved (Ricart et al., 2021).

4.1.3. Analysis of barriers to reclaimed water in agriculture: Cross-impact analysis

Based on the bibliographic analysis, 93 barriers were initially identified. After a process of elimination and grouping according to the various dimensions of the PESTEL analysis, this number was reduced to 16 barriers. These 16 barriers were then analysed using a cross-impact assessment with input from 12 experts from across Spain, including representatives from environmental and social NGOs (expertise in environmental and social issues), public administrations (political and legal expertise), and research centres (technical and economic expertise). Experts evaluated how each barrier affects the others using a scale from 0 to 3, as detailed in the methodology. The values in the cross-impact matrix (Autonomous barriers are characterized by their minimal influence on and dependence on other barriers. These barriers are isolated from the broader context, indicating both limited impacts on and limited susceptibility to influence from other barriers. For instance, barrier En1, which pertains to the threat to maintaining ecological flows, lacks sufficient influence or is not significantly influenced to be considered an immediate barrier for intervention. Hence, addressing other barriers should take precedence.

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Dependent barriers are characterized by their limited influence, suggesting that they are weak drivers, but their significant reliance on other barriers classifies them as passive barriers. This dependency means actions on other barriers are needed to mitigate their effect. An example of this category is barrier P3, which refers to commercial barriers affecting products irrigated with reclaimed water.

Independent barriers are characterized by their strong influence and minimal dependence on other barriers. They also act as key drivers due to their impact on the remaining barriers. As such, these barriers should be prioritized for intervention. This group includes the other two environmental barriers (En2 and En3) and the other two political barriers (P1 and P2). This indicates that initial measures should focus on addressing these barriers, followed by those demonstrating a “relatively independent” linkage.

Linkage barriers exhibit strong influence and dependence. They are divided into two categories based on their position relative to the diagonal: above the diagonal when the active sum is greater than the passive sum and below the diagonal when the active sum is less than the passive sum. Barriers above the diagonal are “relatively independent” and should be addressed after independent barriers. This group includes barriers S1, S2, Ec3, T1, Ec1, Ec2, L1, L2, S3 and T2. Among these, the first four are considered proper linkage barriers, while the remainder above the diagonal are categorized as linkage barriers that are “relatively independent.”

Table 13 represent the average of these ratings. Based on this data, active and passive sums were calculated to assess each barrier's influence on the others and its level of dependence.

From this matrix, the passive sum (X-axis) and the active sum (Y-axis) have been extracted to create Figure 19. This figure elucidates the most influential barriers and categorizes them accordingly.

Table 13. Cross impact matrix of barriers to water reuse implementation in Spain.

P_ (Political barrier), Ec_ (Economic barrier), S_(Social barrier), T_(Technological barrier), E_(Environmental barrier) and L_(Legal barrier)

	Barriers	P1	P2	P3	Ec1	Ec2	Ec3	S1	S2	S3	T1	T2	En1	En2	En 3	L1	L2	Active sum
P1	Lack of agility in administrative procedures		2	1	1	1	1	1	2	0	0	1	1	1	0	2	1	14
P2	Lack of institutional coordination	2		1	1	1	1	1	2	1	1	1	1	1	1	2	2	15
P3	Trade barriers to products irrigated with reclaimed water	0	0		1	1	1	2	2	1	1	1	0	0	0	1	1	12
Ec1	High cost of reclamation infrastructures	1	1	1		3	3	1	2	1	2	2	1	1	1	1	1	19
Ec2	The high price of reclaimed water	0	1	1	1		2	2	3	1	2	1	1	1	1	0	1	17
Ec3	Investment risks	1	1	1	2	2		1	2	0	1	2	1	1	1	1	1	15
S1	Low social acceptance	1	1	1	1	1	2		3	1	2	1	1	1	1	1	1	17
S2	Resistance from farmers	1	1	1	2	1	2	2		1	1	1	0	1	1	2	2	16
S3	Health risks	1	1	2	1	1	1	3	2		2	2	0	1	1	2	2	21
T1	Need for improvement of reclamation technologies	1	1	1	2	2	2	1	1	2		2	0	2	2	1	1	19
T2	Lack of suitable technology in all WWTP	0	0	2	2	2	1	1	2	2	2		1	2	2	1	1	21
En1	Threat of maintenance of ecological flows	1	1	0	0	1	1	2	1	1	1	1		1	1	1	1	12
En2	Presence of emerging pollutants and heavy metals	1	1	2	2	2	2	2	2	3	2	2	1		1	2	2	26
En3	Salinity of reclaimed water	0	1	1	2	2	2	1	3	1	2	2	1	1		1	1	19
L1	Difficulty in establishing risk management plans	1	1	1	1	1	1	1	2	2	1	1	1	2	1		1	19
L2	Regulations too strict in minimum quality requirements	1	1	1	2	2	2	1	2	2	2	2	1	2	1	2		22
	Passive sum	11	14	17	19	20	24	21	31	18	23	21	9	15	14	19	19	

Source: Own elaboration

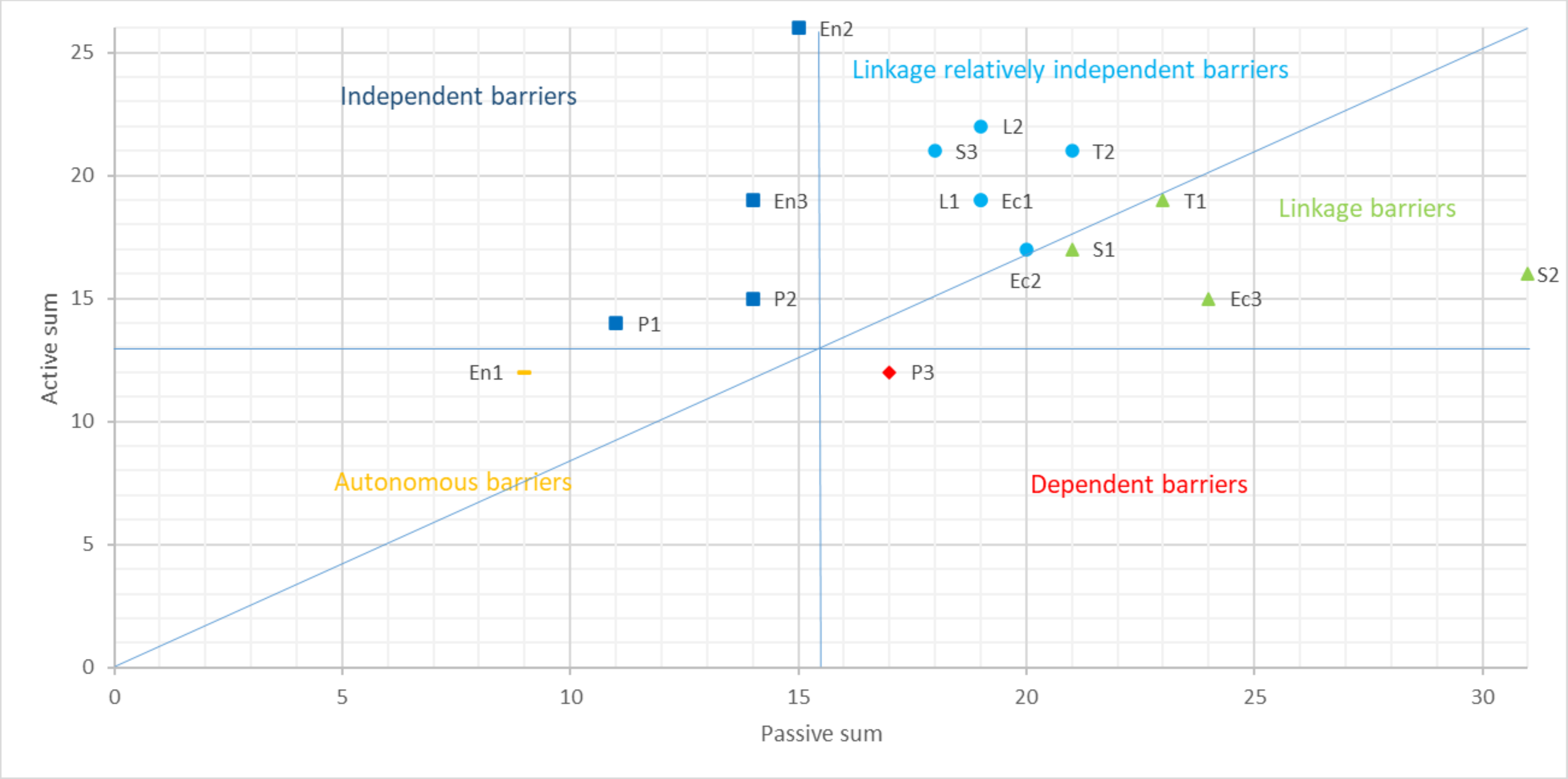


Figure 19. Projection of the relative impact of barriers on the indirect influence–dependence chart.

Dark blue squares (Independent barriers), Light blue circles (Relatively independent barriers), Green triangles (Linkage barriers), Yellow lines (Autonomous barriers) and Red diamonds (Dependent barriers)

Source: Own elaboration

4.2. Social perspectives of reclaimed water in agriculture.

To obtain perspectives on the use of reclaimed water in agriculture, the Q methodology was used, following the objective criteria of Watts & Stenner (2012). The solution that met these criteria was the 3-factor solution, each reflecting a social perspective (discourse). Together, the 3-factors explained 61% of the variance.

Each of the three discourses identified represents a unique social perspective on reclaimed water use and its implications in economic, social, and environmental terms. We labelled the discourses (factor) as: Discourse 1: Reclaimed water secures water supply for agriculture; Discourse 2: Reclaimed water has potential for improvement; and Discourse 3: Reclaimed water adversely affects the environment. All perspectives emphasised the importance of promoting reclaimed water to address climate change and droughts, and the differences across them lie mainly in perceptions of technologies, the costs/risks involved, and the potential for undesirable environmental impacts.

Table 14 shows the discourses obtained from the factor analysis. Each row displays the z-scores and the idealised Q sorts (IQS) for each factor in relation to the statements. The z-scores represent the weighted average of the Q sort values, which indicates the relationship between the statements and the factors, i.e., how much each factor matches a statement. These z-scores are also used to construct the idealised Q sorts for each factor (Pagot & Gatto, 2024). The IQS scores represent the positions in the Q grid that discourses would assign to each statement. The last column highlights both the consensus statements for all factors and distinguishing statements, identified based on the degree of statistical distinction between the factors.

In addition, Table 15 reports the factor loadings of different stakeholders, including those defining each factor, which are marked with an asterisk (*).

The following sections provide a description and interpretation of each discourse. The idealised scores of statements are given in parentheses. Distinguishing statements are marked with an asterisk next to the statement number.

Table 14. Statements with z-scores (Z), idealised Q sort positions (IQS), and assessment of consensus and distinguishing statements.

Statement		Factor 1		Factor 2		Factor 3		Consensus/Distinguishing
Nº	Description	Z	IQS	Z	IQS	Z	IQS	
1	Growing water scarcity makes society favour greater use of reclaimed water	2.21	5	1.27	2	0.79	2	Distinguishes Factor 1
2	Social perception of the use of reclaimed water in agriculture is negative	-1.58	-4	0.52	2	0.11	0	Distinguishes Factor 1
3	Reclaimed water is socially perceived as a 'waste' and not as a 'resource' in the form of recovered water	-1.61	-4	0.35	1	-0.14	0	Distinguishes Factor 1
4	The yuck factor is one of the main barriers to the adoption of reclaimed water in agriculture	-1.27	-3	1.61	4	-0.54	-2	Distinguishes all factors: 1, 2, 3
5	Consumers are sufficiently informed about the quality of reclaimed water and its benefits	-1.67	-5	-1.98	-5	-1.41	-3	Consensus
6	Food retailers are reluctant to market products irrigated with reclaimed water	-1.17	-3	0.20	1	-0.53	-1	Distinguishes all factors: 1, 2, 3
7	Public administrations are willing to promote the use of reclaimed water	1.40	3	2.03	4	1.53	4	
8	Bureaucracy is a barrier to the establishment of new reclamation projects	1.29	3	-0.09	0	-1.03	-2	Distinguishes all factors: 1, 2, 3
9	Irrigation with reclaimed water has quality requirements that are difficult to meet	-1.14	-3	-0.32	0	-1.54	-4	Distinguishes Factor 2
10	Very strict risk management plans for reclaimed water discourage its use	0.38	1	0.21	1	-0.63	-2	Distinguishes Factor 3
11	Strict quality standards for agricultural use improve confidence in the use of reclaimed water	1.59	4	1.42	3	1.28	3	Consensus
12	Meeting the quality standards of the new EU Regulation means wasting resources (removing too many nutrients, which means higher costs)	-0.47	-1	-0.55	-1	-1.66	-4	Distinguishes Factor 3

13	Without public subsidies, water reclaim projects in agricultures cannot be developed	0.79	2	-1.57	-4	-0.25	-1	Distinguishes all factors: 1, 2, 3
14	Farmers using reclaimed water are worried about water quality and its effects on the crop and soil	0.92	2	-0.40	-1	-0.38	-1	Distinguishes Factor 1
15	Farmers are trained in the use of reclaimed water	0.98	3	-0.60	-1	0.65	2	Distinguishes Factor 2
16	The use of reclaimed water is a guarantee of supply for irrigation	1.80	4	1.49	3	-0.64	-2	Distinguishes Factor 3
17	Reclaimed water can reduce fertilizer application in agriculture	0.34	1	2.12	5	-0.25	-1	Distinguishes all factors: 1, 2, 3
18	The presence of emerging pollutants in reclaimed water is a limiting factor in the long term	0.49	1	-0.61	-2	1.40	3	Distinguishes all factors: 1, 2, 3
19	Use of reclaimed water in agriculture improves river water quality	0.10	0	-0.54	-1	-1.79	-5	Distinguishes all factors: 1, 2, 3
20	The water resources mix is essential to counteract the negative effects of reclaimed water	0.70	2	-0.94	-3	-0.12	0	Distinguishes all factors: 1, 2, 3
21	Use of reclaimed water in agriculture lead to better water purification	0.42	1	0.72	2	0.90	2	Consensus
22	Irrigation with reclaimed water causes risk of salinization soil	0.29	0	-0.85	-2	0.00	0	Distinguishes Factor 2
23	Irrigation with reclaimed water leads to soil pollution with heavy metals	-0.73	-2	-1.02	-3	0.38	1	Distinguishes Factor 3
24	Irrigation with reclaimed water reduces discharges of nutrients and pollutants to sensitive marine environments	-0.16	0	0.66	2	0.28	1	
25	Irrigation with reclaimed water is a more environmentally friendly alternative water source to conventional water resources	0.69	2	1.44	3	-1.26	-3	Distinguishes all factors: 1, 2, 3
26	Irrigation with reclaimed water endangers compliance with ecological flows by reducing returns to rivers	-0.72	-2	-0.32	0	2.43	5	Distinguishes Factor 3

27	The use of reclaimed water is an obligation for all basins, both deficit and surplus	0.09	0	-0.91	-2	-1.27	-3	Distinguishes Factor 1
28	Reclaimed water is water that is easy for farmers to access and manage	-0.80	-2	-0.35	0	0.13	1	Distinguishes Factor 1
29	The use of reclaimed water in agriculture is costly compared to conventional water resources	-0.20	0	0.01	0	0.51	2	
30	Farmers must pay for the full cost of reclaimed water	-0.42	-1	-0.95	-3	1.53	4	Distinguishes all factors: 1, 2, 3
31	Irrigating with reclaimed water is affordable for farmers	-0.40	-1	0.19	1	-0.12	0	
32	Water reclamation projects need to be large to be profitable	-0.30	0	-0.25	0	0.50	1	Distinguishes Factor 3
33	Current reclamation technology has a high degree of maturity, with little possibility for improvement	-1.04	-2	-1.09	-4	-0.13	0	Distinguishes Factor 3
34	The low value of agricultural products in certain areas prevents the use of reclaimed water	-0.52	-1	-0.66	-2	0.38	1	Distinguishes Factor 3
35	Use of reclaimed water helps ensure stable food prices	0.41	1	0.14	1	-0.38	-1	
36	The amount of reclaimed water that can be used is overestimated	-0.69	-1	-0.38	-1	1.28	3	Distinguishes Factor 3

Source: Own elaboration

Table 15. Factor loadings obtained by extraction and rotation of significant factors.

Respondent ID	Stakeholder group	Factor 1	Factor 2	Factor 3
CO	Consumer organisation	-0.3115	0.114	0.7673*
EXP1	Water reuse expert	0.1084	0.467*	-0.1381
EXP2	Water reuse expert	0.5720*	0.383	0.2370
EXP3	Water reuse expert	0.7851*	0.039	-0.0467
EXP4	Water reuse expert	0.5590*	0.368	-0.1421
FA1	Farmer association	0.0091	0.636*	-0.2785
FA2	Farmer association	0.7346*	0.418	0.0449

FA3	Farmer association	0.5617*	-0.089	-0.0628
FR1	Food retailer	0.7010*	0.177	-0.0096
FR2	Food retailer	0.8057*	-0.185	0.1848
NGO1	Environmental NGO	-0.0843	-0.234	0.7715*
NGO2	Environmental NGO	0.1678	0.216	0.7755*
NGO3	Environmental NGO	0.3618	-0.034	0.7769*
NGO4	Environmental NGO	-0.0337	0.656*	0.4320
PA1	Public administration	0.5884*	0.450	0.0788
PA2	Public administration	0.1333	0.593*	0.2057
PA3	Public administration	0.6975*	0.257	0.0755
PA4	Public administration	0.0630	0.646*	0.0293
TC1	Private water treatment company	0.3302*	0.302	0.0070
TC2	Private water treatment company	0.6033*	0.031	0.4317
TC3	Private water treatment company	0.1830	0.463*	0.0381
WTA1	Water treatment association	0.1241	0.718*	0.0521
WTA2	Water treatment association	0.5192*	0.338	-0.1242

Source: Own elaboration

4.2.1. Discourse 1. Reclaimed water secures water supply for agriculture

This discourse explains 22% of the total variance and includes 12 participants belonging to different stakeholder groups, such as public administrators, food retailers, farmer associations, water treatment associations and experts in water reuse.

This discourse emphasises the importance of reclaimed water as a constant and reliable water source for agricultural irrigation. The use of reclaimed water is regarded as a critical resource to ensure irrigation supply (16: +4), especially in situations where conventional water resources are limited or unavailable. In such circumstances, the demand for reclaimed water rises, further enhancing society's appreciation of reclaimed water (1*: +5). This shift towards a more positive perception of reclaimed water is particularly notable among farmers, who are the largest users of this resource (2*: -4):

> “Water scarcity raises awareness in society, which improves the social perception of the use of reclaimed water in agriculture” (FR2).

This discourse agrees on the overall lack of awareness regarding the benefits of reclaimed water, linked to misconceptions and misinformation about its quality and safety (5: -5). This knowledge gap prevents many from recognizing its potential advantages. Therefore, public education and awareness campaigns could improve social acceptance and encourage the adoption of this resource:

> “The perception of reclaimed water is not negative as such; the problem is that there is a lack of knowledge” (PA3).
>
> “With more information, consumers would likely support reclaimed water use, as it aligns with their growing preference for sustainable products” (FR1).

This discourse also highlights that meeting the strict quality requirements of reclaimed water for agricultural use is achievable with existing technology. Furthermore, adhering to these standards seen as key to building public trust in this resource (11: +4).

> "Reclaimed water must meet strict quality standards to protect health the environment, which positively influences its social perception” (FA2).

Rigorous treatment processes effectively transform wastewater into a safe and valuable resource making it inappropriate to classify or label it as "waste” (3*: -4). Similarly, food retailers express confidence in marketing products from crops irrigated with reclaimed water (6*: -3). Therefore, the negative opinions often associated with reclaimed water (harmful, dangerous, disgusting) are considered unsubstantiated and are not seen as an obstacle to its use (4*: -3).

This discourse underscores that government support is crucial for implementing water reclamation projects, and that public subsidies are necessary for their development (13*: +2):

> "Due to high initial costs, reclamation projects need public support and increased investment from public administrations." (PA3).

Overall, public administrations are seen as supportive of reclaimed water reuse initiatives (7: +3). However, excessive red tape remains a significant barrier to widespread adoption (8*: +3). Complex permitting and authorisation procedures can make it difficult for farmers to access and manage reclaimed water (28*: -2):

> "The administration favours the use of reclaimed water, but it involves lengthy bureaucratic processes and delays." (PA1).

This discourse also supports the "polluter pays" principle, suggesting that citizens (polluters) should bear the cost of treating wastewater to its original quality before discharge. Consequently, farmers should not cover the full cost (30*: -1):

> "As end-users of reclaimed water, farmers are only required to cover distribution costs, not reclamation expenses." (FA3).

This discourse agrees that irrigation with reclaimed water has positive environmental effects (25*: +2). It reduces the demand for conventional freshwater, preserving this valuable resource for other essential users. In addition, by removing pollutants from wastewater, it lowers the risk of contaminating natural ecosystems.

However, it also recognizes that water reuse can diminish returns to rivers, potentially reducing their self-purification capacity. Therefore, while reclaimed water in agriculture may enhance water quality in some aspects, it may also pose certain challenges (19*: 0).

> "The quality of reclaimed water for irrigation can be better than that of rivers because it has to meet strict treatments standards." (PA1).
>
> "Reclaimed water improves water quality of rivers, provided it does not affect the flow." (EXP2).

Due to this concern, there is no consensus on whether the use of reclaimed water should be required in all basins, both deficit and surplus (27*: 0):

> "The use of reclaimed water in different river basins is considered an ethical principle, meaning it is recommended but not mandatory" (PA3)

Finally, ensuring the quality of reclaimed water is considered crucial for farmers to crop health and preserve soil (14*: +2). Emerging contaminants, whose long-term effects on the environment and human health are still unknown, can be a significant barrier (18*: +1). To mitigate potential negative effects, blending reclaimed water with conventional sources may be necessary (20*: +2):

> "In some areas of Spain, reclaimed water with high salt concentration, is mixed with conventional or desalinated water to reduce the salinity" (FA2).

4.2.2. Discourse 2. Reclaimed water has potential for improvement

This discourse explains 16% of the total variance and encompasses 7 participants from various stakeholder groups, including water treatment associations, farmer associations, public administrators, and experts in water reuse, who typically possess a more technical orientation.

This discourse acknowledges the benefits of reclaimed water but suggests that there is still room for improvement in various aspects, particularly in enhancing treatment processes and public acceptance.

In line with discourse 1, irrigation with reclaimed water is considered an environmentally friendly alternative to traditional water sources (25*: +3). It not only alleviates pressure on freshwater resources but also improves soil health. Its nutrient-rich composition reduces the need for chemical fertilisers, thereby enhancing long-term soil fertility and sustainability (17*: +5).

Furthermore, unlike discourse 1, discourse 2 perceives reclaimed water as a safe and reliable resource with minimal risks of salinization (22*: -2) or the presence of emerging contaminants (18*: -2):

> "The salinity of reclaimed water depends on its source, i.e. wastewater, and is generally not a significant concern" (WTA1).
>
> "Scientific evidence confirms the safety of reclaimed water, with no substantial proof of emerging contaminants or related risks" (PA4).

Therefore, mixing reclaimed water with conventional water sources is not considered necessary to mitigate potential negative effects (20*: -3):

> "Blending water can reduce salinity, but it is ineffective from a microbiological perspective. In fact, conventional water is of poorer quality than reclaimed water" (PA2).

However, this discourse tends to agree that the use of reclaimed water in agriculture can diminish the quality of rivers (19*: -1), as it reduces the flow of water with higher quality than would otherwise be discharged into the river.

In addition, this discourse suggests that reclaimed water is subject to a negative social perception (2*: +2) largely due to its origin as wastewater and the "yuck factor" (instinctive aversion or feeling of disgust towards treated wastewater) (4*: +4):

> "The yuck factor fuels society reluctance towards the use reclaimed water, but greater awareness of the urban water cycle may reduce this perception" (PA4).

Like the findings in discourse 1, consumers are unaware of the benefits and high quality of reclaimed water (5: -5). However, this discourse presents a contrasting perspective, suggesting that this lack of knowledge is among the reasons why food retailers are reluctant to market products irrigated with reclaimed water (6*: +1):

> "Food retailers worry that mismanagement of reclaimed water could alarm consumers and damage their brand image" (TC3).

In terms of reclamation technology, this discourse considers that it has reached a high level of maturity and that meeting irrigation quality standards is no longer a challenge (9*: 0). However, it recognizes that further improvements are possible to increase the efficiency of these technologies (33: -4). Ongoing technological advancements provide opportunities to make water treatment more reliable and cost-effective:

> "The technology has scope to reduce costs, improve membrane lifespan and nutrient management" (WTA3).

This discourse strongly agrees that cost reduction in water treatment processes would allow reclamation projects to be undertaken by farmers, without financial support (13*: -4):

> "Public subsidies are not necessary to develop reclamation projects, as there are existing projects fully funded by farmers" (NGO4).

However, farmer-funded projects often prioritise the irrigation of high-value crops because of their potential for higher economic returns. Reclamation projects require significant investment in infrastructure and pipelines to connect the WWTP to the fields. Therefore, as in discourse 1, it is argued that farmers should not bear the full cost of reclaimed water production (30*: -3):

> "According to the polluter pays principle, water users (citizens) are responsible for treating the water they use. Farmers should only pay for water once it leaves the WWTP" (FA1).

Finally, this discourse agrees with discourse 1 that there is a willingness on the part of administrators to promote the use of reclaimed water in agriculture (7: +4). However, unlike discourse 1, bureaucracy is not seen as a barrier (8*: 0). Instead, it emphasises the necessity for farmers to receive better training in the use of reclaimed water (15*: -1):

> "Managing reclaimed water is challenging for farmers, requiring knowledge and precautions, particularly concerning storage. In addition, implementing the risk management plans required by the new Royal Decree is complex and demands support and guidance" (WTA1).

4.2.3. Discourse 3. Reclaimed water adversely affects the environment

This discourse explains 13% of the total variance and includes 4 participants belonging to different stakeholder groups, such as consumer organisations and environmental NGOs.

The discourse stresses the importance of taking into account geographical aspects and potential environmental impacts when using reclaimed water for irrigation. It argues that reclaimed water should only be considered as a new resource in coastal areas. In inland basins, it often it often re-enters water bodies through surface runoff or groundwater infiltration, becoming part of the hydrological cycle. Overlooking this may lead to an overestimation of the actual volume of reclaimed water available for use (36*: +3). In addition, it warns that using reclaimed water for agriculture may endanger compliance with ecological flows (26*: +5):

> "There is confusion between direct and indirect reuse. Irrigation with reclaimed water (direct reuse) only makes sense in coastal areas" (NGO2).

> "To prevent damage to ecosystems, reclaimed water should only be used in substitution of conventional water resources (CO).

In contrast to discourse 1, this discourse disputes the notion that reclaimed water can offer a reliable supply for agricultural irrigation (16*: -2) and strongly supports the notion that its use in agriculture negatively impacts river quality (19*: -5).

> "Reclamation projects should be evaluated on a case-by-case basis to carefully assess their impact on river flows and the reduction of the rivers' self-purification capacity" (NGO1).

Unlike discourse 2, it highlights the long-term concerns posed by emerging pollutants (18*: +3) and soil pollution caused by heavy metals resulting from irrigation with reclaimed water (23*: +1). Furthermore, it is believed that blending water resources (reclaimed water and conventional water) can help mitigate the negative effects of reclaimed water, although it will not completely counteract them (20*: 0):

> "The existence of pollutants in treated wastewater may limit the reuse of reclaimed water" (NGO2).

Also, in contrast to discourse 2, this discourse suggests that irrigation with reclaimed water may not consistently reduce fertiliser consumption, and could even require additional fertilisation in some cases (17*: -1):

> "Reclaimed water contains nutrients beneficial to plants, but it does not provide all the essential nutrients for optimal growth. Additionally, it may contain contaminants that could inhibit plant nutrient uptake or negatively affect soil fertility." (NGO1).

As a result, this discourse agrees that the use of reclaimed water for irrigation is detrimental from an environmental point of view (25*: -3). Though technological advances in reclamation could help to alleviate these negative environmental effects, economic barriers hinder progress in this direction (33*: 0):

> "Increased economic investment is necessary to achieve enhancements in reclamation technology, particularly given the existence of emerging contaminants that lack treatment solutions." (NGO1).

In line with discourse 2, this discourse acknowledges that public subsidies are not the only option for developing water reclamation projects in agriculture (13*: -1):

> "There is significant private initiative for water reclamation projects, driven by the profitability of irrigation" (NGO2).

In contrast to the other two discourses (1 and 2), this discourse asserts that farmers should bear the entire cost of the reclamation process (30*: +4), because they directly benefit from it. It acknowledges that large reclamation projects are more profitable due to economies of scale (32*: +1), but highlights the difficulty of implementing such projects in regions where agricultural products have low value (34*: +1).

According to this discourse, the new European regulation imposes rigorous quality requirements and risk management plans which, though not without challenge, are not difficult to meet (9: -4) and therefore do not discourage the use of reclaimed water (10*: -2). Furthermore, this discourse opposes the idea that complying with the quality standards of the new EU regulation results in resource wastage by removing excessive nutrients (12*: -4):

> "The quality standards are not overly strict; on the contrary, they are necessary to ensure food safety." (CO).

Like in the other two discourses (1 and 2), this discourse reveals a strong consensus regarding administrator willingness to promote the use of reclaimed water (7: +4). Moreover, bureaucracy (8*: -2) and the "yuck factor" (4*: -2) are not perceived as impediments, indicating that reclaimed water is considered a valuable resource rather than waste (3*: 0). This suggests that there is no reluctance to promote food irrigated with reclaimed water (6*: -1):

> "Using reclaimed water in agriculture can boost a food brand's image by showcasing its commitment to sustainability and environmental responsibility" (NGO2)

In line with discourses 1 and 2, the primary issue is the lack of consumer information (5*: -3):

> "There is no reluctance to reclaimed water because there is no information However, with a well-executed campaign, this situation could be easily and effectively changed" (NGO3).

4.2.4. Consensus y disagreement

Findings from a Q study can be valuable for identifying specific areas of agreement and disagreement among different perspectives (Brannstrom et al., 2022). This understanding, often overlooked in Q studies, can be important for guiding discussions, focusing on the most significant issues and facilitating negotiations and compromises by overcoming seemingly irreconcilable positions (Huaranca et al., 2019; Iribarnegaray et al., 2021).

Figure 20 illustrates specific statements with the highest level of agreement between the factors (discourses). The central section highlights the statement with the greatest consensus among the three factors, indicated by the smallest differences in Z-scores. Notably, all discourses agree that consumers are not sufficiently informed about the quality and benefits of reclaimed water (statement 5; 1: -5, 2: -5, 3: -3).

Intermediate sections show statements with the highest agreement between pairs of factors (smaller differences in Z-scores identified by pairs of factors). Discourses 1 and 2 agree that current reclamation technology is not fully mature and can be improved (statement 33; 1: -2, 2: -4), while discourses 1 and 3 share the view in recognising public administrations' eagerness to promote the use of reclaimed water (statement 7; 1: +3, 3: +4). Discourses 2 and 3 concur that rigorous quality control ensures reclaimed water meets high standards, alleviating farmers' concerns about its effects on crops and soil (statement 14; 2: -1; 3: -1)

Finally, the outer section contains the statements each discourse agrees with the most. For example, Figure 20 shows a strong agreement regarding the idea that growing water scarcity makes society favour greater use of reclaimed water (statement 1, factor 1).

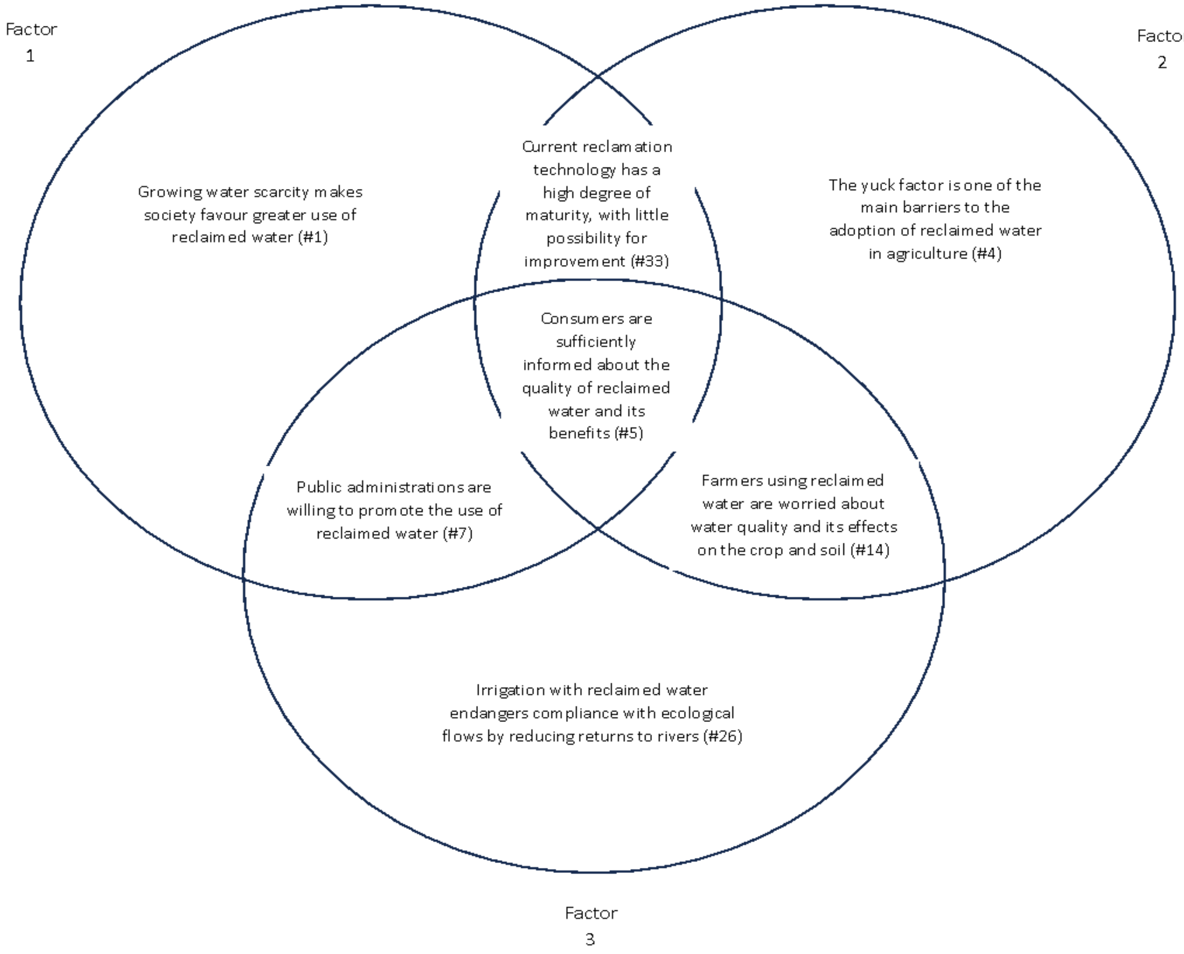


Figure 20. Consensus. Statements with highest level of agreement between discourses 1, 2 and 3.

Source: Own elaboration

Figure 21 illustrates the statements with the level of disagreement between the discourses, indicated by the largest differences in Z-scores.

As shown in the central section of Figure 21, the main point of contention between all discourses is the idea that irrigation with reclaimed water endangers compliance with ecological flows by reducing returns to rivers (statement 26; 1: -2, 2: 0, 3: +5). This statement also shows the greatest disagreement between discourses pairs 1-3 and 2-3 (see intermediate sections in Figure 21). In addition, between discourses 1 and 2 there is strong disagreement on the statement concerning the "yuck factor" as a barrier to the adoption of reclaimed water in agriculture (statement 4; 1: -3; 2: +4).

Lastly, the outer section contains the statements with which each discourse disagrees the most. Different statements related to social perception (statement 2; discourse 1), public subsidies to reclaimed water projects (statement 13; discourse 2) and water quality (statement 19; discourse 3) elicit strong disagreement.

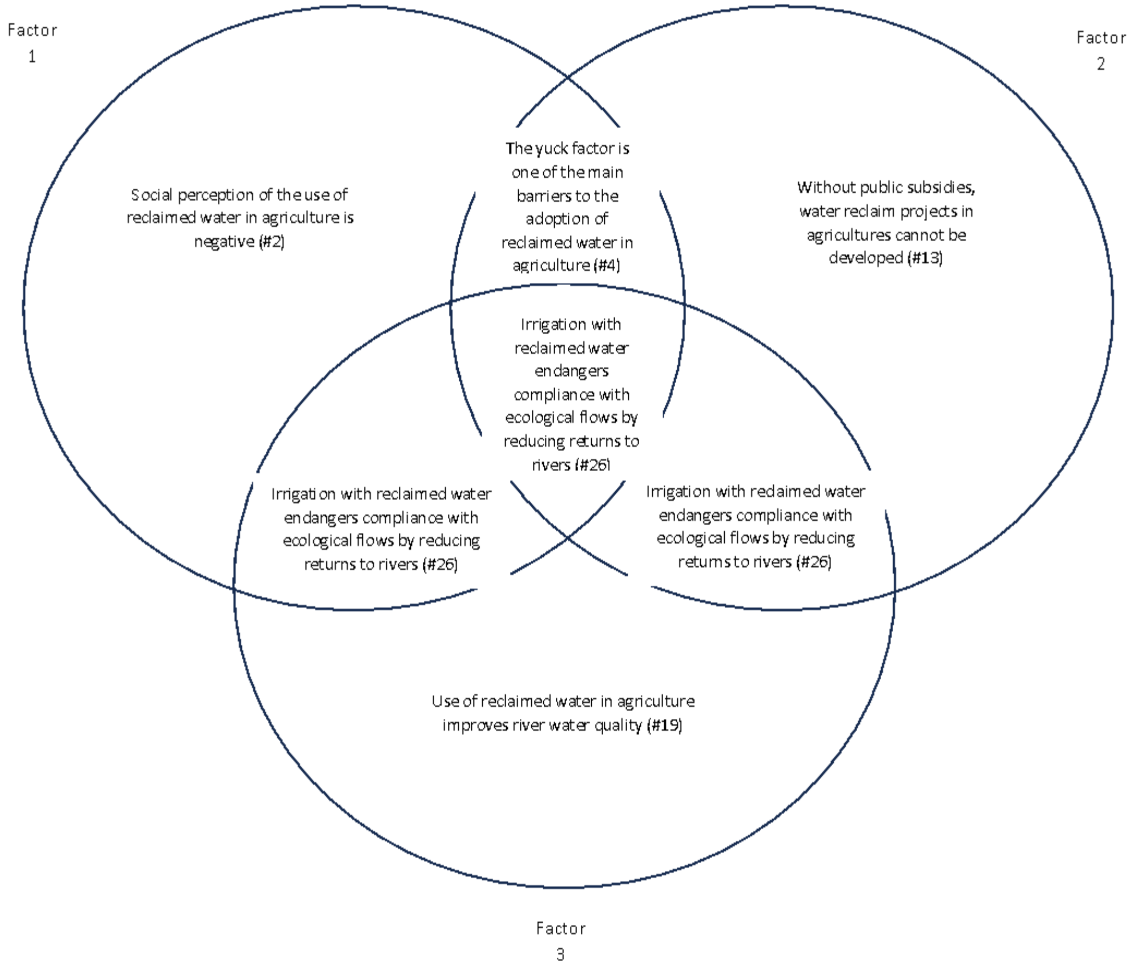


Figure 21. Disagreement. Statements with the lowest level of agreement between discourses 1, 2 and 3.

Source: Own elaboration

4.3. Stakeholder-based assessment of NCW for agricultural irrigation

4.3.1. Study of the FCM structure

Figure 22 presents the FCM developed to represent the current state of NCW use in agriculture in the Region of Murcia. The graphical representation was created using Pajek software, with solid black lines denoting positive relationships and dotted red lines indicating negative relationships. As shown in Table 16, participants identified 25 variables and established 37 links among them, yielding an average of 1.48 connections per component.

Analysis of the indegree (id) and outdegree (od) indicators (Table S5) shows that the system comprises eight transmitter components represented as squares; two receivers components represented as triangles; and fifteen ordinary components represented as circles. The low complexity index (0.25) indicates a predominance of transmitters over receivers, suggesting a fundamentally hierarchical structure.

The components identified by participants include the regulatory and institutional framework, the costs and quality of NCW, the environmental status of water bodies, the social acceptance of water reuse for irrigation, and aspects related to farmers' income, among others (see Figure 22). These components were classified into three dimensions, reflecting their heterogeneity: 14 components in the economic-technical dimension, 6 in the environmental dimension, and 5 in the socio-institutional dimension. According to centrality values (CT) depicted by component size in Figure 22, the most influential elements in the system are the use of desalinated and reclaimed water by farmers (CT = 3.8 and 3.6, respectively), followed by the cost of desalinated water for farmers (CT = 3.2). Other key variables include the cost of reclaimed water and the availability of conventional water resources, both with centrality scores above 2.5.

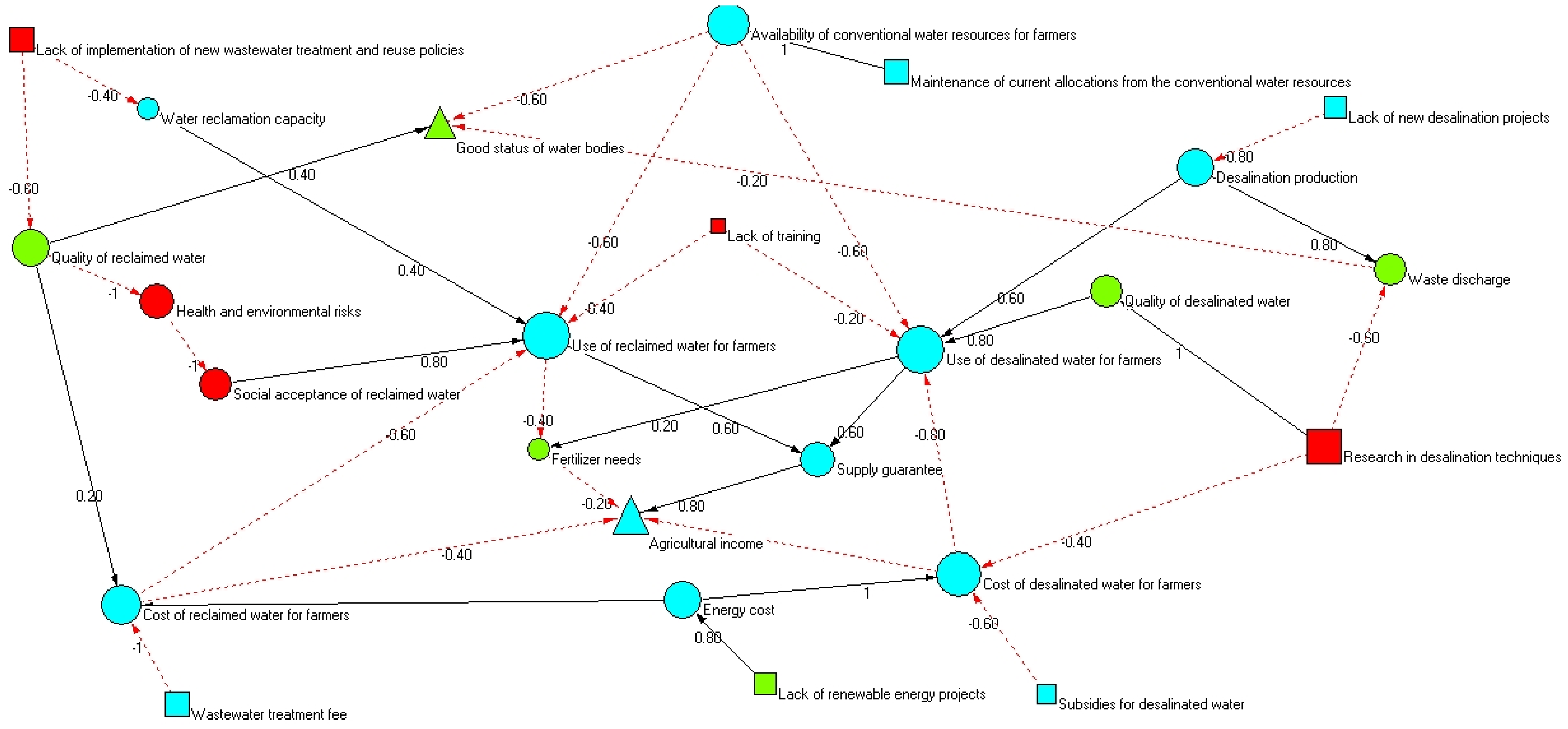


Figure 22. Visualization of the stakeholder-based FCM.

The size of each component represents its centrality. Solid black lines indicate positive connections, while dashed red lines represent negative connections. The shape of each component denotes its type (square: transmitters; circle: ordinary; triangle: receiver), and the colours indicate its dimension (green: environmental; blue: economic-technical; red: socio-institutional)

Source: Own elaboration using Pajek software

Table 16. FCM structural metrics.

Index	*Value*
Components	25
Relations	37
Density	0.0592
Relations per component	1.48
Transmitters	8
Receivers	2
Ordinary components	15
Complexity	0.25

Source: Own elaboration

4.3.2. Dynamic analysis of the FCM

4.3.2.1. Baseline assessment

Figure 23 presents the steady-state values of the FCM components (after 20 iterations) under the baseline scenario. In this scenario, the system shows notably high values for the availability of conventional water resources for farmers, while the agricultural sector's use of desalinated and reclaimed water registers slightly lower values.

In the case of reclaimed water, its quality presents relatively low values, which leads to low levels of social acceptance. Although energy cost is high, applying wastewater treatment fee paid by urban users keeps the cost of reclaimed water for farmers relatively low.

Conversely, the cost of desalinated water for farmers shows relatively high value due to the high energy cost, while its quality presents relatively high values as well. Despite this, the good status of water bodies remains low value, mainly due to the low quality of reclaimed water and the relatively high waste discharge (brine) from desalination plants.

On the other hand, agricultural income exhibits relatively high values, reflecting the strong supply guarantee. Nevertheless, both the capacity for water reclamation and desalination production remains relatively low values, leaving room for growth that will be analysed in the proposed scenarios.

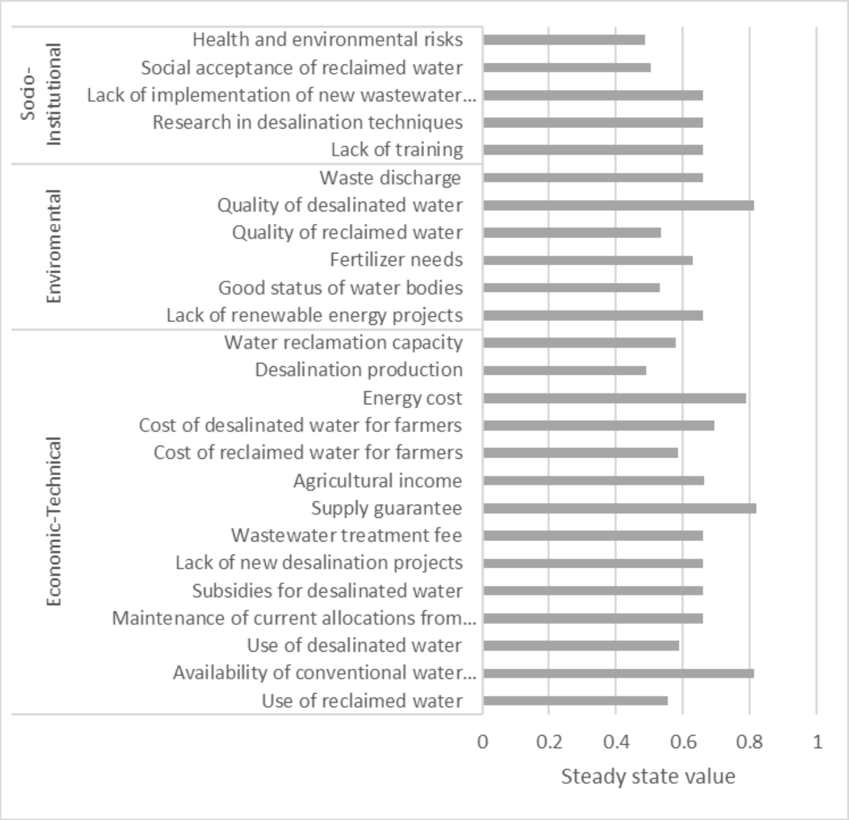


Figure 23. Component values under steady state baseline conditions.

Values close to 0 represent a strong decrease in the component, whilst values closer to 1 represent a strong increase.

Source: Own elaboration

4.3.2.2. Future scenarios

Figure 24 and Figure 25 present the relative changes in each component for the simulated scenarios, in aggregated and individual forms, respectively. The results include scenarios with and without the implementation of the new Segura RBMP regarding the reductions in the TST and groundwater extractions. This allows assessing the extent to which the Segura RBMP measures influence scenario outcomes. Transmitter variables have been excluded in order to focus the analysis exclusively on the components affected in each simulated scenario.

Figure 24 presents the aggregated changes across scenarios and dimensions. The cost recovery scenario is the only one generating an overall negative change, mainly driven by declines in the economic-technical components, which indicates a non-desired effect for the system. In contrast, the NCW expansion scenario produces the greatest positive impact, followed by investment in renewable energy projects and capacity building. In these three scenarios, the overall positive effect results primarily from improvements in the economic-technical dimension, while the environmental dimension also contributes positively in the NCW expansion and capacity building scenarios. The socio-institutional dimension shows a positive effect only in the NCW expansion scenario.

When Segura RBMP is applied, all four scenarios exhibit improved outcomes compared to their effects without Segura RBMP implementation, although their relative magnitudes remain unchanged. The NCW expansion scenario continues to generate the largest positive change, followed by renewable energy investment, capacity building, and, finally, cost recovery. In the latter, the aggregated outcome remains negative but of lower magnitude. The RBMP also strengthens both the economic–technical and environmental dimensions in absolute terms, narrowing the relative differences between scenarios. Thus, while the aggregate positive effect of the NCW expansion scenario is 47% and 1% higher than those of renewable energy investment and capacity building, respectively, these differences increase to 54% and 10% under Segura RBMP implementation.

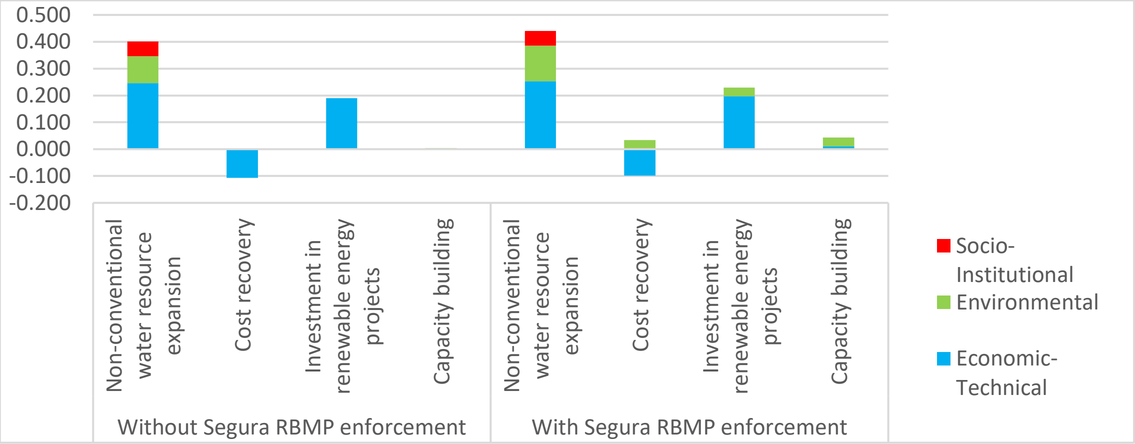


Figure 24. Aggregated relative changes in the system for each simulated scenario compared to the baseline scenario.

For each scenario, the left bar shows results without implementation of the Segura River Basin Management Plan (RBMP), while the right bar shows the effects of its implementation. Positive values indicate desirable changes, and negative values indicate undesirable changes. Bar colours correspond to the dimension of change, as indicated in the legend

Source: Own elaboration

Figure 25 details the relative changes for each component, disaggregated by dimension and scenario. In the NCW expansion scenario, the development of new desalination projects and the improvement of reclaimed water uptake increase farmers' production and use of these resources, thereby strengthening water supply guarantee and slightly boosting agricultural income. Although the new water quality requirements for reclaimed water raise its cost for farmers, they also improve its quality, reducing health and environment risks and enhancing social acceptance. The increase in desalination production generates greater waste discharge (brine); however, this effect is partially offset by the improved quality of reclaimed water, contributing to a better status of water bodies. With the implementation of the Segura RBMP, the reduced availability of conventional resources further stimulates the use of NCW, enhancing supply guarantee, increasing agricultural income, and lowering fertilizer needs, particularly through greater utilization of reclaimed water.

In the cost-recovery scenario, removing subsidies for desalinated significantly increased its cost to farmers, reducing its use and, consequently, lowering the supply guarantee and agricultural income. Fertilization needs, however, decrease as reclaimed water provides nutrients, unlike desalinated water. Following the implementation of the Segura RBMP, the reduced availability of conventional resources encourages greater use of both desalinated and reclaimed water, despite their higher costs. This shift contributes to improvements in the good status of water bodies and supply guarantee. Agricultural income still decreases, but to a lesser extent than without RBPM implementation.

In the renewable energy investment scenario, reduced energy costs lower the overall cost of NCW, particularly desalinated water, which is highly energy intensive. This cost reduction encourages greater NCW use, enhancing water supply guarantee and agricultural income. The implementation of the Segura RBMP further reinforces this trend, as the reduced availability of conventional resources promotes substitution with NCW.

Finally, the capacity-building scenario promotes more efficient and widespread use of NCW by farmers, particularly reclaimed water. Its nutrient content helps reduce fertilizer requirements, while an improved water supply guarantees a moderate positive effect on agricultural income. As in the previous scenario, implementing the Segura RBMP amplifies these effects, encouraging greater adoption of NCW in response to declining conventional water availability.

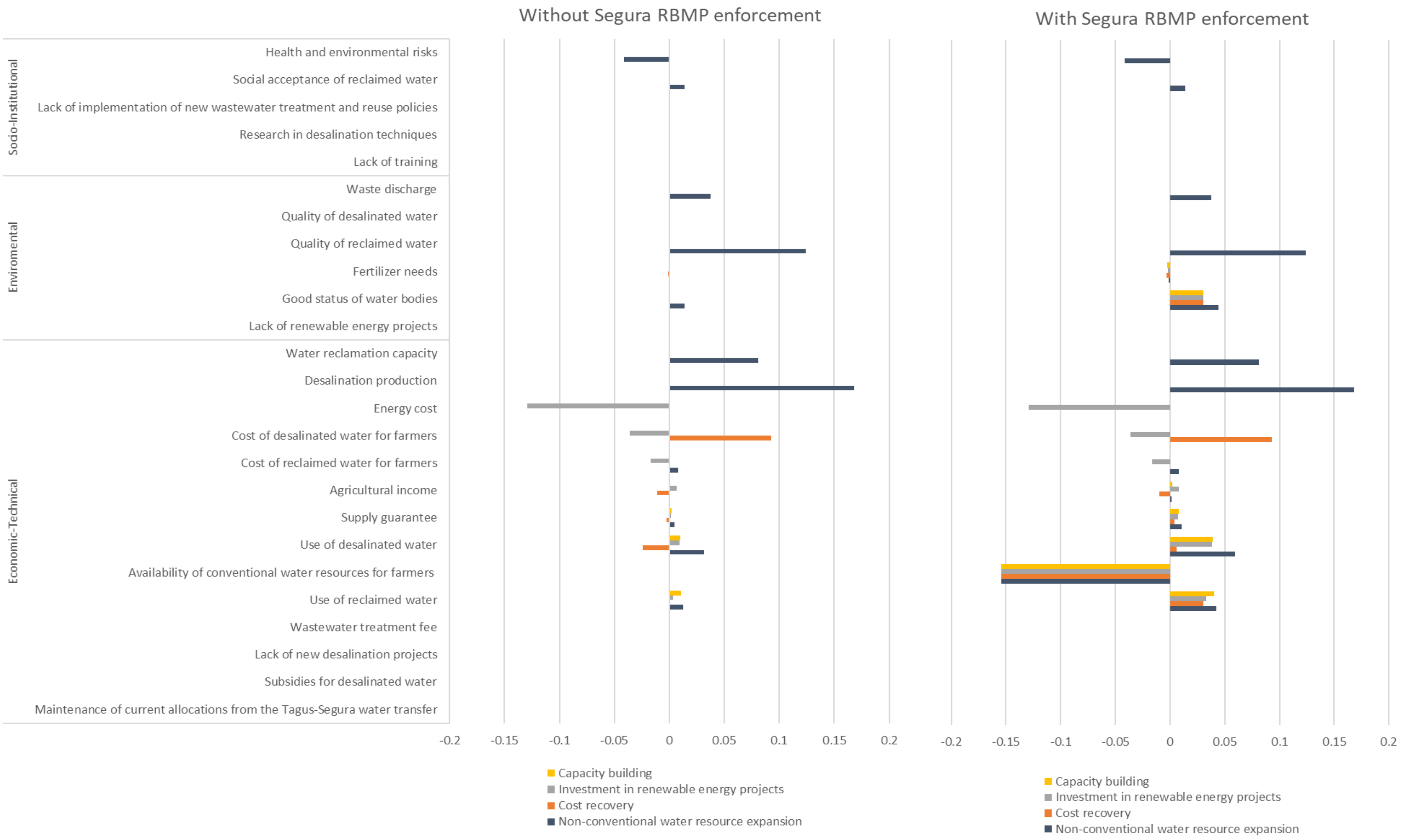


Figure 25. Relative changes of the concepts' values in each simulated scenario, compared to the baseline situation. Left: without the implementation of the Segura RBMP; Right: with the implementation of the Segura RBMP. Source: Own elaboration

4.4. Evaluation of NCW as an alternative to traditional water resources.

4.4.1. Baseline scenario

The baseline scenario represents the current situation, based on the average data from 2018 to 2020. According to data from CARM (2024) the main crops were selected by area and extrapolated to the total cultivated area during that period, resulting in the distribution of the Table 17. In addition, the gross margin (including revenues minus costs, excluding water and labour costs), water and labour requirements per crop are also shown.

Table 17. Data of crops of CRCC.

Crop	Area (ha)	Gross margin (€/ha)	Water needs (m^3/ha)	Labor needs (worker/ha)
Artichoke	4315 (12%)	8223	3871	0.64
Cauliflower	4154 (11%)	7175	2396	0.17
Lettuce-Melon	7078 (19%)	13989	5434	0.40
Pepper	2347 (6%)	40618	5397	1.48
Lemon tree	6878 (18%)	4792	5733	0.60
Fallow	12493 (34%)	0	0	
Total	37265			

Source: Own elaboration based on data CARM (2024).

The predominant crops, in order of importance, are vegetables (lettuce-melon, artichoke, and cauliflower), citrus (lemon tree), and greenhouse crops (pepper). Nearly all crops use localized irrigation (96%), the most efficient irrigation system (CRCC, 2022a).

Historically, the low availability of surface water restricted irrigation to groundwater with high salinity. This influenced crop rotation with salt-tolerant species such as alfalfa, cotton, melon, and tomato, alternating with fallow periods to allow soil rest. Over time, more tolerant species have been introduced, such as pepper for paprika (now scarcely cultivated) and artichoke (Sánchez Navarro et al., 2020).

At present, lettuce occupies a large area due to its short cycle; it is usually planted from September and combined with melon, which remains a traditional crop planted in March and cultivated until July. Cauliflower, also incorporated in recent years and suitable for industrialization, is planted from September to harvest in December, with a possible second planting in

January for a March harvest. Artichoke, transplanted in summer, is maintained for 2-3 seasons. In greenhouses, pepper dominates, transplanted in November-December and harvested until June depending on demand (Guerrero et al., 2019).

Crop choice depends on the previous year's prices, cooperative information, and the availability and quality of irrigation water. A recurring problem is the uncertainty about the available annual water volume (Calatrava et al., 2021). In this scenario, the results for farm income, total water use, labour use shows in Table 18.

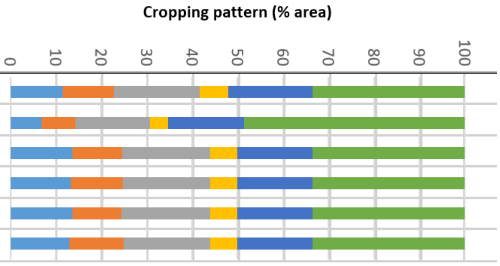
While the Net water use by sources is shown in the first column of Figure 26, showing a predominance of TST, followed by groundwater and NCW. All resources are mixed and distributed through the Campo de Cartagena Main Canal, 64 km long, which transports and distributes resources to the main pipes of each irrigation sector (CRCC, 2022b). Additionally, CARM promotes precision agriculture and aquifer control projects to improve the efficiency of water and fertilizer use, fostering sustainability and preventing excessive leaching (CRCC, 2024).

4.4.2. Scenario analysis

For each scenario, Table 18 shows the results for farm income, total water use, labor use, and cropping patterns, while Figure 26 illustrates net water use by source.

Table 18. Results across scenarios.

Scenarios	Farm income € millions	Total water use hm³	Labor workers	Cropping pattern (% area)
Baseline	256	117.2	18091	
Reduction Water Transfer	227 (-11%)	93.3 (-20%)	14109 (-22%)	
Increased Alternative Water Sources	255 (-0%)	116.1 (-1%)	18081 (0%)	
Constrained Alternative Water Sources	252 (-1%)	115.7 (-1%)	17969 (-1%)	
Desalinated Water Subsidy	259 (1%)	116.2 (-1%)	18135 (0%)	
No Subsidies for Non-Conventional Sources	245 (-4%)	115.3 (-1%)	17858 (-1%)	



Source: Own elaboration

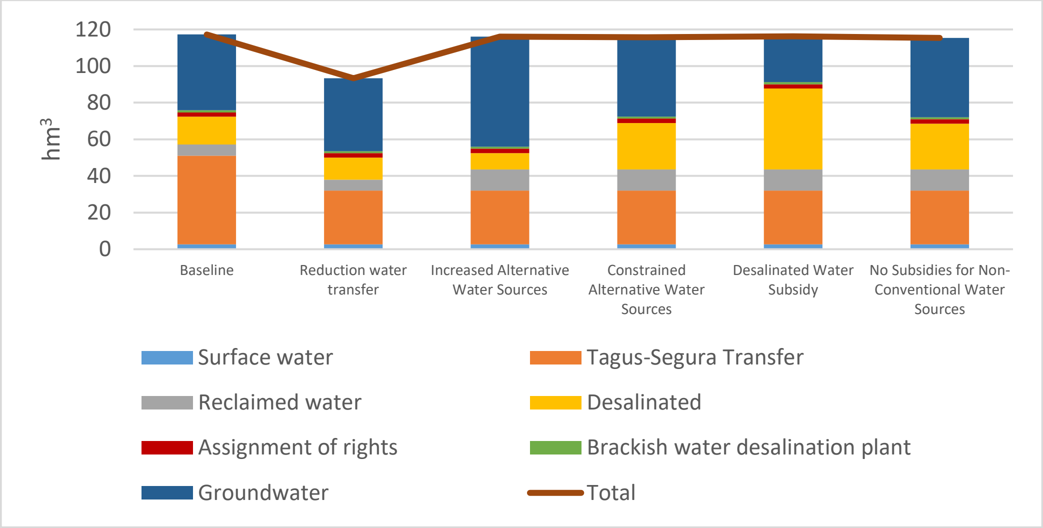


Figure 26. Net water use by source across scenarios.

Source: Own elaboration

Impacts of water transfer reduction. A 40% reduction in the TST is expected to result in a 20% decline in overall water use. This reduction affects not only water from the TST but also reduces reliance on costlier sources like groundwater and desalinated water, which fall by 3% and 20%, respectively. Consequently, the average water cost rises by 5.5% (from €0.291/m^3 to €0.307/m^3), due to the reduction in the TST, which is one of the most cost-effective sources. Reduced water supplies result in a 23% decline in cultivated area, affecting all crops, while fallow land increases by 45%. This scenario translates into an 11% reduction in farm income—equivalent to €28 million—and a 22% loss in employment, representing nearly 4,000 jobs.

Impacts of increased alternative water supplies. The greater availability of alternative sources, such as groundwater, reclaimed water, and desalinated water, partially mitigates the adverse effects of reduced water transfer. Total water usage decreases only slightly (1% below the baseline scenario). Groundwater use increases by nearly 19 hm^3, representing a 31% rise, while reclaimed water reaches the CRCC's full concession limits, rising from 6 hm^3 to 11.5 hm^3. However, desalinated water declines by 20% (6.2 hm^3), as its high costs limit its adoption. These adjustments limit economic losses to €600,000 (0.23% below the baseline scenario) and reduce employment losses to just 10 jobs. Nevertheless, the intensive reliance on groundwater poses a critical concern, as the region's aquifer is already overexploited, and projected pumping levels would exceed current rates, highlighting the urgent need for usage limits.

Impacts of constrained alternative water sources. Water availability restrictions outlined in the 2027 RBMP significantly reshape system dynamics. Groundwater use is limited to a 4% increase (almost 2 hm^3), while desalinated water usage grows by 40% (more than 10 hm^3), and reclaimed water remains at its maximum permitted level. These measures stabilize total water use near baseline scenario levels, albeit at a higher cost: average water prices for farmers increase by 13% (from €0.291/m^3 to €0.33/m^3). Economic losses rise to €3.5 million (1.4% higher than the baseline scenario), resulting in the loss of over 100 jobs. High-water-demand and low-profitability crops, such as lemons and peppers, lose cultivated area to more resilient alternatives, including artichokes, cauliflower, and lettuce-melon crop rotation.

Impacts of higher subsidies for desalinated water. In this scenario, desalinated water becomes more affordable than groundwater, leading to its use increasing to the permitted limit, while groundwater use drops by 40% (16 hm^3), relieving pressure on the aquifer. Additionally, water costs decrease by 6.5% compared to the baseline scenario (from €0.291/m^3 to €0.272/m^3), which boosts agricultural profits by €3 million and creates 44 new jobs. However, this scenario raises essential concerns. Implementing such subsidies requires substantial public expenditure (see Table 19), and the assumed doubling of desalinated water availability may be unfeasible due to existing infrastructure constraints.

Impacts of eliminating subsidies for NCW. This scenario implies paying the full cost of desalinated and reclaimed water. Although water usage and crop distribution remain largely consistent with the baseline scenario, the average water cost increases by 34% (from €0.291/m^3 to €0.391/m^3), resulting in €7 million in farm income losses (4% below the baseline scenario) and the loss of 110 jobs. Additionally, the economic returns of subsidies decrease as desalinated water consumption increases. For instance, while in a scenario with baseline water prices (Constrained Alternative Water Sources), the subsidy generates an economic benefit equivalent to the invested amount, under Desalinated Water Subsidy scenario, the subsidy cost exceeds the generated 29%, requiring €1.40 of subsidy to generate €1 of additional agricultural profit, as shown in Table 19.

Table 19. Analysis of Subsidy Efficiency and Agricultural Profitability.

Scenario	**Farm profit**	**Profit difference concerning the no-subsidies scenario**	**Cost of DW subsidy**	**Cost of RW subsidy**	**Total subsidies cost**	**Ratio subsidy/ profit difference**
	(€ millions)	(€ millions)	(€ millions)	(€ millions)	(€ millions)	
Constrained Alternative Water Sources	252	7	3	4	7	1.00
Desalinated Water Subsidy	259	14	15.5	4	19.5	1.40
No Subsidies for NCW	245					

Source: Own elaboration

5. Discussion

5.1. Barriers to reclaimed water in agriculture.

It is observed that in recent years there has been a notable increase in scientific production on the use of reclaimed water in Spanish agriculture. Furthermore, there has been a territorial expansion, no longer restricted only to the traditional Mediterranean areas but also extended to inland basins such as the Guadiana and Guadalquivir, as well as the Community of Madrid.

Nevertheless, barriers to the development of water reclamation projects persist, with several key factors identified in the existing literature, such as social perception, management practices and quality, environmental impacts, and regulatory framework (Delgado et al., 2012; Lavrnić et al., 2017).

The identified barriers were classified into political, economic, social, technological, environmental, and legal factors using the PESTEL analysis. The results revealed barriers across all dimensions, emphasizing the necessity of adopting a comprehensive approach for their mitigation. Although all barriers may initially be considered equally important, the

Cross-Impact Analysis demonstrated that some exert a significantly greater influence on the system, underscoring their critical role in the dynamic interactions among different factors.

This analysis further identified independent barriers as the most influential, given their broad impact on multiple dimensions. Among these, environmental factors such as salinity in reclaimed water (En3), as noted by Urkiaga et al. (2008), and the presence of emerging pollutants and heavy metals (En2), as discussed by Aznar-Crespo et al. (2019). These barriers can profoundly impact the economic, social, and technological dimensions of the PESTEL analysis. Therefore, it is crucial to mitigate these barriers, which can be achieved by adopting two strategies mentioned by Yalin et al. (2023): developing regulatory policies that restrict the use of certain materials in products that ultimately enter wastewater, and enforcing stricter requirements for water treatment, particularly in regions prone to pollution, such as highly industrialized areas.

The other two independent barriers pertain to the political dimension and are mentioned by Ballesteros-Olza et al. (2022). These include the inefficiency in administrative procedures (P1) for initiating reclamation projects and the lack of institutional coordination (P2). According to Sánchez-Cerdà et al. (2020), both political barriers are interrelated and can be overcome by fostering effective collaboration among various public and private entities involved in the wastewater reclamation sector. Such cooperation is essential for achieving more significant progress and momentum. Indeed, promoting this collaboration is one of the critical objectives of EU Regulation 2020/471 on minimum water reuse requirements.

The EU Regulation aims to ensure that reclaimed water adheres to specific quality and control standards, thereby addressing environmental barriers. As stated by Yalin et al. (2023), the establishment of stringent guidelines for controlling pollutants helps mitigate issues such as En2 (emerging pollutants and heavy metals) and En3 (salinity). Additionally, these guidelines ensure the continued safety and effectiveness of reclaimed water for agricultural applications.

Other barriers requiring attention due to their significant influence are the “relatively independent” linkage barriers. One such barrier is health risks (S3), which, as Maestre-Valero et al. (2019) notes can also be mitigated by applying EU Regulation 2020/741, or as highlighted by Ferro et al. (2015), these risks can be substantially reduced by implementing proper treatment of reclaimed water.

However, Ricart et al. (2019) highlight concerns regarding the new quality requirements, with some stakeholders perceiving them as too stringent (L2), potentially leading to higher purification costs (López-Serrano et al., 2022). Despite these concerns, Yalin et al. (2023) argue that these stringent requirements are crucial for preventing health and environmental risks, and the associated cost increases can be alleviated through government economic aid.

In accordance with Ballesteros-Olza et al. (2022), our study also identifies a critical barrier: the difficulty of establishing risk management plans (L1). To address this issue, the new EU Regulation 2020/471 proposes the creation of a Reclaimed Water Manager role. This role is designed to oversee the implementation of risk management plans and ensure environmental and health safety in the use of reclaimed water (Ricart et al., 2021).

Furthermore, it is essential to highlight that 54% of Spanish WWTP only apply secondary treatment (T2) (MITECO, 2021). Consequently, the treated water fails to meet the quality standards required for reclamation as mandated by the new EU Regulation 2020/471 (Sánchez-Cerdà et al., 2020). This suboptimal water quality enters the wastewater reclamation station, hindering the implementation of reclaimed water reuse projects (Truchado et al., 2021). This issue can be addressed through measures to improve technical aspects of sanitation and water treatment systems under the PRTR (Orden TED/934/2022, 2022). The PRTR initiative addresses other “relatively independent” linkage barriers related to reclaimed water reuse projects, such as the high cost of infrastructure (Ec1), as noted by Elbana et al., (2010). These costs can increase the price of reclaimed water (Ec2), making it less competitive compared to conventional water resources (López-Serrano et al., 2022). Therefore, providing economic aid through the PRPR initiative or other similar programs can help reduce initial investment costs and facilitate the implementation of these projects. (Heinz et al., 2011).

The linkage barriers (T1, Ec3, S1, and S2) are difficult to address individually due to their strong influence and high susceptibility to influence. Therefore, prioritizing efforts on the aforementioned barriers is essential, as addressing these will facilitate progress in overcoming the linkage barriers (Nazlabadi et al., 2023). Both the need to improve reclamation technologies (T1) and investment risks (Ec3) could be mitigated through economic aid provided by the PRTR (López-Serrano et al., 2022). Social barriers (S1 and S2) require institutional intervention. According to Mesa-Pérez et al. (2020), these barriers can be overcome by alleviating concerns related to reclaimed water's perceived environmental and health risks. In this regard, Yalin et al. (2023) suggest implementing social awareness campaigns to clarify the distinction between wastewater and reclaimed water, thereby promoting a more informed and positive perception of this resource.

Commercial barriers to products irrigated with reclaimed water (P3) are considered dependent barriers and are consequently classified as passive. This classification is supported by studies from Truchado et al. (2021), which indicates that the market does not actively distinguish between products irrigated with reclaimed water and those irrigated with conventional water. The lack of such distinction means commercial barriers are influenced by external factors (e.g., consumer perception or regulatory policies), rendering them passive.

Finally, autonomous barriers, which do not affect others, must be addressed independently. One such barrier is the potential threat to ecological flows in rivers (En1), as highlighted by Ballesteros-Olza et al. (2022). This issue is predominant in inland areas where the outflow from WWTP used for irrigation eventually enters rivers. In contrast, in coastal areas, this outflow discharges into the sea and does not threaten river flow. (López-Serrano et al., 2021). Consequently, this barrier must be tackled individually by conducting comprehensive impact analyses on rivers for each reclaimed water reuse project (Bolinches et al., 2022).

In summary, although the proposed solutions to overcome the barriers to reclaimed water reuse in agriculture in Spain are technically feasible and aligned with the European regulatory framework, their implementation is highly complex and face significant challenges (Cipolletta et al., 2021). Overcoming environmental, social, economic, and political barriers requires not only substantial investments in infrastructure and advanced technologies, but also effective coordination among stakeholders. Long-term commitment from all parties, supported by strong political and economic will, is crucial to ensuring the successful implementation of these solutions and managing the associated costs (Ballesteros-Olza et al., 2022).

5.2. Social perspectives of reclaimed water in agriculture.

In general, there is an agreement regarding the use of reclaimed water in agriculture to address water scarcity in Spain. However, there are differences between social perspectives with respect to who should bear the cost of the projects (consumers, farmers or administrators), the effects of these projects on river flows and the environment, and consumers' perceptions of this water source.

In line with Ricart et al., (2021), our findings indicate that the growing concern over climate change and water resource scarcity favours the development of water reclamation projects (discourse 1). However, these projects can be hindered by the high cost of reclaimed water as indicated in discourse 2 and raised by previous work on the topic (Berbel et al., 2024; Molinos-Senante et al., 2013; Santos et al., 2023). Generally, the cost of reclaimed water is higher than that of conventional water resources due to the technology required for its production (Mesa-Pérez et al., 2020; Expósito et al., 2024). In many regions of Spain, such as Valencia (Hagenvoort et al., 2019) and Murcia (Alcon et al., 2013), it is the citizens who bear the cost through a "treatment charge" ('canon de saneamiento') in their water bills, following the "polluter pays" principle. This is in line with the points mentioned in discourses 1 and 2. However, as indicated by discourse 3, and supported by Ricart et al., (2019), the actual cost of reclaimed water should be borne by the end user, in this case the farmer, rather than the polluter since under the terms of the WFD, reclaimed water can be considered a private asset with market value (Hernández-Sancho & Bellver-Domingo, 2022).

To address this situation, measures such as investment in the nationalisation of WWTP to enhance their use, or public subsidies that reduce the cost for farmers, as suggested by López-Serrano et al., (2022), could be implemented. A solution that encompasses both measures is proposed by Jodar-Abellan et al., (2019), which involves distributing the costs of reclamation and wastewater management among citizens, farmers and the administration, establishing incentives to ensure that reclaimed water is used whenever possible.

Palacios-Diaz et al., (2015) suggests that subsidies can be used to cover part of the cost of reclaimed water. This aligns with the views presented in discourse 1. However, some respondents from discourses 2 and 3 have indicated that subsidies are not necessary, citing experiences of self-financed projects by farmers who can afford using reclaimed water because they irrigate high-value crops.

In addition, according to discourse 3, the use of reclaimed water may negatively impact the environment both quantitatively (reduction of river flow) and qualitatively (altered water composition). Ballesteros-Olza et al., (2022) and Expósito et al., (2024) suggest that in inland areas, using reclaimed water reduces discharges from wastewater treatment plants to rivers, potentially endangering ecological flows and affecting biodiversity and water quality. The other two discourses (1 and 2) offer a more neutral perspective on the ecological impacts of reclaimed water use, noting that various river basin authorities are actively working to prevent the reduction of ecological flows through case-by-case studies. To avoid negative impacts, Gómez-Ramos et al., (2024) state that a river basin vision is needed as it is crucial to consider the whole water cycle to determine the available amount of reclaimed water for irrigation.

In terms of water quality, discourse 2 shares the view of Alcaide et al., (2020) that reclaimed water contains nutrients that can reduce the need for fertilisers in agriculture. However, it can also contain salts, heavy metals and emerging pollutants, depending on its origin (M. Xu et al., 2016), making it an environmentally unfriendly resource. This argument was raised by discourse 3 and supported by Wang et al., (2017). The other two discourses (1 and 2), however, view reclaimed water as a more environmentally friendly alternative to conventional water resources, consistent with Dolnicar & Schäfer, (2009). Nonetheless, discourse 1 expresses concerns about the long-term effects of salts and emerging pollutants on soil and irrigation systems, echoing similar issues raised by Sunyer-Caldú et al., (2022). As noted by Jodar-Abellan et al., (2024), the cumulative effects on soil health, water quality, and irrigation infrastructure remain insufficiently understood, emphasizing the urgent need for further research to comprehensively assess these risks. To minimise environmental impacts, an integrated approach is essential, including the improvement of treatment technologies, effective management at both the catchment level and by farmers through sustainable soil and crop practices, and a robust regulatory framework ensuring compliance with quality standards and continuous monitoring (Ballesteros-

Olza et al., 2022; Heinz, Salgot, & Mateo-Sagasta Dávila, 2011; Santos et al., 2023).

Another significant barrier to the adoption of reclaimed water projects, as stated by Savchenko et al. (2019) and highlighted in discourse 1, is the high level of bureaucracy required to implement these projects. According to Berbel et al. (2023) and Ramm & Smol (2023) this bureaucracy leads to delays and increased costs, thereby hampering the use of reclaimed water in agriculture. However, there are efforts to overcome this challenge. Qtaishat et al. (2022) and McLennan et al. (2024) notes that the current transposition of the new EU regulation 2020/741, supported by the new Spanish Royal Decree 1085/2024, aims to address this issue by streamlining procedures and creating a more cohesive regulatory framework.

The social perception of reclaimed water use in agriculture is generally positive, but still needs improvement according to all discourses. As indicated in discourse 1, farmers express concerns about the effects of reclaimed water on the crops and soil. This aligns with Sheidaei et al. (2016) who argue that farmers have conflicting attitudes toward using wastewater for irrigation due to concerns about its negative impacts on health and the environment. In terms of consumer perception of reclaimed water, discourse 2 emphasises the "yuck factor" associated with its origin in wastewater (McClaran et al., 2020), leading to it being seen as waste rather than a valuable resource (Ellis et al., 2019). In contrast, Mendoza-Espinosa et al., (2019), in agreement with discourses 1 and 3, considers reclaimed water a valid resource for agricultural irrigation due to its high quality, meeting standards of the new EU regulation 2020/741, and therefore does not view the "yuck factor" as a significant obstacle to promoting reclaimed water. Nonetheless, according to Ricart et al., (2019), it is important to improve public perception through awareness campaigns, which would also allow consumers to better understand its use and benefits (Garin et al., 2021).

The findings of this study underscore the potential of reclaimed water as a promising option for semi-arid regions. However, they also emphasize the need to address critical aspects such as financing, ecological impacts, and social perception, while fostering stakeholder dialogue to align interests, encourage coordinated action, and achieve equitable and sustainable outcomes.

Finally, it is important to consider that the findings are shaped by the socioeconomic and physical context of the case studied, which may limit their direct applicability to other regions. Nevertheless, key themes, such as technological development, ecological impacts, cost allocation, and public awareness, remain relevant to many water-scarce countries seeking to integrate reclaimed water into their water management strategies. For instance, similar challenges and opportunities have been explored in the Mediterranean area (Michetti et al., 2019) the Middle East (Alzahrani et al., 2023), Australia (Radcliffe & Page, 2020), and California (Paul et al., 2020). These shared themes provide a foundation for broader applicability and emphasize areas where insights from this study may contribute to advancing reclaimed water initiatives globally.

5.3. Stakeholder-based assessment of NCW for agricultural irrigation.

This study applied a participatory FCM model to analyse the current and future role of NCW in irrigated agriculture in the Region of Murcia, a region where growing water scarcity and declining conventional resources are accelerating the integration of desalinated and reclaimed water as key components of supply reliability.

Structurally, the FCM shows a clear predominance of dynamic driving (transmitter) components over receivers, shaping a hierarchical system. This architecture facilitates the identification of key variables that, functioning as leverage points, can accelerate change processes (Edwards & Kok, 2021). The 25 components and 37 causal links identified reflect substantial cognitive richness among stakeholders. Of these components, 14 belong to the economic-technical dimension, compared to 6 in the environmental and 5 in the socio-institutional dimensions. This heterogeneous distribution suggests that stakeholders mainly perceive NCW as economic instruments to secure irrigation supply and agricultural income, as noted by Hurtado et al. (2024), rather than as an environmental solution, in line with Quon & Jiang (2023).

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However, the baseline assessment reveals a clear gap between this perceived importance and current practice. Conventional water availability remains high, while NCW use is still limited due to quality concerns, high energy costs and insufficient production capacity—barriers widely documented in the literature (Simón & Oller, 2024; Villacorta-Ranera et al., 2025). Both reclamation capacity and desalination output therefore show significant room for improvement, aspects directly addressed in the simulated scenarios.

Across scenarios, the NCW expansion pathway generates the most substantial positive effect. Its impact is driven primarily by the increase in desalination capacity, which significantly boosts water availability and strengthens supply guarantee. Improvements in reclaimed-water quality also contribute by reducing perceived health and environmental risks, enhancing acceptance despite higher production costs (Nkhoma et al., 2021). Although greater desalination output leads to higher brine discharge, enhanced reclaimed-water quality helps partially mitigate environmental pressures by improving the ecological status of water bodies. Overall, this scenario underscores the importance of institutional and regulatory support, consistent with Fornés et al. (2021), as well as the strong political and financial commitment currently directed toward NCW. Recent public investments in infrastructure and treatment upgrades are creating more favourable conditions for the wider adoption of both desalinated and reclaimed water (Berbel et al., 2023; Zuluaga-Guerra et al., 2023)

Cost remains one of the main barriers to NCW adoption, particularly for desalinated water. A large share of this cost burden arises from investment and distribution expenses, which account for 33% and 37% of final prices for desalinated and reclaimed water, respectively, while production costs represent 67% and 62% (Berbel et al., 2023; Zarzo & Prats, 2018). Notably, roughly one-third of these production costs are energy-related, making energy a key determinant of final prices. Consistent with Gómez Martínez & Pérez Martín (2023), the renewable-energy scenario shows that reducing energy costs can significantly lower the price of NCW—particularly desalinated water—thereby stimulating its use and improving both supply guarantee and agricultural income. Consequently, this scenario generates the second-highest aggregated positive effect.

Conversely, the cost recovery scenario demonstrates that eliminating subsidies for desalinated water (expected after 2026, Order TED 157/2023) sharply increases its cost to farmers, reducing its use and leading to declines in supply guarantee and income. This aligns with previous warnings that subsidy removal could undermine agricultural viability given the high price of desalinated water (Ricart et al., 2021). The scenario thus generates a clearly undesired aggregated outcome.

Capacity building emerges as another relevant pathway. Stakeholders frequently highlight insufficient training, particularly on the safe and efficient use of reclaimed water, as a key barrier to NCW adoption (Ballesteros-Olza et al., 2022). The capacity-building scenario increases reclaimed-water use, reduces fertilizer needs and moderately improves agricultural income, reinforcing the importance of farmer training for enabling effective NCW management (Berti Suman & Toscano, 2021). This scenario generates the third-highest aggregated desired effect.

The implementation of the Segura RBMP substantially modifies scenario outcomes by reducing allocations from the TST and groundwater abstractions. This reduction in conventional resources systematically increases NCW uptake across all scenarios, even in the cost recovery case, where desalinated water use rises despite higher costs. This confirms that supply constraints can accelerate the transition to NCW (Quon & Jiang, 2023). Although agricultural income decreases under the cost recovery scenario, the decline is less severe than in the case without the RBMP implementation. This is because of the increased use of both NCW, and their combined use, help to smooth the reduction in agricultural income in line with Gallego-Elvira et al. (2021). A similar pattern is observed in the other scenarios, which also show improvements in both supply reliability and farmers' income.

Finally, the results suggest that current water governance remains dominated by economic–technical considerations (La Roca & Martínez, 2023), as reflected in the higher number of components identified in this dimension. Nonetheless, the Segura RBMP, and the broader principles of the EU Water Framework Directive, highlight the increasing importance of environmental considerations, particularly ecological status and long-term water-body sustainability. This aligns with Hurtado et al. (2024) who stress the need to evaluate not only economic costs but also ecological balance. Consistent with this perspective, our results show that expanding NCW use improves water-body status and lowers fertilizer needs across scenarios, revealing clear co-benefits.

5.4. Evaluation of NCW as an alternative to traditional water sources.

Water transfers are central to the water management debate, not only for their technical and economic relevance but also for their social and environmental implications (Zhuang, 2016). The case of the TST exemplifies this complexity, as the anticipated reduction in its contributions poses significant challenges in reconciling the agricultural, social, and ecological interests in the region (Buendía-Azorín et al., 2025).

One of the most evident consequences of the TST reduction is decreased water availability, which restricts the flexibility to blend water sources in a cost-effective manner (Vélez-Nicolás et al., 2020; Martínez-Medina et al., 2024). As a result, total water consumption declines, its average costs rise, and cultivated areas shrink significantly, with nearly half of the irrigation community's area left fallow. As noted by Cañizares et al. (2022), this phenomenon has a direct impact on the local economy, causing agricultural profits to decline and resulting in the loss of thousands of jobs across the entire network of farmers and workers who depend on the transferred water.

In line with Morote et al. (2020), greater integration of all available water resources is proposed as a strategic solution. Our findings suggest that expanding the use of desalinated, reclaimed, and groundwater sources can help mitigate the impacts of transfer reductions, although each source presents distinct challenges. Desalination, while reliable during droughts, remains costly and reliant on public subsidies to remain viable for agriculture (Villar-Navascués et al., 2020). Reclaimed water is nearing its permitted usage limits and, further constrained by salinity issues, cannot expand sufficiently to compensate for the reduction in transferred water fully. (Gil-Meseguer et al., 2019). In contrast, groundwater emerges as the most effective short-term alternative for minimizing economic and social costs (farm income, employment, and public expenditure). However, its intensive use raises serious environmental concerns and requires stringent regulation and management to ensure long-term sustainability. This urgency is particularly relevant given the increased reliance on groundwater in some areas due to its accessibility (Vélez-Nicolás et al., 2020), despite the high energy costs associated with extraction (Jasechko & Perrone, 2021) and the risks of salinity (Martínez-Pérez et al., 2022). Previous studies (Caparrós-Martínez et al., 2020 and Mateo et al., 2024) warn that further groundwater exploitation offers only a temporary reprieve, as overexploitation is accelerating seawater intrusion and degrading water quality. Moreover, the combined use of groundwater and reclaimed water, both prone to salinity, could further compromise irrigation water quality, potentially reducing crop productivity over time (Devkota et al., 2022).

The near future, shaped by the implementation of the new Segura RBMP (CHS, 2022a) in 2027, will introduce additional restrictions on groundwater and desalinated water use. These restrictions are expected to affect water costs and, consequently, agricultural profitability directly. Our findings show that limiting groundwater use increases reliance on desalinated water, which raises overall costs and reduces farm income, as also noted by Villar-Navascués et al. (2020). However, this approach may help curb aquifer over-exploitation and support a more sustainable water management model in the long-term (Morote et al., 2017).

The feasibility of substituting conventional water sources with desalinated water in agriculture largely hinges on the availability of public subsidies (Maki et al., 2025; Martínez-Alvarez et al., 2023). The simulation of the "Desalinated Water Subsidy" scenario, based on the provisions of Order TED/157/2023, suggests that a drastic reduction in the price of desalinated water can restore the competitiveness of irrigated agriculture, boost agricultural income, and sustain employment. However, achieving these outcomes requires a significant fiscal commitment: the State must invest €1.40 in subsidies for every additional euro of agricultural profit. This is the only scenario in which income and employment levels approach those of the baseline period, while avoiding further aquifer overexploitation, though it raises concerns about the efficiency and long-term financial sustainability of such support measures (see Table 19).

In contrast, the no subsidies scenario shows that although the high value of crops may sustain agricultural activity, the absence of subsidies leads to a 4% decline in farmers' profits and imposes additional financial burdens on irrigation communities.

The effectiveness of subsidies in enhancing profitability depends heavily on their level and the design of support applied to both desalinated and reclaimed water. In line with Zhang & Ok (2023), this study underscores the need for robust economic analyses to inform subsidy policies, with a particular focus on determining the optimal mix of supply water sources that maximizes returns. Such analyses should also clarify water pricing structures and farmers' willingness to pay for water. Beyond purely economic outcomes, subsidy schemes should be guided by broader assessments that account for non-monetary benefits such as aquifer conservation, soil protection, or conflict prevention. This broader perspective aligns with international experiences, such as environmental levies in France and rural infrastructure subsidies in Egypt (Maki et al., 2025).

Overall, the implementation of well-designed subsidy policies and effective water regulation emerges as a key strategy to ensure the sustainability of agriculture in the CRCC, with potential applicability to other water-scarce regions (Maki et al., 2025). Although desalinated water remains costly, its use can be made more viable through policies that support its adoption without compromising agricultural profitability (Aznar-Sánchez et al., 2021). However, these policies may impose costs on other stakeholders, such as the government and citizens (Calatrava et al., 2022). In this context, cost-sharing mechanisms —such as taxes or user fees—could offer a feasible solution to distribute the burden of developing NCW. This is the case in Murcia, where reclaimed water is funded through sanitation fees paid by urban users (Gómez-Ramos et al., 2024). Another strategy to reduce the costs of NCW is to lower the energy expenses required for its production. In the case of desalinated water, energy accounts for 50%-60% of total production costs. Investments in renewable energy projects could reduce these costs by around 50%, potentially lowering the final price of desalinated water by 20% to 30% (Gómez Martínez & Pérez Martín, 2023).

Nevertheless, this study has several limitations that should be acknowledged. First, the mathematical programming models employed rely on simplifying assumptions that do not fully capture the complexity and dynamics of agricultural systems (Howitt, 2005). The analysis was also conducted at the irrigation community level, which, while suitable for policy-relevant insights, may obscure variability at finer scales. Future research could explore more detailed analyses at the plot or farm level or extend the study to other irrigation communities.

Another limitation is the model's assumption of stability in key variables, such as water prices, crop yields, and production costs, when projecting scenarios for 2027. This approach does not account for potential market fluctuations or uncertainties. In addition, the model does not explicitly consider the impacts of climate change, such as reduced yields, increased water demand, or lower availability of conventional water due to declining rainfall and rising temperatures (Gomez-Gomez et al., 2022; Medellín-Azuara et al., 2024). Addressing these aspects falls beyond the scope of this study.

Despite these limitations, the model offers a valuable tool for assessing the effects of reduced TST and evaluating potential mitigation strategies. Future research could build on these findings to enhance the robustness and applicability of the results.

6. Conclusions

6.1. Main findings

The general objective of the thesis was to examine the challenges and opportunities of NCW, with a particular focus on Spain and, more specifically, the southeastern Mediterranean region. To address this overarching objective, four specific objectives were formulated, each developed through a scientific research article. The analysis of these articles revealed several cross-cutting findings.

First, growing water scarcity has intensified farmers' interest in NCW, which many now view as essential to sustaining agricultural production. However, effective implementation still faces significant barriers and will require coordinated action and supportive policies to ensure sustainable adoption. The literature review confirms that reclaimed water is widely used in the Mediterranean coastal area, and is gradually expanding to inland regions. This expansion is driven by advances in regeneration and reuse technologies, as well as stronger institutional support through policies that promote its use in agriculture, despite the persistence of notable constraints. The most influential barriers relate to potential pollution, insufficient institutional coordination, and administrative delays. Addressing these challenges requires improvements in the regulatory framework governing reclaimed water, an effort currently underway through the implementation of

Regulation (EU) 2020/741 and Royal Decree 1085/2024. Other relevant barriers, such as high costs, health risks, and legal and technological limitations, require public awareness campaigns, greater financial support, and review of regulatory frameworks to balance environmental protection and economic viability.

Strengthening collaboration among stakeholders involved in agricultural water reuse is essential to develop and implement comprehensive strategies that effectively support reclamation and reuse. In this context, analysing the diverse social perspectives becomes particularly important, as it helps to better understand the factors that shape acceptance and influence the use of reclaimed water in agriculture.

The Q-methodology results show that different stakeholder groups hold distinct positions regarding reclaimed water, but analysing patterns of similarity allowed the identification of three main discourses: 1: "Reclaimed water secures water supply for agriculture"; 2: "Reclaimed water has potential for improvement"; and 3: "Reclaimed water adversely affects the environment". Overall, the three discourses converge on that consumers lack adequate information about the quality and benefits of reclaimed water and on the need to promote water reuse through stronger support from public administrations and society, especially in a context of growing scarcity and widespread.

However, two significant divergences exist concerning cost allocation and environmental impacts. In terms of costs, discourses 1 and 2 endorse the “polluter pays” principle, meaning that those who generate pollution should bear the associated expenses. Conversely, discourse 3 argues that the end user (the farmer) should assume all costs under the cost recovery principle established by the WFD. This approach, however, may hinder project implementation, underscoring the need for policies that alleviate financial burdens and encourage adoption.

Regarding environmental impacts, discourse 3 highlights potential reductions in river return flows in inland areas. In contrast, discourses 1 and 2 place confidence in river basin authorities to enforce ecological flow regulations. Although currently perceived as a minor barrier, this view largely reflects the limited knowledge and scarce research in this field, which generates uncertainty and disagreement. Addressing these concerns requires case-by-case environmental assessments and adaptive, site-specific strategies balancing agricultural needs and ecosystem protection.

Desalination represents an additional NCW option that complements reclaimed water. Despite its strategic importance, desalinated water remains less promoted than reuse due to its higher costs and energy intensity and is generally regarded as a last resort or a complementary resource when other options prove insufficient. Nevertheless, desalination plays a critical role in coastal areas facing severe water scarcity, contributing to the diversification of NCW.

The Region of Murcia exemplifies the advanced use of NCW. FCM results indicate that increased production, together with improved quality and safety standards, has strengthened water supply security and supported agricultural income. The Segura RBMP, which gradually reduces TST deliveries and groundwater extraction while promoting desalinated water, further reinforces this transition. However, the elimination of subsidies for desalinated water, requiring full cost recovery, increases prices and limits use, jeopardising water security and agricultural viability. Economic instruments therefore remain essential to ensure equitable access. Complementary strategies include incorporating renewable energy to reduce energy costs (the main component of desalination expenses) and improve market competitiveness. Strengthening technical skills and continuous training is also key to overcoming knowledge and social perception barriers, facilitating efficient, safe, and socially acceptable adoption. Equally important are advances in brine management, as brine discharge remains one of the most significant environmental challenges associated with desalination.

The agro-economic modelling results for the CRCC show that TST reduction adversely affects profitability and employment, leading to decreased cultivated area, increased fallow land, and higher water costs, causing economic losses and lower labor demand. Nonetheless, evaluated mitigation strategies can almost fully compensate total water reduction, albeit with notable differences in sources used and economic outcomes. Several scenarios show minimal changes in irrigated area by crop, indicating agricultural viability despite substantial TST reduction.

Alternative sources analyzed include groundwater, desalinated, and reclaimed water, each with limitations. Groundwater, accessible in some areas, faces high extraction costs and salinity issues jeopardizing sustainability. Reclaimed water, more sustainable but limited by salinity and availability, cannot fully compensate transfer reductions. And desalinated water, although characterized by its reliability, remains a high-cost resource. The combination of these water sources can help maintain the viability of agriculture by providing blends with prices and qualities suitable for crops. Likewise, lower energy costs and the availability of subsidies further reinforce this viability. However, subsidies represent a considerable fiscal burden, as the state must allocate a larger amount of public funds to achieve relatively modest increases in agricultural benefits.

Consequently, the effectiveness of subsidies in improving profitability largely depends on their level and the design of the support mechanisms. Therefore, it is essential to conduct rigorous economic analyses to underpin such subsidy policies. These analyses should also provide a detailed understanding of water pricing structures and farmers' willingness to pay for these resources.

Furthermore, beyond strictly economic outcomes, subsidy programs should also be guided by broader evaluations that consider non-monetary benefits, such as aquifer conservation, soil protection, and the prevention of conflicts over water use.

In sum, the results highlight the need for coordinated action among all actors and for policies that address remaining disagreements and strengthen public acceptance of NCW. Targeted financial incentives, the integration of renewable energy, coordinated management of diverse water sources, and environmental policies supported by awareness efforts can enhance economic viability and reduce environmental pressures, offering useful guidance for other Mediterranean regions.

Ultimately, the long-term sustainability of irrigated agriculture in southeastern Spain depends on a diversified and integrated water strategy that combines conventional resources with NCW. This integration, supported by technological innovation and coherent policy frameworks, must balance economic, social, and environmental objectives to enhance resilience and ensure a stable and sustainable water supply under increasing scarcity.

6.2. Limitations and lines for future research

Although this thesis provides valuable insights into the use of NCW, several limitations must be acknowledged.

First, the literature review revealed that historical records on reclaimed water in Spain are scarce and relatively recent. The scientific literature is growing annually, yet a substantial proportion consists of technical papers that do not specifically address barriers to reclaimed water use, while many of the remaining studies offer only superficial descriptions. Accordingly, this thesis should be viewed as a foundation for advancing the literature by compiling and systematizing the main barriers to agricultural reclaimed water use. Although the review process entails a degree of subjectivity, particularly in barrier identification, the application of the PRISMA protocol strengthens replicability, and subsequent cross-impact analysis enhances the reliability of results.

Second, the Q methodology is inherently dependent on purposive sampling, prioritizing diversity of viewpoints rather than statistical representativeness. While key stakeholders were carefully selected, the findings cannot be generalised to society as a whole. Future research could combine Q methodology with quantitative surveys or representative sampling to triangulate and validate results. Moreover, the concourse used in this study reflects the current state of knowledge and opinions, which are expected to evolve in response to regulatory changes, technological developments, or shifts in agricultural practices. Longitudinal studies would therefore be valuable to capture how these perceptions change over time.

Third, interpretations derived from the FCM should be understood as relative comparisons within the analysed system rather than as absolute values. Moreover, FCM construction relies on subjective judgments regarding variable selection and causal links, which may introduce individual cognitive biases or reflect uneven levels of technical expertise. Group dynamics may also influence the final structure, potentially leading to dominance effects or the underrepresentation of less assertive viewpoints. In addition, translating qualitative stakeholder knowledge into numerical weights involves simplification, and some relevant factors may remain underrepresented. Finally, although scenarios were evaluated independently, analysing their combinations would help identify synergies and trade-offs, particularly under increasing water scarcity. These limitations nonetheless point to clear next steps, broadening stakeholder participation, enriching the set of variables, and developing integrated scenario analyses, which would further strengthen the approach without undermining the robustness or relevance of the present findings.

Lastly, the mathematical programming model relies on simplifying assumptions that do not fully capture the complexity and dynamics of agricultural systems. The analysis was conducted at the irrigation community level, providing relevant policy insights for the case study, but the model could be adjusted to plot or farm levels or extended to other irrigation communities to test its applicability under different conditions. Additional limitations include assuming stability of key variables (water prices, crop yields, production costs) and excluding climate change impacts when projecting 2027 scenarios. While this approach offers meaningful conclusions, future work should incorporate sensitivity analyses and dynamic scenarios that reflect market variability and climatic uncertainty.

Despite these limitations, the thesis provides a valuable framework to assess current NCW use and to explore future development pathways as mitigation strategies for declining conventional water supplies. Extending these analyses to other semi-arid regions would further enable the identification of best practices and the assessment of the transferability of results.

References

Abbaszadegan, M., Alum, A., Kitajima, M., Fujioka, T., Matsui, Y., Sano, D., & Katayama, H. (2025). Water Reuse—Retrospective Study on Sustainable Future Prospects. Water, 17(6), 789. https://doi.org/10.3390/w17060789

Abushaban, A., Salinas-Rodriguez, S. G., Pastorelli, D., Schippers, J. C., Mondal, S., Goueli, S., & Kennedy, M. D. (2021). Assessing Pretreatment Effectiveness for Particulate, Organic and Biological Fouling in a Full-Scale SWRO Desalination Plant. Membranes, 11(3), 167. https://doi.org/10.3390/membranes11030167

Acosta, J. A., Imbernón-Mulero, A., Martínez-Álvarez, V., Gallego-Elvira, B., & Maestre-Valero, J. F. (2025). Midterm effects of irrigation with desalinated seawater on soil properties and constituents in a

Mediterranean citrus orchard. Agriculture, Ecosystems & Environment, 381, 109421. https://doi.org/10.1016/j.agee.2024.109421

AEDyR. (2018). Desalación en España en primera persona: De hitos pioneros, a referente internacional. Informe. . https://aedyr.com/wp-content/uploads/2024/02/AEDYR_HistoriaDesalacion_PUBLICACION.pdf

AEDyR. (2019). Cifras de desalación en España. https://aedyr.com/cifras-desalacion-espana/

AEDyR. (2024a). Grandes plantas desaladoras de agua de mar en España – 2024. https://aedyr.com/plantas-desaladoras-agua-mar-espana/

AEDyR. (2024b). Grandes plantas desaladoras de agua salobre en España – 2024. https://aedyr.com/plantas-desaladoras-agua-salobre-espana/

Alcaide Zaragoza, C., González Perea, R., Fernández García, I., Camacho Poyato, E., & Rodríguez Díaz, J. A. (2020). Open source application for optimum irrigation and fertilization using reclaimed water in olive orchards. Computers and Electronics in Agriculture, 173, 105407. https://doi.org/10.1016/j.compag.2020.105407

Alcolea, A., Contreras, S., Hunink, J. E., García-Aróstegui, J. L., & Jiménez-Martínez, J. (2019). Hydrogeological modelling for the watershed management of the Mar Menor coastal lagoon (Spain). Science of The Total Environment, 663, 901–914. https://doi.org/10.1016/j.scitotenv.2019.01.375

Alcon, F., Martin-Ortega, J., Pedrero, F., Alarcon, J. J., & de Miguel, M. D. (2013). Incorporating Non-market Benefits of Reclaimed Water into Cost-Benefit Analysis: A Case Study of Irrigated Mandarin Crops in southern Spain. Water Resources Management, 27(6), 1809–1820. https://doi.org/10.1007/s11269-012-0108-z

Aleisa, E., & Al-Haddad, S. (2024). Optimizing the Nonconventional Water Supply across the Water-Energy-Food Nexus for Arid Regions Using a Life Cycle Assessment. Journal of Water Resources Planning and Management, 150(12). https://doi.org/10.1061/JWRMD5.WRENG-6103

Álvarez-Rogel, J., Barberá, G. G., Maxwell, B., Guerrero-Brotons, M., Díaz-García, C., Martínez-Sánchez, J. J., Sallent, A., Martínez-Ródenas, J., González-Alcaraz, M. N., Jiménez-Cárceles, F. J., Tercero, C., & Gómez,

R. (2020). The case of Mar Menor eutrophication: State of the art and description of tested Nature-Based Solutions. Ecological Engineering, 158, 106086. https://doi.org/10.1016/j.ecoleng.2020.106086

Alzahrani, F., Elsebaei, M., & Tawfik, R. (2023). Public Acceptance of Treated Wastewater Reuse in the Agricultural Sector in Saudi Arabia. Sustainability, 15(21), 15434. https://doi.org/10.3390/su152115434

Amali, A. A., Mersha, A. N., Nofal, E. R., Murray, K., Norouzi, S., Saboory, S., Salo, H., Chevuru, S. R., Sarai Tabrizi, M., Reddy, P. K., Abdullahi, A. O., Farahani, H., Kolhe, P., Dowlati Fard, R., Salik, A. W., Hussein, A. H., Najafi, H., Poormoghadam, M., & Adiaha, M. (2021). Non-conventional sources of agricultural water management: Insights from young professionals in the irrigation and drainage sector. Irrigation and Drainage, 70(3), 524–540. https://doi.org/10.1002/ird.2495

Axelrod, R. (1948). Structure of decision: The cognitive maps of political elites, (Princeton University Press, Ed.). Princeton University Press.

Aznar-Crespo, P., Aledo, A., & Melgarejo, J. (2019). Factors of uncertainty in the integrated management of water resources: The case of water reuse. International Journal of Sustainable Development and Planning, 14(02), 141–151. https://doi.org/10.2495/SDP-V14-N2-141-151

Aznar-Sánchez, J. A., Belmonte-Ureña, L. J., Velasco-Muñoz, J. F., & Valera, D. L. (2021). Farmers' profiles and behaviours toward desalinated seawater for irrigation: Insights from South-east Spain. Journal of Cleaner Production, 296, 126568. https://doi.org/10.1016/j.jclepro.2021.126568

Bali, M., & Ghanem, S. (2025). Assessment and simulation of brine discharge impact from a seawater desalination plant on the Mediterranean marine environment. International Journal of Environmental Science and Technology, 22(10), 9337–9346. https://doi.org/10.1007/s13762-024-06263-7

Ballesteros-Olza, M., Blanco-Gutiérrez, I., Esteve, P., Gómez-Ramos, A., & Bolinches, A. (2022). Using reclaimed water to cope with water scarcity: an alternative for agricultural irrigation in Spain. Environmental Research Letters, 17(12). https://doi.org/10.1088/1748-9326/aca3bb

Ballesteros-Olza, M., Blanco-Gutiérrez, I., Gómez-Ramos, A., & Stempfle, S. (2025). Does Non-conventional Water Use Impact the Performance of Irrigation Communities in Water-Scarce Regions? Water Resources Management. https://doi.org/10.1007/s11269-025-04281-9

Berbel, J., Cuadrado-Alarcón, B., Martínez-Dalmau, J., & Delgado-Ramos, F. (2024). Hydro-economic basin impacts of extensive adoption of deficit irrigation by farmers: Are we overestimating water resources? Journal of Hydrology, 634, 131075. https://doi.org/10.1016/j.jhydrol.2024.131075

Berbel, J., Mesa-Pérez, E., & Simón, P. (2023). Challenges for Circular Economy under the EU 2020/741 Wastewater Reuse Regulation. Global Challenges, 7(7). https://doi.org/10.1002/gch2.202200232

Bernabé Crespo, M. B., Gil-Meseguer, E., & Gómez-Espín, J. M. (2019). Desalination and water security in Southeastern Spain. Journal of Political Ecology, 26(1). https://doi.org/10.2458/v26i1.22911

Berti Suman, A., García-Herrero, L., Lavrnić, S., Sole, M. C., Toscano, A., & Vittuari, M. (2023). The advent of EU water reuse regulation in the Mediterranean region: policy and legislative adaptation to address non-conventional water resources utilization in agriculture. Water International, 48(7), 839–860. https://doi.org/10.1080/02508060.2023.2277619

Berti Suman, A., & Toscano, A. (2021). Public Acceptance of Water Reuse for Agriculture in the Wake of the New EU Regulation: Early Reflections. Journal for European Environmental & Planning Law, 18(3), 225–255. https://doi.org/10.1163/18760104-18030001

Birnhack, L., Voutchkov, N., & Lahav, O. (2011). Fundamental chemistry and engineering aspects of post-treatment processes for desalinated water—A review. Desalination, 273(1), 6–22. https://doi.org/10.1016/j.desal.2010.11.011

Blanco Fonseca, M., & Iglesias Martinez, E. (2005). Modelling New EU Agricultural Policies: Global Guidelines, Local Strategies.

Blanco, M., & Viladrich-Grau, M. (2014). La creación de un centro de intercambio de derechos de agua en la Cuenca del Segre y la contribución de los flujos de retorno. Informacion Tecnica Economica Agraria, 110(4). https://doi.org/10.12706/itea.2014.024

Blanco-Gutiérrez, I., Manners, R., Varela-Ortega, C., Tarquis, A. M., Martorano, L. G., & Toledo, M. (2020). Examining the sustainability and development challenge in agricultural-forest frontiers of the Amazon Basin through the eyes of locals. Natural Hazards and Earth System Sciences, 20(3), 797–813. https://doi.org/10.5194/nhess-20-797-2020

Bolinches, A., Blanco-Gutiérrez, I., Zubelzu, S., Esteve, P., & Gómez-Ramos, A. (2022). A method for the prioritization of water reuse projects in agriculture irrigation. Agricultural Water Management, 263, 107435. https://doi.org/10.1016/j.agwat.2021.107435

Bourguignon, N., Villamayor-Tomás, S., & Boelens, R. (2024). Fabricating Irrigators: Contested Hydrosocial Territories and Subject-Making in Spain's Tagus–Segura Interbasin Transfer Arena. Water, 16(2), 192. https://doi.org/10.3390/w16020192

Brannstrom, C., Jepson, W., Beckner, S., Sneegas, G., & Seghezzo, L. (2022). Not a silver bullet: social perspectives on desalination and water reuse in Texas. Urban Water Journal, 19(10), 1025–1037. https://doi.org/10.1080/1573062X.2022.2134808

Buendía-Azorín, J. D., Alpañez, R. M., & Sánchez de la Vega, M. del M. (2025). The vulnerability of regional agriculture regarding irrigation water from the Tagus-Segura transfer. Agricultural Water Management, 309, 109332. https://doi.org/10.1016/j.agwat.2025.109332

Cabrera, E., Estrela, T., & Lora, J. (2019). Desalination in Spain. Past, present and future. La Houille Blanche, 105(1), 85–92. https://doi.org/10.1051/lhb/2019011

Calatrava, J., Martínez-Alvarez, V., & Martínez-Granados, D. (2022). Addressing aquifer overexploitation with desalinated seawater: an economic assessment of alternatives in south-eastern Spain. International Journal of Water Resources Development, 38(2), 199–216. https://doi.org/10.1080/07900627.2021.1877635

Calatrava, J., & Martínez-Granados, D. (2012). El valor del uso del agua en el regadío de la cuenca del Segura y en las zonas regables del trasvase Tajo-Segura. Economia Agraria y Recursos Naturales, 7–32. https://doi.org/10.7201/earn.2012.01.01

Calatrava, J., Martínez-Granados, D., Zornoza, R., González-Rosado, M., Lozano-García, B., Vega-Zamora, M., & Gómez-López, M. D. (2021).

Barriers and Opportunities for the Implementation of Sustainable Farming Practices in Mediterranean Tree Orchards. Agronomy, 11(5), 821. https://doi.org/10.3390/agronomy11050821

Cañizares, A. O., Cantos, J. O., & Baños Castiñeira, C. J. (2022). The Effects of Climate Change on the Tagus–Segura Transfer: Diagnosis of the Water Balance in the Vega Baja del Segura (Alicante, Spain). Water, 14(13), 2023. https://doi.org/10.3390/w14132023

CARM. (2024). Comunidad Autónoma de la Región de Murcia. Estadística Agraria Regional. Estadísticas Agrícolas. https://www.carm.es/web/pagina?IDCONTENIDO=72277&IDTIPO=100&RASTRO=c1415$m1174

Chowdhury, S., Rahaman, Md. S., & Mazumder, M. A. J. (2024). Global mapping of seawater desalination research: A bibliometric analysis of research trends from 1980–2022. Quality & Quantity, 58(1), 781–802. https://doi.org/10.1007/s11135-023-01672-1

Christou, A., Beretsou, V. G., Iakovides, I. C., Karaolia, P., Michael, C., Benmarhnia, T., Chefetz, B., Donner, E., Gawlik, B. M., Lee, Y., Lim, T. T., Lundy, L., Maffettone, R., Rizzo, L., Topp, E., & Fatta-Kassinos, D. (2024). Sustainable wastewater reuse for agriculture. Nature Reviews Earth & Environment, 5(7), 504–521. https://doi.org/10.1038/s43017-024-00560-y

CHS. (2022a). Plan Hidrológico de la Demarcación del Segura 2022–2027. Anejo II Inventario de Recursos Hídricos.

CHS. (2022b). Plan Hidrológico de la Demarcación del Segura 2022–2027. Anexo V del Anejo III Fichas de caracterización de las unidades de demanda agraria.

CHS. (2022c). Plan Hidrológico de la Demarcación del Segura 2022–2027. Memoria.

Cipolletta, G., Ozbayram, E. G., Eusebi, A. L., Akyol, Ç., Malamis, S., Mino, E., & Fatone, F. (2021). Policy and legislative barriers to close water-related loops in innovative small water and wastewater systems in Europe: A critical analysis. Journal of Cleaner Production, 288, 125604. https://doi.org/10.1016/j.jclepro.2020.125604

Clark, T. P., Smolski, A. R., Allen, J. S., Hedlund, J., & Sanchez, H. (2022). Capitalism and Sustainability: An Exploratory Content Analysis of Frameworks in Environmental Political Economy. Social Currents, 9(2), 159–179. https://doi.org/10.1177/23294965211043548

Cochrane, Logan., & Al-Hababi, Reem. (2023). Sustainable Qatar : Social, Political and Environmental Perspectives. Springer Nature.

Cooper, C. M., & Wardropper, C. B. (2021). Environmental, public health, and economic development perspectives at a Superfund site: A Q methodology approach. Journal of Environmental Management, 279, 111571. https://doi.org/10.1016/j.jenvman.2020.111571

CRCC. (2022a). Estructura Agraria. Comunidad de Regantes Campo de Cartagena. https://www.crcc.es/estructura-agraria/

CRCC. (2022b). Información de la Comunidad Regantes del Campo de Cartagena. Infraestructuras. https://www.crcc.es/informacion-c-r-c-c/

CRCC. (2024). Memoria de actividades año 2023/2024.

CREM. (2025a). Agricultura de la Región de Murcia. Estadística Agraria Regional. In Centro Regional de Estadística de Murcia. https://econet.carm.es/web/crem/inicio/-/crem/sicrem/PU590/Indice10.html

CREM. (2025b). Datos básicos de la Región de Murcia. In Centro Regional de Estadística de Murcia. https://econet.carm.es/inicio/-/crem/sicrem/PU_datosBasicos/Indice5.html

Cruz-Pérez, N., Santamarta, J. C., Gamallo-Paz, I., Rodríguez-Martín, J., & García-Gil, A. (2022). A comparison between carbon footprint of water production facilities in the Canary Islands: groundwater resources vs. seawater desalination. Sustainable Water Resources Management, 8(4), 121. https://doi.org/10.1007/s40899-022-00706-0

Cucari, N., Tutore, I., Montera, R., & Profita, S. (2023). A bibliometric performance analysis of publication productivity in the corporate social responsibility field: Outcomes of <scp>SciVal</scp> analytics. Corporate Social Responsibility and Environmental Management, 30(1), 1–16. https://doi.org/10.1002/csr.2346

Custodio, E. (2018). Salinity problems in Mediterranean and island coastal aquifers in Spain. E3S Web of Conferences, 54, 00005. https://doi.org/10.1051/e3sconf/20185400005

Custodio, E., Sahuquillo, A., & Albiac, J. (2019). Sustainability of intensive groundwater development: experience in Spain. Sustainable Water Resources Management, 5(1), 11–26. https://doi.org/10.1007/s40899-017-0105-8

De las Heras, J., & Mañas, P. (2020). Reclaimed Wastewater to Irrigate Olive Groves and Vineyards: Effects on Soil Properties. Agronomy, 10(5), 649. https://doi.org/10.3390/agronomy10050649

Del Villar García, A., Inmaculada, M., Ortiz, L., & Moreno, J. M. (2020). Valoración económica de las actividades agrarias en el Campo de Cartagena. https://sede.administracionespublicas.gob.es/valida

Delgado, S., Rodríguez-Gómez, L. E., Vera, L., Álvarez, M., Díaz, F., & Rodríguez-Sevilla, J. (2012). Water reuse in the management of island water resources: the case of the Canary Islands and the Region of Madeira. Journal of Water Supply: Research and Technology-Aqua, 61(8), 484–493. https://doi.org/10.2166/aqua.2012.028

Devkota, K. P., Devkota, M., Rezaei, M., & Oosterbaan, R. (2022). Managing salinity for sustainable agricultural production in salt-affected soils of irrigated drylands. Agricultural Systems, 198, 103390. https://doi.org/10.1016/j.agsy.2022.103390

Dolnicar, S., & Schäfer, A. I. (2009). Desalinated versus recycled water: Public perceptions and profiles of the accepters. Journal of Environmental Management, 90(2), 888–900. https://doi.org/10.1016/j.jenvman.2008.02.003

Domenech, T., & Bahn-Walkowiak, B. (2019). Transition Towards a Resource Efficient Circular Economy in Europe: Policy Lessons From the EU and the Member States. Ecological Economics, 155, 7–19. https://doi.org/10.1016/j.ecolecon.2017.11.001

Edwards, G. I., & Kok, K. (2021). Building a Fuzzy Cognitive Map from stakeholder knowledge: An Episodic, asynchronous approach. Current Research in Environmental Sustainability, 3, 100053. https://doi.org/10.1016/j.crsust.2021.100053

Eekhout, J. P. C., Delsman, I., Baartman, J. E. M., van Eupen, M., van Haren, C., Contreras, S., Martínez-López, J., & de Vente, J. (2024). How future changes in irrigation water supply and demand affect water security in a Mediterranean catchment. Agricultural Water Management, 297, 108818. https://doi.org/10.1016/j.agwat.2024.108818

Efthimiou, N., Giotis, T., & Ragkos, A. (2025). Applications for Non-Conventional Water Resources in the Mediterranean Basin: A Literature Review. Sustainability, 17(11), 4964. https://doi.org/10.3390/su17114964

Eierle, B., Hartlieb, S., Hay, D. C., Niemi, L., & Ojala, H. (2022). External Factors and the Pricing of Audit Services: A Systematic Review of the Archival Literature Using a PESTLE Analysis. AUDITING: A Journal of Practice & Theory, 41(3), 95–119. https://doi.org/10.2308/AJPT-2019-510

Eke, J., Yusuf, A., Giwa, A., & Sodiq, A. (2020). The global status of desalination: An assessment of current desalination technologies, plants and capacity. Desalination, 495, 114633. https://doi.org/10.1016/j.desal.2020.114633

Elbana, M., Puig-Bargués, J., Pujol, J., & de Cartagena, F. R. (2010). Preliminary planning for reclaimed water reuse for agricultural irrigation in the province of Girona, Catalonia (Spain). Desalination and Water Treatment, 22(1–3), 47–55. https://doi.org/10.5004/dwt.2010.1523

Ellis, S. F., Savchenko, O. M., & Messer, K. D. (2019). What's in a name? Branding reclaimed water. Environmental Research, 172, 384–393. https://doi.org/10.1016/j.envres.2019.01.059

Elsawah, S., Hamilton, S. H., Jakeman, A. J., Rothman, D., Schweizer, V., Trutnevyte, E., Carlsen, H., Drakes, C., Frame, B., Fu, B., Guivarch, C., Haasnoot, M., Kemp-Benedict, E., Kok, K., Kosow, H., Ryan, M., & van Delden, H. (2020). Scenario processes for socio-environmental systems analysis of futures: A review of recent efforts and a salient research agenda for supporting decision making. Science of The Total Environment, 729, 138393. https://doi.org/10.1016/j.scitotenv.2020.138393

Escriva-Bou, A., Hanak, E., Cole, S., & Medellín-Azuara, J. (2023). The Future of Agriculture in the San Joaquin Valley, Technical Appendix.

European Commission. (2000). Water Framework Directive (WFD) 2000/60/EC.

European Commission. (2025). European Water Resilience Strategy.

European Environment Agency. (2016). Use of freshwater resources in Europe. In EEA Report (Vol. 5). https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-1

European Parliament. (2020). Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on Minimum Requirementsfor Water Reuse.

European Parliament, & Council of the European Union. (2024). Directive (EU) 2024/3019 of 27 November 2024 concerning urban wastewater treatment. In Official Journal of the European Union, L 3019.

Expósito, A., Díaz-Cano, E., & Berbel, J. (2024). The Potential use of Reclaimed Water for Irrigation Purposes: Is it Overestimated? Water Resources Management. https://doi.org/10.1007/s11269-024-03878-w

Expósito, A., Lorenzo Lopez, A. M., & Berbel, J. (2024). How much does reclaimed wastewater cost? A comprehensive analysis for irrigation uses in the European Mediterranean context. Water Reuse, 14(3), 434–447. https://doi.org/10.2166/wrd.2024.040

Fabregat, V. (2025). Unlocking the Potential of Reclaimed Water: Analysis of the Challenges and Market Size as a Strategic Solution for Water Scarcity in Europe. Challenges, 16(3), 43. https://doi.org/10.3390/challe16030043

Fayyaz, S., Khadem Masjedi, S., Kazemi, A., Khaki, E., Moeinaddini, M., & Irving Olsen, S. (2023). Life cycle assessment of reverse osmosis for high-salinity seawater desalination process: Potable and industrial water production. Journal of Cleaner Production, 382, 135299. https://doi.org/10.1016/j.jclepro.2022.135299

Fazelpoor, K., Martínez-Fernández, V., & García de Jalón, D. (2021). Exploring the hydromorphological response to human pressure in Tagus River (1946–2014) by complementary diagnosis. CATENA, 198, 105052. https://doi.org/10.1016/j.catena.2020.105052

Félix-López, M., Ormaza-Murillo, M., Álvarez-Santana, C., & Banchon, C. (2023). Exploring the Impact of Reclaimed Water on Latin America's Development. Journal of Ecological Engineering, 24(10), 157–173. https://doi.org/10.12911/22998993/169962

Feo-García, J., Pulido-Alonso, A., Florido-Betancor, A., & Florido-Suárez, N. R. (2024). Cost Studies of Reverse Osmosis Desalination Plants in the Range of 23,000–33,000 m3/day. Water, 16(6), 910. https://doi.org/10.3390/w16060910

Ferro, G., Polo-López, M. I., & Fernández-Ibáñez, P. (2015). Conventional and New Processes for Urban Wastewater Disinfection: Effect on Emerging and Resistant Microorganisms (pp. 107–128). https://doi.org/10.1007/698_2015_390

Finchilescu, G., & Muthal, S. (2019). Transforming Research Methods in the Social Sciences: Case Studies from South Africa.

Fito, J., & Van Hulle, S. W. H. (2021). Wastewater reclamation and reuse potentials in agriculture: towards environmental sustainability. Environment, Development and Sustainability, 23(3), 2949–2972. https://doi.org/10.1007/s10668-020-00732-y

Forde, M. S., Cashman, A., & Mitchell, K. (2024). Sustainability of water resources in Caribbean small island developing states: an overview. Discover Sustainability, 5(1), 265. https://doi.org/10.1007/s43621-024-00478-x

Fornés, J. M., López-Gunn, E., & Villarroya, F. (2021). Water in Spain: paradigm changes in water policy. Hydrological Sciences Journal, 66(7), 1113–1123. https://doi.org/10.1080/02626667.2021.1918697

Frantzi, S., Carter, N. T., & Lovett, J. C. (2009). Exploring discourses on international environmental regime effectiveness with Q methodology: A case study of the Mediterranean Action Plan. Journal of Environmental Management, 90(1), 177–186. https://doi.org/10.1016/j.jenvman.2007.08.013

Gallego-Elvira, B., Reca, J., Martin-Gorriz, B., Maestre-Valero, J. F., & Martínez-Alvarez, V. (2021). Irriblend-DSW: A decision support tool for the optimal blending of desalinated and conventional irrigation waters in dry regions. Agricultural Water Management, 255, 107012. https://doi.org/10.1016/j.agwat.2021.107012

Gallego-Valero, L., Moral-Pajares, E., & Román-Sánchez, I. M. (2019). Crop production and irrigation: deciding factors of wastewater reuse in Spain? DESALINATION AND WATER TREATMENT, 150, 91–98. https://doi.org/10.5004/dwt.2019.23618

García Castellanos, B., García García, B., & García García, J. (2024). Economic and Environmental Assessment of Conventional Lemon Cultivation: The Case of Southeastern Spain. Agronomy, 14(8), 1842. https://doi.org/10.3390/agronomy14081842

García-Herrera, R., Garrido-Perez, J. M., Barriopedro, D., Ordóñez, C., Vicente-Serrano, S. M., Nieto, R., Gimeno, L., Sorí, R., & Yiou, P. (2019). The European 2016/17 Drought. Journal of Climate, 32(11), 3169–3187. https://doi.org/10.1175/JCLI-D-18-0331.1

García-López, M., Montano, B., & Melgarejo, J. (2022). The Tariff Structure in the Tagus-Segura Water Transfer. Water, 14(3), 413. https://doi.org/10.3390/w14030413

García-López, M., Montano, B., & Melgarejo, J. (2023). The financial competitiveness of photovoltaic installations in water utilities: The case of the Tagus-Segura water transfer system. Solar Energy, 249, 734–743. https://doi.org/10.1016/j.solener.2022.12.025

García-Valverde, M., Aragonés, A. M., Andújar, J. A. S., García, M. D. G., Martínez-Bueno, M. J., & Fernández-Alba, A. R. (2023). Long-term effects on the agroecosystem of using reclaimed water on commercial crops. Science of The Total Environment, 859, 160462. https://doi.org/10.1016/j.scitotenv.2022.160462

Garfield, E. (1955). Citation Indexes for Science. Science, 122(3159), 108–111. https://doi.org/10.1126/science.122.3159.108

Garin, P., Montginoul, M., & Noury, B. (2021). Waste water reuse in France – social perception of an unfamiliar practice. Water Supply, 21(5), 1913–1926. https://doi.org/10.2166/ws.2020.242

Gholamrezai, S., Azadi, H., Karamian, F., Khosravi, E., Moghaddam, S. M., Goli, I., & Scheffran, J. (2023). Smart control of agricultural water wells in western Iran: Application of the Q-methodology. Journal of Soil and Water Conservation, 78(1), 58–69. https://doi.org/10.2489/jswc.2023.00066

Gil-Meseguer, E., Bernabé-Crespo, M. B., & Gómez-Espín, J. M. (2019). Recycled Sewage - A Water Resource for Dry Regions of Southeastern Spain. Water Resources Management, 33(2), 725–737. https://doi.org/10.1007/s11269-018-2136-9

Gil-Meseguer, E., Bernabé-Crespo, M. B., Gómez-Gil, J. M., & Gómez-Espín, J. M. (2024). Environmental Crisis in the Mar Menor Lagoon (Region of Murcia – Spain). Revista de Gestão Social e Ambiental, 18(11), e010040. https://doi.org/10.24857/rgsa.v18n11-238

Gómez Martínez, G., & Pérez Martín, M. Á. (2023). Water Management Adaptation to Climate Change in Mediterranean Semiarid Regions by Desalination and Photovoltaic Solar Energy, Spain. Water, 15(18), 3239. https://doi.org/10.3390/w15183239

Gomez-Gomez, J.-D., Pulido-Velazquez, D., Collados-Lara, A.-J., & Fernandez-Chacon, F. (2022). The impact of climate change scenarios on droughts and their propagation in an arid Mediterranean basin. A useful approach for planning adaptation strategies. Science of The Total Environment, 820, 153128. https://doi.org/10.1016/j.scitotenv.2022.153128

Gómez-Ramos, A., Blanco-Gutiérrez, I., Ballesteros-Olza, M., & Esteve, P. (2024). Are Non-Conventional Water Resources the Solution for the Structural Water Deficit in Mediterranean Agriculture? The Case of the Segura River Basin in Spain. Water, 16(7), 929. https://doi.org/10.3390/w16070929

Gray, S. A., Gray, S., De Kok, J. L., Helfgott, A. E. R., O'Dwyer, B., Jordan, R., & Nyaki, A. (2015). Using fuzzy cognitive mapping as a participatory approach to analyze change, preferred states, and perceived resilience of social-ecological systems. Ecology and Society, 20(2), art11. https://doi.org/10.5751/ES-07396-200211

Guerrero, M. M., Lacasa, C. M., Martínez, V., Martínez-Lluch, M. C., Larregla, S., & Lacasa, A. (2019). Soil biosolarization for Verticillium dahliae and Rhizoctonia solani control in artichoke crops in southeastern Spain. Spanish Journal of Agricultural Research, 17(1), e1002. https://doi.org/10.5424/sjar/2019171-13666

Gupta, B. G. (2024). Urban Development with Treated Recycled and Reuse of Wastewater: Sustainable Management (B. G. Gupta, Ed.). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-0857-7

Hage, P., & Harary, F. (1983). Structural models in anthropology. Oxford University Press, New York, USA.

Hagenvoort, J., Ortega-Reig, M., Botella, S., García, C., de Luis, A., & Palau-Salvador, G. (2019). Reusing Treated Waste-Water from a Circular Economy Perspective—The Case of the Real Acequia de Moncada in Valencia (Spain). Water, 11(9), 1830. https://doi.org/10.3390/w11091830

Hampson, D. I., Ferrini, S., & Turner, R. K. (2022). Assessing subjective preferences for river quality improvements: combining Q-methodology and choice experiment data. Journal of Environmental Economics and Policy, 11(1), 56–74. https://doi.org/10.1080/21606544.2021.1879682

Heinz, I., Salgot, M., & Koo-Oshima, S. (2011). Water reclamation and intersectoral water transfer between agriculture and cities – a FAO economic wastewater study. Water Science and Technology, 63(5), 1067–1073. https://doi.org/10.2166/wst.2011.292

Heinz, I., Salgot, M., & Mateo-Sagasta Dávila, J. (2011). Evaluating the costs and benefits of water reuse and exchange projects involving cities and farmers. Water International, 36(4), 455–466. https://doi.org/10.1080/02508060.2011.594984

Hejazi, M., Santos Da Silva, S. R., Miralles-Wilhelm, F., Kim, S., Kyle, P., Liu, Y., Vernon, C., Delgado, A., Edmonds, J., & Clarke, L. (2023). Impacts of water scarcity on agricultural production and electricity generation in the Middle East and North Africa. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1082930

Hernández-Cuenca, S., González-Camejo, J., Pachés, M., Fatone, F., & Eusebi, A. L. (2025). Standard risk assessment methodology for quantifying potential risks in reusing wastewater treated by microalgae-based photorefinery. Bioresource Technology, 431, 132599. https://doi.org/10.1016/j.biortech.2025.132599

Hernández-Mora, N., del Moral Ituarte, L., La-Roca, F., La Calle, A., & Schmidt, G. (2014). Interbasin Water Transfers in Spain: Interregional Conflicts and Governance Responses. In Globalized Water (pp. 175–194). Springer Netherlands. https://doi.org/10.1007/978-94-007-7323-3_13

Hernández-Sancho, F., & Bellver-Domingo, Á. (2022). Economics and Innovative Financing Mechanisms in a Circular Economy. In Unconventional Water Resources (pp. 281–297). Springer International Publishing. https://doi.org/10.1007/978-3-030-90146-2_13

Howitt, R. E. (1995). Positive Mathematical Programming. American Journal of Agricultural Economics, 77(2), 329–342. https://doi.org/10.2307/1243543

Howitt, R. E. (2005). Agricultural and Environmental Policy Models: Calibration, Estimation and Optimization.

Hristov, J., Barreiro-Hurle, J., Salputra, G., Blanco, M., & Witzke, P. (2021). Reuse of treated water in European agriculture: Potential to address water scarcity under climate change. Agricultural Water Management, 251, 106872. https://doi.org/10.1016/j.agwat.2021.106872

Hurtado, A. R., & Berbel, J. (2024). A Cost–Benefit Analysis of Reclaimed Water and Desalinated Seawater for Irrigation in Axarquia, Southern Spain. Land, 13(12), 2156. https://doi.org/10.3390/land13122156

Hurtado, A. R., Mesa-Pérez, E., & Berbel, J. (2024). Systems Modeling of the Water-Energy-Food-Ecosystems Nexus: Insights from a Region Facing Structural Water Scarcity in Southern Spain. Environmental Management, 74(6), 1045–1062. https://doi.org/10.1007/s00267-024-02037-6

Hussein Abouzied, A. (2023). The Connection between the Impacts of Desalination and the Surrounding Environment. In Desalination - Ecological Consequences. IntechOpen. https://doi.org/10.5772/intechopen.110140

Ibor, C. S., Mollá, M. G., Reus, L. A., & Genovés, J. C. (2011). Reaching the limits of water resources mobilization: Irrigation development in the Segura river basin, Spain. Water Alternatives, 4(3), 259–278.

INE. (2024). Estadística Sobre el Suministro y Saneamiento del Agua. Recogida y tratamiento de las aguas residuales por comunidades y ciudades autónomas, tipo de indicador y periodo. https://www.ine.es/jaxi/Tabla.htm?tpx=53450&L=0

Instituto Valenciano de Investigaciones Agrarias. (2010). Tolerancia de los cultivos a la salinidad. http://agrosal.ivia.es/tolerancia.html

Jasechko, S., & Perrone, D. (2021). Global groundwater wells at risk of running dry. Science, 372(6540), 418–421. https://doi.org/10.1126/science.abc2755

Jiménez-Benítez, A., Ferrer, F. J., Greses, S., Ruiz-Martínez, A., Fatone, F., Eusebi, A. L., Mondéjar, N., Ferrer, J., & Seco, A. (2020). AnMBR, reclaimed water and fertigation: Two case studies in Italy and Spain to assess economic and technological feasibility and CO2 emissions within the EU Innovation Deal initiative. Journal of Cleaner Production, 270, 122398. https://doi.org/10.1016/j.jclepro.2020.122398

Jodar-Abellan, A., Albaladejo-García, J. A., Aznar-Crespo, P., de los Santos, M. B., Seyed Asadollah, S. B. H., Derdour, A., Martínez-Nicolás, J. J., Melgarejo, P., Prats, D., & Serrano-Bernardo, F. (2024). Exploring expert perceptions towards emerging pollutants and their impacts in reused wastewater and agriculture. Agricultural Water Management, 304, 109098. https://doi.org/10.1016/j.agwat.2024.109098

Jodar-Abellan, A., López-Ortiz, M. I., & Melgarejo-Moreno, J. (2019). Wastewater Treatment and Water Reuse in Spain. Current Situation and Perspectives. Water, 11(8), 1551. https://doi.org/10.3390/w11081551

Jones, E., Qadir, M., van Vliet, M. T. H., Smakhtin, V., & Kang, S. (2019). The state of desalination and brine production: A global outlook. Science of The Total Environment, 657, 1343–1356. https://doi.org/10.1016/j.scitotenv.2018.12.076

Jones, E. R., van Vliet, M. T. H., Qadir, M., & Bierkens, M. F. P. (2021). Country-level and gridded estimates of wastewater production, collection, treatment and reuse. Earth System Science Data, 13(2), 237–254. https://doi.org/10.5194/essd-13-237-2021

Karef, S., Azlaoui, M., Boussaid, K., Batana, F. Z., Bruzzoniti, M. C., Fodili, M., & Kettab, A. (2025). Fertilizer potential and social perception of the agricultural reuse of sewage sludge and treated wastewater. Desalination and Water Treatment, 322, 101186. https://doi.org/10.1016/j.dwt.2025.101186

Kavitha, J., Rajalakshmi, M., Phani, A. R., & Padaki, M. (2019). Pretreatment processes for seawater reverse osmosis desalination systems—A review. Journal of Water Process Engineering, 32, 100926. https://doi.org/10.1016/j.jwpe.2019.100926

Kesari, K. K., Soni, R., Jamal, Q. M. S., Tripathi, P., Lal, J. A., Jha, N. K., Siddiqui, M. H., Kumar, P., Tripathi, V., & Ruokolainen, J. (2021). Wastewater Treatment and Reuse: a Review of its Applications and

Health Implications. Water, Air, & Soil Pollution, 232(5), 208. https://doi.org/10.1007/s11270-021-05154-8

Khondoker, M., Mandal, S., Gurav, R., & Hwang, S. (2023). Freshwater Shortage, Salinity Increase, and Global Food Production: A Need for Sustainable Irrigation Water Desalination—A Scoping Review. Earth, 4(2), 223–240. https://doi.org/10.3390/earth4020012

Kok, K. (2009). The potential of Fuzzy Cognitive Maps for semi-quantitative scenario development, with an example from Brazil. Global Environmental Change, 19(1), 122–133. https://doi.org/10.1016/j.gloenvcha.2008.08.003

Koseoglu-Imer, D. Y., Oral, H. V., Coutinho Calheiros, C. S., Krzeminski, P., Güçlü, S., Pereira, S. A., Surmacz-Górska, J., Plaza, E., Samaras, P., Binder, P. M., van Hullebusch, E. D., & Devolli, A. (2023). Current challenges and future perspectives for the full circular economy of water in European countries. Journal of Environmental Management, 345, 118627. https://doi.org/10.1016/j.jenvman.2023.118627

Kosko, B. (1986). Fuzzy cognitive maps. International Journal of Man-Machine Studies, 24(1), 65–75. https://doi.org/10.1016/S0020-7373(86)80040-2

Krstikj, A., Sosa Godina, J., García Bañuelos, L., González Peña, O. I., Quintero Milián, H. N., Urbina Coronado, P. D., & Vanoye García, A. Y. (2022). Analysis of Competency Assessment of Educational Innovation in Upper Secondary School and Higher Education: A Mapping Review. Sustainability, 14(13), 8089. https://doi.org/10.3390/su14138089

La Roca, F., & Martínez, J. (2023). Retos de la planificación y gestión del agua en España - Informe 2023. www.fnca.eu

Lavrnić, S., Zapater-Pereyra, M., & Mancini, M. L. (2017). Water Scarcity and Wastewater Reuse Standards in Southern Europe: Focus on Agriculture. Water, Air, & Soil Pollution, 228(7), 251. https://doi.org/10.1007/s11270-017-3425-2

Lefebvre, O. (2018). Beyond NEWater: An insight into Singapore's water reuse prospects. Current Opinion in Environmental Science & Health, 2, 26–31. https://doi.org/10.1016/j.coesh.2017.12.001

Ley 22/1988, de 28 de Julio, de Costas, Pub. L. No. 181, 181 Boletín Oficial del Estado (1988).

Li, X., Li, X., & Li, Y. (2022). Research on reclaimed water from the past to the future: a review. Environment, Development and Sustainability, 24(1), 112–137. https://doi.org/10.1007/s10668-021-01495-w

Lipińska, I., & Cazorla González, M. J. (2023). Sustainable water use for agricultural production - selected legal aspects. Revista Internacional de Doctrina y Jurisprudencia, 29, 53–66. https://doi.org/10.25115/ridj.vi29.9296

Liu, J., Cheng, Y., Zhang, F., Wen, X., & Yang, L. (2023). Research hotspots and trends of groundwater and ecology studies: Based on a bibliometric approach. Journal of Groundwater Science and Engineering, 11(1), 20–36. https://doi.org/10.26599/JGSE.2023.9280003

Liu, J., Yang, H., Gosling, S. N., Kummu, M., Flörke, M., Pfister, S., Hanasaki, N., Wada, Y., Zhang, X., Zheng, C., Alcamo, J., & Oki, T. (2017). Water scarcity assessments in the past, present, and future. Earth's Future, 5(6), 545–559. https://doi.org/10.1002/2016EF000518

Liu, Ye, J.-A., & Sheu, H.-Y. (2022). Exploring the social acceptability for the desalination plant project: Perceptions from the stakeholders. Desalination, 532, 115757. https://doi.org/10.1016/j.desal.2022.115757

Liu, Z., Hou, P., Zha, Y., Muhammad, T., & Li, Y. (2022). Salinity threshold of desalinated saline water used for drip irrigating: The perspective of emitter clogging. Journal of Cleaner Production, 361, 132143. https://doi.org/10.1016/j.jclepro.2022.132143

López-Serrano, M. J., Velasco-Muñoz, J. F., Aznar-Sánchez, J. A., & Román-Sánchez, I. M. (2022). Farmers' Attitudes towards Irrigating Crops with Reclaimed Water in the Framework of a Circular Economy. Agronomy, 12(2). https://doi.org/10.3390/agronomy12020435

López-Serrano, María. J., Velasco-Muñoz, J. F., Aznar-Sánchez, J. A., & Román-Sánchez, I. M. (2021). Economic Analysis of the Use of Reclaimed Water in Agriculture in Southeastern Spain, A Mediterranean Region. Agronomy, 11(11), 2218. https://doi.org/10.3390/agronomy11112218

Maas, E. V., & Hoffman, G. J. (1977). Crop Salt Tolerance—Current Assessment. Journal of the Irrigation and Drainage Division, 103(2), 115–134. https://doi.org/10.1061/JRCEA4.0001137

Maestre-Valero, J. F., González-Ortega, M. J., Martínez-Álvarez, V., & Martin-Gorriz, B. (2019). The role of reclaimed water for crop irrigation in southeast Spain. Water Supply, 19(5), 1555–1562. https://doi.org/10.2166/ws.2019.024

MAGRAMA. (2012). Plan Nacional de Reutilización de Aguas.

MAGRAMA. (2016). BOE. Orden AAA/1747/2016, de 26 de octubre, por la que se establecen los valores medios regionales definitivos y número máximo de derechos de pago básico, establecidos por asignación inicial, que caracterizan a cada una de las regiones del modelo de aplicación regional para el régimen de pago básico. http://www.boe.es

Maki, A., Pedrero, F., Hafsi, M., & Guerber, F. (2025). Desalination for agricultural development: Addressing opportunities and challenges in the context of climate change and the global agricultural commodity market. FAO. https://doi.org/10.4060/cd4781en

MAPA. (2021). Resolution of July 2, 2021, from the Directorate General of Rural Development, Innovation and Agri-food Training, publishing the Agreement between MAPA and SEIASA regarding modernization works of irrigation included in the Plan to Improve the Efficiency and Sustainability of Irrigation (Recovery, Transformation and Resilience Plan) (Issue 158). BOE. https://www.boe.es/diario_boe/txt.php?id=BOE-A-2021-11853

MAPA. (2022a). Cuentas Económicas de la Agricultura (Renta Agraria: Macromagnitudes Agrarias). Producción Vegetal. https://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/economia/cuentas-economicas-agricultura/

MAPA. (2022b). Valores medios regionales de los derechos de pago básico en la campaña 2022.

MAPA. (2024a). Sistema de Información Agroclimática del Regadío: Cálculo de las necesidades hídricas. https://servicio.mapa.gob.es/websiar/NecesidadesHidricas.aspx

MAPA. (2024b). Survey on Crop Areas and Yields in Spain (ESYRCE). https://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/agricultura/esyrce

MAPA. (2025). Encuesta sobre Superficies y Rendimientos Cultivos (ESYRCE). Resultados provisionales nacionales y autonómicos 2024. https://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/agricultura/esyrce/

Markland, S. M., Ingram, D., Kniel, K. E., & Sharma, M. (2017). Water for Agriculture: the Convergence of Sustainability and Safety. Microbiology Spectrum, 5(3). https://doi.org/10.1128/microbiolspec.PFS-0014-2016

Martínez-Alvarez, V., Imbernón-Mulero, A., Gallego-Elvira, B., Soto-García, M., & Maestre-Valero, J. F. (2023). Multidisciplinary assessment of the agricultural supply of desalinated seawater in south-eastern Spain. Desalination, 548, 116252. https://doi.org/10.1016/j.desal.2022.116252

Martínez-Álvarez, V., Imbernón-Mulero, A., Maestre-Valero, J. F., Ben Abdallah, S., & Gallego-Elvira, B. (2023). Agronomic Analysis of the Replacement of Conventional Agricultural Water Supply by Desalinated Seawater as an Adaptive Strategy to Water Scarcity in South-Eastern Spain. Agronomy, 13(12), 2878. https://doi.org/10.3390/agronomy13122878

Martínez-Medina, M. À., Pérez-Martín, M. Á., & Estrela, T. (2024). Desalination in Spain and the Role of Solar Photovoltaic Energy. Journal of Marine Science and Engineering, 12(6), 859. https://doi.org/10.3390/jmse12060859

Martínez-Pérez, L., Luquot, L., Carrera, J., Marazuela, M. A., Goyetche, T., Pool, M., Palacios, A., Bellmunt, F., Ledo, J., Ferrer, N., del Val, L., Pezard, P. A., García-Orellana, J., Diego-Feliu, M., Rodellas, V., Saaltink, M. W., Vázquez-Suñé, E., & Folch, A. (2022). A multidisciplinary approach to characterizing coastal alluvial aquifers to improve understanding of seawater intrusion and submarine groundwater discharge. Journal of Hydrology, 607, 127510. https://doi.org/10.1016/j.jhydrol.2022.127510

Mateo, L. F., Más-López, M. I., García-del-Toro, E. M., García-Salgado, S., & Quijano, M. Á. (2024). Artificial Neural Networks to Predict Electrical Conductivity of Groundwater for Irrigation Management: Case of Campo de Cartagena (Murcia, Spain). Agronomy, 14(3), 524. https://doi.org/10.3390/agronomy14030524

McClaran, N., Behe, B. K., Huddleston, P., & Fernandez, R. T. (2020). Recycled or reclaimed? The effect of terminology on water reuse perceptions. Journal of Environmental Management, 261, 110144. https://doi.org/10.1016/j.jenvman.2020.110144

McLennan, C., Rudi, G., Altchenko, Y., & Ait-Mouheb, N. (2024). Will the European Regulation for water reuse for agricultural irrigation foster this practice in the European Union? Water Reuse, 14(2), 115–135. https://doi.org/10.2166/wrd.2024.012

Medellín-Azuara, J., Escriva-Bou, A., Gaudin, A. C. M., Schwabe, K. A., & Sumner, D. A. (2024). Cultivating climate resilience in California agriculture: Adaptations to an increasingly volatile water future. Proceedings of the National Academy of Sciences, 121(32). https://doi.org/10.1073/pnas.2310079121

Medellín-Azuara, J., Escriva-Bou, A., & Jezdimirovic, J. (2019). Water and the Future of the San Joaquin Valley Technical Appendix C: Potential Economic Impacts of Reducing Water Use on San Joaquin Valley Agriculture.

Medina, E., de Arce, R., & Mahía, R. (2015). Barriers to the investment in the Concentrated Solar Power sector in Morocco: A foresight approach using the Cross Impact Analysis for a large number of events. Futures, 71, 36–56. https://doi.org/10.1016/j.futures.2015.06.005

Melgarejo-Moreno, J., López-Ortiz, M.-I., & Fernández-Aracil, P. (2019). Water distribution management in South-East Spain: A guaranteed system in a context of scarce resources. Science of The Total Environment, 648, 1384–1393. https://doi.org/10.1016/j.scitotenv.2018.08.263

Mendoza-Espinosa, L. G., Burgess, J. E., Daesslé, L., & Villada-Canela, M. (2019). Reclaimed water for the irrigation of vineyards: Mexico and South Africa as case studies. Sustainable Cities and Society, 51, 101769. https://doi.org/10.1016/j.scs.2019.101769

Menon, A. K., Jia, M., Kaur, S., Dames, C., & Prasher, R. S. (2023). Distributed desalination using solar energy: A technoeconomic framework to decarbonize nontraditional water treatment. IScience, 26(2), 105966. https://doi.org/10.1016/j.isci.2023.105966

Mesa-Pérez, E., & Berbel, J. (2020). Analysis of Barriers and Opportunities for Reclaimed Wastewater Use for Agriculture in Europe. Water, 12(8), 2308. https://doi.org/10.3390/w12082308

Mesa-Pérez, E., Exposito, A., Casielles, R., & Berbel, J. (2020). 8 SWOT Analysis of Reclaimed Water Use for Irrigation in Southern Spain 141 8 SWOT Analysis of Reclaimed Water Use for Irrigation in Southern Spain. In Water Reuse Within a Circular Economy Context (Vol. 2).

Michetti, M., Raggi, M., Guerra, E., & Viaggi, D. (2019). Interpreting Farmers' Perceptions of Risks and Benefits Concerning Wastewater Reuse for Irrigation: A Case Study in Emilia-Romagna (Italy). Water, 11(1), 108. https://doi.org/10.3390/w11010108

MITECO. (2014). Plan Nacional de Depuración, Saneamiento, Eficiencia, Ahorro y Reutilización (Plan DSEAR) 2014-2023.

MITECO. (2021). Metadata Catalog of the Spatial Data Infrastructure of Spain (IDE). https://www.mapama.gob.es/ide/metadatos/srv/spa/catalog.search#/metadata/04195683-9bc4-4a6e-be78-f899e484e2e7

MITECO. (2022). Informe de seguimiento de Planes Hidrológicos y Recursos Hídricos en España. Año 2021 (Avance, octubre 2022). https://www.miteco.gob.es/es/agua/temas/planificacion-hidrologica/planificacion-hidrologica-seguimiento-planes.aspx

Mohamed, M. M., El-Shorbagy, W., Kizhisseri, M. I., Chowdhury, R., & McDonald, A. (2020). Evaluation of policy scenarios for water resources planning and management in an arid region. Journal of Hydrology: Regional Studies, 32, 100758. https://doi.org/10.1016/j.ejrh.2020.100758

Molina, A., & Melgarejo, J. (2016). Water policy in Spain: seeking a balance between transfers, desalination and wastewater reuse. International Journal of Water Resources Development, 32(5), 781–798. https://doi.org/10.1080/07900627.2015.1077103

Molinos-Senante, M., Hernandez-Sancho, F., & Sala-Garrido, R. (2013). Tariffs and Cost Recovery in Water Reuse. Water Resources

Management, 27(6), 1797–1808. https://doi.org/10.1007/s11269-012-0111-4

Moreno-Silva, C., Pagliero, L., & McIntyre, N. (2025). Environmental and social impacts from desalinated water supply projects. Environmental Impact Assessment Review, 115, 107961. https://doi.org/10.1016/j.eiar.2025.107961

Morote, Á., Rico, A., & Moltó, E. (2017). Critical review of desalination in Spain: a resource for the future? Geographical Research, 55(4), 412–423. https://doi.org/10.1111/1745-5871.12232

Morote, Hernández, M., Rico, A. M., & Eslamian, S. (2020). Interbasin water transfer conflicts. The case of the Tagus-Segura Aqueduct (Spain). International Journal of Hydrology Science and Technology, 10(4), 364. https://doi.org/10.1504/IJHST.2020.108267

Morote, Olcina, J., & Hernández, M. (2019). The use of non-conventional water resources as a means of adaptation to drought and climate change in semi-arid regions: South-eastern Spain. Water (Switzerland), 11(1). https://doi.org/10.3390/w11010093

Moya-Fernández, P. J., López-Ruiz, S., Guardiola, J., & González-Gómez, F. (2021). Determinants of the acceptance of domestic use of recycled water by use type. Sustainable Production and Consumption, 27, 575–586. https://doi.org/10.1016/j.spc.2021.01.026

Nápoles, G., Grau, I., & Salgueiro, Y. (2024). A revised cognitive mapping methodology for modeling and simulation. Knowledge-Based Systems, 299, 112089. https://doi.org/10.1016/j.knosys.2024.112089

Navarro, J. M., Antolinos, V., Botía, P., & Robles, J. M. (2023). Deficit Irrigation Applied to Lemon Trees Grafted on Two Rootstocks and Irrigated with Desalinated Seawater. Plants, 12(12), 2300. https://doi.org/10.3390/plants12122300

Nazlabadi, E., Maknoon, R., Reza Alavi Moghaddam, M., & Daigger, G. T. (2023). A novel MICMAC approach for cross impact analysis with application to urban water/wastewater management. Expert Systems with Applications, 230, 120667. https://doi.org/10.1016/j.eswa.2023.120667

Nkhoma, P. R., Alsharif, K., Ananga, E., Eduful, M., & Acheampong, M. (2021). Recycled water reuse: what factors affect public acceptance? Environmental Conservation, 48(4), 278–286. https://doi.org/10.1017/S037689292100031X

Novo, P., Byg, A., & Herrett, S. (2024). Digging for nature: human-nature relations in the context of growing plants. Ecosystems and People, 20(1). https://doi.org/10.1080/26395916.2024.2358499

OECD. (2020). Agriculture and water policy changes. https://doi.org/10.1787/f35e64af-en

Ofori, S., Puškáčová, A., Růžičková, I., & Wanner, J. (2021). Treated wastewater reuse for irrigation: Pros and cons. Science of The Total Environment, 760, 144026. https://doi.org/10.1016/j.scitotenv.2020.144026

Orden TED/934/2022 por la que se aprueban las bases reguladoras y primera convocatoria del PERTE de digitalización del ciclo del agua. (2022). In Boletín Oficial del Estado (Vol. 292).

Ortega-Reig, M., Palau-Salvador, G., Cascant i Sempere, M. J., Benitez-Buelga, J., Badiella, D., & Trawick, P. (2014). The integrated use of surface, ground and recycled waste water in adapting to drought in the traditional irrigation system of Valencia. Agricultural Water Management, 133, 55–64. https://doi.org/10.1016/j.agwat.2013.11.004

Özesmi, U., & Özesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecological Modelling, 176(1–2), 43–64. https://doi.org/10.1016/j.ecolmodel.2003.10.027

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, n71. https://doi.org/10.1136/bmj.n71

Page, M. J., Moher, D., Brennan, S., & McKenzie, J. E. (2023). The PRISMATIC project: protocol for a research programme on novel methods to improve reporting and peer review of systematic reviews of health evidence. Systematic Reviews, 12(1), 196. https://doi.org/10.1186/s13643-023-02363-6

Palacios-Diaz, M., Mendoza-Grimón, V., & Garcia, A. (2015). Influence of Policy Making in the Profitability of Forage Production Irrigated with Reclaimed Water. Water, 7(12), 4274–4282. https://doi.org/10.3390/w7084274

Palma, D., Flores Garcia, J., & Bianco Prevot, A. (2024). Categories, Distribution, Opportunities, and Challenges of Unconventional Water Resources (pp. 39–64). https://doi.org/10.1007/978-3-031-67739-7_3

Paul, M., Negahban-Azar, M., Shirmohammadi, A., & Montas, H. (2020). Assessment of agricultural land suitability for irrigation with reclaimed water using geospatial multi-criteria decision analysis. Agricultural Water Management, 231, 105987. https://doi.org/10.1016/j.agwat.2019.105987

Pellicer-Martínez, F., & Martínez-Paz, J. M. (2018). Climate change effects on the hydrology of the headwaters of the Tagus River: implications for the management of the Tagus–Segura transfer. Hydrology and Earth System Sciences, 22(12), 6473–6491. https://doi.org/10.5194/hess-22-6473-2018

Pérez de las Heras, B. (2023). The Spanish recovery plan: assessing its contribution to the green transition in the European Union. Gestión y Análisis de Políticas Públicas. https://doi.org/10.24965/gapp.11207

Pérez Morales, A., Gil Meseguer, E., & Gómez Espín, J. M. (2014). Las aguas residuales regeneradas como recurso para los regadíos de la demarcación hidrográfica del Segura (España). Boletín de La Asociación de Geógrafos Españoles, 64. https://doi.org/10.21138/bage.1691

Phiri, L., Etale, A., & Thatcher, A. (2023). Reclaimed water systems in office buildings: Perceptions of building facilities managers. Human Factors and Ergonomics in Manufacturing & Service Industries, 33(2), 201–211. https://doi.org/10.1002/hfm.20977

Pistocchi, Alberto., Aloe, Alberto., Dorati, C., Alcalde Sanz, Laura., Vigiak, Olga., Pastori, Marco., Grizzetti, Bruna., Gawlik, Bernd., & Bouraoui, Fayçal. (2017). The potential of water reuse for agricultural irrigation in the EU : a hydro-economic analysis. Publications Office.

Poch-Massegú, R., Jiménez-Martínez, J., Wallis, K. J., Ramírez de Cartagena, F., & Candela, L. (2014). Irrigation return flow and nitrate leaching under different crops and irrigation methods in Western Mediterranean weather conditions. Agricultural Water Management, 134, 1–13. https://doi.org/10.1016/j.agwat.2013.11.017

Poirier, K., Lotfi, M., Garg, K., Patchigolla, K., Anthony, E. J., Faisal, N. H., Mulgundmath, V., Sahith, J. K., Jadhawar, P., Koh, L., Morosuk, T., & Al Mhanna, N. (2023). A comprehensive review of pre- and post-treatment approaches to achieve sustainable desalination for different water streams. Desalination, 566, 116944. https://doi.org/10.1016/j.desal.2023.116944

Polo, J. F. (2012). Recycling and Reuse of Treated Wastewater: Challenges and Perspectives – The Example of the Júcar River Basin District and the Albufera Lake. In Integrated Water Resources Management in the Mediterranean Region (pp. 195–219). Springer Netherlands. https://doi.org/10.1007/978-94-007-4756-2_11

PricewaterhouseCoopers. (2020). Impacto Económico del Trasvase Tajo-Segura. PWC. http://www.scrats.es/memorias-e-informes.html

Qin, Y., Mueller, N. D., Siebert, S., Jackson, R. B., AghaKouchak, A., Zimmerman, J. B., Tong, D., Hong, C., & Davis, S. J. (2019). Flexibility and intensity of global water use. Nature Sustainability, 2(6), 515–523. https://doi.org/10.1038/s41893-019-0294-2

Qtaishat, Y., Hofman, J., & Adeyeye, K. (2022). Circular Water Economy in the EU: Findings from Demonstrator Projects. Clean Technologies, 4(3), 865–892. https://doi.org/10.3390/cleantechnol4030054

Quon, H., & Jiang, S. (2023). Decision making for implementing non-traditional water sources: a review of challenges and potential solutions. Npj Clean Water, 6(1), 56. https://doi.org/10.1038/s41545-023-00273-7

Radcliffe, J. C., & Page, D. (2020). Water reuse and recycling in Australia — history, current situation and future perspectives. Water Cycle, 1, 19–40. https://doi.org/10.1016/j.watcyc.2020.05.005

Ramm, K., & Smol, M. (2023). Water Reuse—Analysis of the Possibility of Using Reclaimed Water Depending on the Quality Class in the European Countries. Sustainability, 15(17), 12781. https://doi.org/10.3390/su151712781

Real Decreto 1085/2024, de 22 de Octubre, Por El Que Se Aprueba El Reglamento de Reutilización de Agua., Pub. L. No. 255, Boletín Oficial del Estado (2024).

Real Decreto 1327/1995, de 28 Julio, Sobre Instalaciones de Desalación de Aguas Marinas o Salobres, Pub. L. No. 189, Boletín Oficial del Estado 24648 (1995).

Real Decreto 1620/2007, de 7 de Diciembre, Por El Que Se Establece El Régimen Jurídico de La Reutilización de Las Aguas Depuradas., n 294 Boletín Oficial del Estado (2007).

Real Decreto Legislativo 1/2001, de 20 de Julio, Por El Que Se Aprueba El Texto Refundido de La Ley de Aguas., 176 Boletín Oficial del Estado (2001).

Real Decreto-Ley 2/2004, de 18 de Junio, Por El Que Se Modifica La Ley 10/2001, Del Plan Hidrológico Nacional., Boletín Oficial del Estado 23001 (2004).

Real Decreto-Ley 4/2023, de 11 de Mayo, de Medidas Urgentes En Materia Agraria y de Aguas., Pub. L. No. 113, n 113 Boletín Oficial del Estado (2023).

Reckien, D. (2014). Weather extremes and street life in India—Implications of Fuzzy Cognitive Mapping as a new tool for semi-quantitative impact assessment and ranking of adaptation measures. Global Environmental Change, 26, 1–13. https://doi.org/10.1016/j.gloenvcha.2014.03.005

Ricart, S., Castelletti, A., & Gandolfi, C. (2022). On farmers' perceptions of climate change and its nexus with climate data and adaptive capacity. A comprehensive review. Environmental Research Letters, 17(8), 083002. https://doi.org/10.1088/1748-9326/ac810f

Ricart, S., & Rico, A. M. (2019). Assessing technical and social driving factors of water reuse in agriculture: A review on risks, regulation and the yuck factor. Agricultural Water Management, 217, 426–439. https://doi.org/10.1016/j.agwat.2019.03.017

Ricart, S., Rico, A., & Ribas, A. (2019). Risk-Yuck Factor Nexus in Reclaimed Wastewater for Irrigation: Comparing Farmers' Attitudes and Public Perception. Water, 11(2), 187. https://doi.org/10.3390/w11020187

Ricart, S., Villar-Navascués, R. A., Hernández-Hernández, M., Rico-Amorós, A. M., Olcina-Cantos, J., & Moltó-Mantero, E. (2021). Extending Natural Limits to Address Water Scarcity? The Role of Non-Conventional Water Fluxes in Climate Change Adaptation Capacity: A Review. Sustainability, 13(5), 2473. https://doi.org/10.3390/su13052473

Ricart, S., Villar-Navascués, R., Gil-Guirado, S., Rico-Amorós, A. M., & Arahuetes, A. (2020). How to Close the Gap of Desalinated Seawater for Agricultural Irrigation? Confronting Attitudes between Managers and Farmers in Alicante and Murcia (Spain). Water, 12(4), 1132. https://doi.org/10.3390/w12041132

Rich, D., Andiroglu, E., Gallo, K., & Ramanathan, S. (2023). A review of water reuse applications and effluent standards in response to water scarcity. Water Security, 20, 100154. https://doi.org/10.1016/j.wasec.2023.100154

Rodríguez-Flores, J. M., Valero Fandiño, J. A., Cole, S. A., Malek, K., Karimi, T., Zeff, H. B., Reed, P. M., Escriva-Bou, A., & Medellín-Azuara, J. (2022). Global Sensitivity Analysis of a Coupled Hydro-Economic Model and Groundwater Restriction Assessment. Water Resources Management, 36(15), 6115–6130. https://doi.org/10.1007/s11269-022-03344-5

Sadhwani Alonso, J. J., & Melián-Martel, N. (2018). Environmental Regulations—Inland and Coastal Desalination Case Studies. In Sustainable Desalination Handbook (pp. 403–435). Elsevier. https://doi.org/10.1016/B978-0-12-809240-8.00010-1

Salsabila, N., Anwar, A., Shubbar, H. T., Khan, M. I., Al-Ansari, T., & Bicer, Y. (2025). Comparative sustainability assessment of hybrid desalination systems for freshwater production. Energy Nexus, 18, 100440. https://doi.org/10.1016/j.nexus.2025.100440

Samnakay, N., Alexandra, J., Wyborn, C., & Bender, I. (2024). Climate adaptive water policy in Australia's Murray Darling basin: soft options or hard commitments? Ecology and Society, 29(1), art1. https://doi.org/10.5751/ES-14578-290101

Sánchez Navarro, A., Girona Ruiz, A., & Delgado Iniesta, M. J. (2020). Influence of intensive horticultural cultivation on soil salinity in Campo de Cartagena (Murcia). Spanish Journal of Soil Science, 10. https://doi.org/10.3232/SJSS.2020.V10.N3.03

Sánchez-Barroso, G., González-Domínguez, J., Almeida-Fernandes, J. P., & García-Sanz-Calcedo, J. (2023). A fuzzy cognitive map-based algorithm for predicting water consumption in Spanish healthcare centres. Building Simulation, 16(11), 2193–2205. https://doi.org/10.1007/s12273-023-1028-y

Sánchez-Cerdà, C., Salgot, M., & Folch, M. (2020). Reuse of reclaimed water: What is the direction of its evolution from a European perspective? (pp. 1–64). https://doi.org/10.1016/bs.apmp.2020.07.001

San-Martín, E., Larraz, B., & Gallego, M. S. (2020). When the river does not naturally flow: a case study of unsustainable management in the Tagus River (Spain). Water International, 45(3), 189–221. https://doi.org/10.1080/02508060.2020.1753395

Santos, A. F., Alvarenga, P., Gando-Ferreira, L. M., & Quina, M. J. (2023). Urban Wastewater as a Source of Reclaimed Water for Irrigation: Barriers and Future Possibilities. Environments, 10(2), 17. https://doi.org/10.3390/environments10020017

Sarmiento, I., Dion, A., Šajna, M., & Andersson, N. (2024). Four analysis moments for fuzzy cognitive mapping in participatory research. Global Health Action, 17(1). https://doi.org/10.1080/16549716.2024.2430024

Savchenko, O. M., Kecinski, M., Li, T., & Messer, K. D. (2019). Reclaimed water and food production: Cautionary tales from consumer research. Environmental Research, 170, 320–331. https://doi.org/10.1016/j.envres.2018.12.051

Schunke, A. J., Hernandez Herrera, G. A., Padhye, L., & Berry, T.-A. (2020). Energy Recovery in SWRO Desalination: Current Status and New Possibilities. Frontiers in Sustainable Cities, 2. https://doi.org/10.3389/frsc.2020.00009

Senent-Aparicio, J., López-Ballesteros, A., Cabezas, F., Pérez-Sánchez, J., & Molina-Navarro, E. (2021). A Modelling Approach to Forecast the Effect of Climate Change on the Tagus-Segura Interbasin Water Transfer. Water Resources Management, 35(11), 3791–3808. https://doi.org/10.1007/s11269-021-02919-y

Shabib, A., Tatan, B., Elbaz, Y., Aly Hassan, A., Hamouda, M. A., & Maraqa, M. A. (2025). Advancements in reverse osmosis desalination: Technology, environment, economy, and bibliometric insights. Desalination, 598, 118413. https://doi.org/10.1016/j.desal.2024.118413

Shah, M. P. ., Rodriguez-Couto, Susana., & Biswas, J. Kumar. (2022). Development in wastewater treatment research and processes : removal of emerging contaminants from wastewater through bio-nanotechnology. Elsevier.

Sheidaei, F., Karami, E., & Keshavarz, M. (2016). Farmers' attitude towards wastewater use in Fars Province, Iran. Water Policy, 18(2), 355–367. https://doi.org/10.2166/wp.2015.045

Shemer, H., Wald, S., & Semiat, R. (2023). Challenges and Solutions for Global Water Scarcity. Membranes, 13(6), 612. https://doi.org/10.3390/membranes13060612

Silva, J. A. (2023). Wastewater Treatment and Reuse for Sustainable Water Resources Management: A Systematic Literature Review. Sustainability, 15(14), 10940. https://doi.org/10.3390/su151410940

Simón, P., & Oller, I. (2024). Water Reuse in Spain: Drivers and Barriers in Murcia and Almeria Region (pp. 617–641). https://doi.org/10.1007/978-3-031-67739-7_26

Sirota, R., Winters, G., Levy, O., Marques, J., Paytan, A., Silverman, J., Sisma-Ventura, G., Rahav, E., Antler, G., & Bar-Zeev, E. (2024). Impacts of Desalination Brine Discharge on Benthic Ecosystems. Environmental Science & Technology, 58(13), 5631–5645. https://doi.org/10.1021/acs.est.3c07748

Smakhtin, V., Ashton, P., Batchelor, A., Meyer, R., Murray, E., Barta, B., Bauer, N., Naidoo, D., Olivier, J., & Terblanche, D. (2001). Unconventional Water Supply Options in South Africa. Water International, 26(3), 314–334. https://doi.org/10.1080/02508060108686924

Sneegas, G., Seghezzo, L., Brannstrom, C., Jepson, W., & Eckstein, G. (2022). Do not put all your eggs in one basket: social perspectives on desalination and water recycling in Israel. Water Policy, 24(11), 1772–1795. https://doi.org/10.2166/wp.2022.085

Soto García, M. (2015). El regadío en la Región de Murcia. Caracterización y análisis.

Soto García, M. (2020). La gestión de los recursos no convencionales en el regadío. Experiencia de la CR Campo de Cartagena.

Stephenson, W. (1980). Newton's Fifth Rule and Q methodology: Application to educational psychology. American Psychologist, 35(10), 882–889. https://doi.org/10.1037/0003-066X.35.10.882

Stylios, C. D., & Groumpos, P. P. (2004). Modeling Complex Systems Using Fuzzy Cognitive Maps. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 34(1), 155–162. https://doi.org/10.1109/TSMCA.2003.818878

Sunyer-Caldú, A., Sepúlveda-Ruiz, P., Salgot, M., Folch-Sánchez, M., Barcelo, D., & Diaz-Cruz, M. S. (2022). Reclaimed water in agriculture: A plot-scale study assessing crop uptake of emerging contaminants and pathogens. Journal of Environmental Chemical Engineering, 10(6), 108831. https://doi.org/10.1016/j.jece.2022.108831

Thilmany, E. A., Newton, S., Goeringer, P., & Rosenberg Goldstein, R. E. (2024). Reclaimed Water Use Regulations in the U.S.: Evaluating Changes and Regional Patterns in Patchwork State Policies from 2004–2023. Water, 16(2), 334. https://doi.org/10.3390/w16020334

Tolman, E. C. (1948). Cognitive maps in rats and men. Psychological Review, 55(4), 189–208. https://doi.org/10.1037/h0061626

Truchado, P., Gil, M. I., López, C., Garre, A., López-Aragón, R. F., Böhme, K., & Allende, A. (2021). New standards at European Union level on water reuse for agricultural irrigation: Are the Spanish wastewater treatment plants ready to produce and distribute reclaimed water within the minimum quality requirements? International Journal of Food Microbiology, 356, 109352. https://doi.org/10.1016/j.ijfoodmicro.2021.109352

Urkiaga, A., de las Fuentes, L., Bis, B., Chiru, E., Balasz, B., & Hernández, F. (2008). Development of analysis tools for social, economic and ecological effects of water reuse. Desalination, 218(1–3), 81–91. https://doi.org/10.1016/j.desal.2006.08.023

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Vargas, J., & Paneque, P. (2019). Challenges for the Integration of Water Resource and Drought-Risk Management in Spain. Sustainability, 11(2), 308. https://doi.org/10.3390/su11020308

Vélez-Nicolás, M., García-López, S., Ruiz-Ortiz, V., & Sánchez-Bellón, Á. (2020). Towards a Sustainable and Adaptive Groundwater Management: Lessons from the Benalup Aquifer (Southern Spain). Sustainability, 12(12), 5215. https://doi.org/10.3390/su12125215

Verma, G., Mondal, K., Islam, M., & Gupta, A. (2024). Recent Advances in Advanced Micro and Nanomanufacturing for Wastewater Purification. ACS Applied Engineering Materials, 2(2), 262–285. https://doi.org/10.1021/acsaenm.3c00711

Villacorta-Ranera, C., Eckstein, G., & Blanco-Gutiérrez, I. (2025). Challenges and prospects of reclaimed water reuse in Spanish agriculture. Water International, 1–21. https://doi.org/10.1080/02508060.2025.2485856

Villar-Navascués, R., Ricart, S., Gil-Guirado, S., Rico-Amorós, A. M., & Arahuetes, A. (2020). Why (Not) Desalination? Exploring Driving Factors from Irrigation Communities' Perception in South-East Spain. Water, 12(9), 2408. https://doi.org/10.3390/w12092408

Voutchkov, N. (2022). Desalinated Water. In Unconventional Water Resources (pp. 233–254). Springer International Publishing. https://doi.org/10.1007/978-3-030-90146-2_11

Wang, Z., Li, J., & Li, Y. (2017). Using Reclaimed Water for Agricultural and Landscape Irrigation in China: a Review. Irrigation and Drainage, 66(5), 672–686. https://doi.org/10.1002/ird.2129

Wasserman, S., & Faust, K. (1994). Social Network Analysis. In Structural Analysis in the Social Sciences. Cambridge University Press. https://doi.org/10.1017/CBO9780511815478

Watts, S., & Stenner, P. (2012). Doing Q Methodological Research: Theory, Method and Interpretation. SAGE Publications Ltd. https://doi.org/10.4135/9781446251911

White, C. T., Mitasova, H., BenDor, T. K., Foy, K., Pala, O., Vukomanovic, J., & Meentemeyer, R. K. (2021). Spatially Explicit Fuzzy Cognitive Mapping for Participatory Modeling of Stormwater Management. Land, 10(11), 1114. https://doi.org/10.3390/land10111114

Wildenberg, M., Bachhofer, M., Adamescu, M., De Blust, G., Diaz-Delgadod, R., Isak, K. G. Q., Skov F., & Riku, V. (2010). Linking thoughts to flows-Fuzzy cognitive mapping as tool for integrated landscape modeling. Proc. of the 2010 Int. Conf. on Integrative Landscape Modelling—Linking Environmental, Social and Computer Sciences, 1–15. www.symposcience.orgwww.symposcience.org

Williams, J., Beveridge, R., & Mayaux P.-L. (2023). Unconventional waters: A critical understanding of desalination and wastewater reuse. Water Alternatives, 16(2), 429–443.

Xu, M., Bai, X., Pei, L., & Pan, H. (2016). A research on application of water treatment technology for reclaimed water irrigation. International Journal of Hydrogen Energy, 41(35), 15930–15937. https://doi.org/10.1016/j.ijhydene.2016.05.020

Xu, P., Jia, Z., Ning, H., & Wang, J. (2024). Global Bibliometric Analysis of Research on the Application of Unconventional Water in Agricultural Irrigation. Water, 16(12), 1698. https://doi.org/10.3390/w16121698

Xu, X., Ness, J. E., Miara, A., Sitterley, K. A., Talmadge, M., O'Neill, B., Coughlin, K., Akar, S., Edirisooriya, E. M. N. T., Kurup, P., Rao, N., Macknick, J., Stokes-Draut, J. R., & Xu, P. (2022). Analysis of Brackish Water Desalination for Municipal Uses: Case Studies on Challenges and Opportunities. ACS ES&T Engineering, 2(3), 306–322. https://doi.org/10.1021/acsestengg.1c00326

Yalin, D., Craddock, H. A., Assouline, S., Ben Mordechay, E., Ben-Gal, A., Bernstein, N., Chaudhry, R. M., Chefetz, B., Fatta-Kassinos, D., Gawlik, B. M., Hamilton, K. A., Khalifa, L., Kisekka, I., Klapp, I., Korach-Rechtman, H., Kurtzman, D., Levy, G. J., Maffettone, R., Malato, S., … Cytryn, E. (2023). Mitigating risks and maximizing sustainability of treated wastewater reuse for irrigation. Water Research X, 21, 100203. https://doi.org/10.1016/j.wroa.2023.100203

Yazdandoost, F., Noruzi, M. M., & Yazdani, S. A. (2021). Sustainability assessment approaches based on water-energy Nexus: Fictions and nonfictions about non-conventional water resources. Science of The Total Environment, 758, 143703. https://doi.org/10.1016/j.scitotenv.2020.143703

Zabala, A. (2014). qmethod: A Package to Explore Human Perspectives Using Q Methodology. The R Journal , 163–173.

Zabala, A., Sandbrook, C., & Mukherjee, N. (2018). When and how to use Q methodology to understand perspectives in conservation research. Conservation Biology, 32(5), 1185–1194. https://doi.org/10.1111/cobi.13123

Zabala, J. A., Dolores de Miguel, M., Martínez-Paz, J. M., & Alcon, F. (2019). Perception welfare assessment of water reuse in competitive categories. Water Supply, 19(5), 1525–1532. https://doi.org/10.2166/ws.2019.019

Zarzo, D. (2020). La desalación del agua en España. Presupuesto y Gasto Público, 101, 169–188.

Zarzo, D., & Prats, D. (2018). Desalination and energy consumption. What can we expect in the near future? Desalination, 427, 1–9. https://doi.org/10.1016/j.desal.2017.10.046

Zhu, Z., & Dou, J. (2018). Current status of reclaimed water in China: an overview. Journal of Water Reuse and Desalination, 8(3), 293–307. https://doi.org/10.2166/wrd.2018.070

Zhu, Z., Peng, D., & Wang, H. (2019). Seawater desalination in China: an overview. Journal of Water Reuse and Desalination, 9(2), 115–132. https://doi.org/10.2166/wrd.2018.034

Zhuang, W. (2016). Eco-environmental impact of inter-basin water transfer projects: a review. Environmental Science and Pollution Research, 23(13), 12867–12879. https://doi.org/10.1007/s11356-016-6854-3

Zuluaga-Guerra, P. A., Martinez-Fernandez, J., Esteve-Selma, M. A., & Dell'Angelo, J. (2023). A socio-ecological model of the Segura River basin, Spain. Ecological Modelling, 478, 110284. https://doi.org/10.1016/j.ecolmodel.2023.110284

Annexes

A. Methodological details of the stakeholder-based assessment of non-conventional water for agricultural irrigation

Table S1. List of stakeholders classified by groups

Stakeholder group	**Participants**	**Stakeholder**
Public Administration	1	Segura River Basin Authority (CHS)
	2	Murcia Health Department
	1	Murcia Municipal Water and Sanitation Company (EMUASA)
Farmer associations	2	Irrigation Community Miraflores (Water User Association)
	1	Irrigation Community Campo de Cartagena (Water User Association)
	1	Central Irrigation Board of the Tajo-Segura Aqueduct (SCRATS)
Water Companies	1	AZUD (International provider of water efficiency technologies for agriculture, industry, and municipal reuse applications)
	1	SACYR Agua (International water company specializing in desalination, water treatment, purification, reuse, and integrated water cycle management for municipalities, industry, and agriculture)
	1	TRAGSA (Spanish state-owned company providing integrated solutions in rural development, environmental protection, emergency response, and advanced water management technologies for public administrations and large-scale infrastructure projects)
Environmental organizations	2	Aqua Positive (International advisory firm specializing in the development and implementation of water benefit projects and Water Positive strategies for corporate sustainability and water stewardship)
Academic and technical experts	1	Polytechnic University of Cartagena (UPTC)
	3	Technical University of Madrid (UPM)
	1	CEBAS-CSIC (Center for Soil and Applied Biology of Segura)

Table S2. FCM`s adjacency matrix.

	Good status of water bodies	Use of reclaimed water	Availability of conventional water resources for farmers	Use of desalinated water	Fertilizer needs	Supply guarantee	Agricultural income	Social acceptance of reclaimed water	Quality of reclaimed water	Cost of reclaimed water for farmers	Cost of desalinated water for farmers	Energy cost	Lack of renewable energy projects	Quality of desalinated water	Health and environmental risks	Maintenance of current allocations from the	Subsidies for desalinated water	Desalination production	Waste discharge	Lack of training	Research in desalination techniques	Lack of new desalination projects	Wastewater treatment fee	Lack of implementation of new wastewater	Water reclamation capacity
Good status of water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Use of reclaimed water	0.00	0.00	0.00	0.00	-0.40	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Availability of conventional water resources for farmers	-0.60	-0.60	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Use of desalinated water	0.00	0.00	0.00	0.00	0.20	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fertilizer needs	0.00	0.00	0.00	0.00	0.00	0.00	-0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Supply guarantee	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agricultural income	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Social acceptance of reclaimed water	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Quality of reclaimed water	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost of reclaimed water for farmers	0.00	-0.60	0.00	0.00	0.00	0.00	-0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost of desalinated water for farmers	0.00	0.00	0.00	-0.80	0.00	0.00	-0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lack of renewable energy projects	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Quality of desalinated water	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Health and environmental risks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintenance of current allocations from the conventional water resources	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidies for desalinated water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Desalination production	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Waste discharge	-0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lack of training	0.00	-0.20	0.00	-0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Research in desalination techniques	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.40	0.00	0.00	1.00	0.00	0.00	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00
Lack of new desalination projects	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wastewater treatment fee	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lack of implementation of new wastewater treatment and reuse policies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.40
Water reclamation capacity	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table S3. FCM's structural metrics.

Structural metric	**Description**	**Source**
Density (*D*)	Number of connections (*c*) divided by the maximum number of possible connections between a number *N* of concepts. $D = \frac{c}{N(N-1)}$	Hage and Haray [1]

Complexity (CM)	Number of receiver variables (R) divided by the number of transmitters (T). Receivers are variables with outdegree = 0, while transmitters are concepts with indegree = 0. $CM = \frac{R}{T}$	Özesmi and Özesmi [2]
Indegree (id)	Cumulative total of received connection weights to each concept (vertical sum within adjacency matrix).	Wasserman and Faust [3]
Outdegree (od)	Cumulative total of transmitted connection weights from each concept (horizontal cumulative sum within adjacency matrix).	Wasserman and Faust [3]
Centrality (CT)	Sum of indegree plus outdegree values, which measures the relative importance of the concept within the studied system. $CT = id + od$	Wasserman and Faust [3]
Types of components	Transmitters have id = 0; od ≠ 0 Receivers have id ≠ 0; od = 0 Ordinary id ≠ 0; od ≠ 0	Wasserman and Faust [3]

References

[1] P. Hage and F. Harary, *Structural models in anthropology*. Oxford University Press, New York, USA, 1983.

[2] U. Özesmi and S. L. Özesmi, “Ecological models based on people’s knowledge: a multi-step fuzzy cognitive mapping approach,” *Ecol. Modell.*, vol. 176, no. 1–2, pp. 43–64, Aug. 2004, doi: 10.1016/j.ecolmodel.2003.10.027.

[3] S. Wasserman and K. Faust, *Social Network Analysis*. Cambridge: Cambridge University Press, 1994.

Table S4. List of every component identified by the stakeholders in the FCM, and their desired-change category.

Dimension	**Component**	**Desired change**
Economic-Technical	Supply guarantee	Increase (positive)
	Agriculture income	Increase (*positive*)
	Cost of reclaimed water for farmers	Decrease (*negative*)
	Cost of desalinated water for farmers	Decrease (*negative*)
	Energy cost	Decrease (*negative*)
	Desalination production	Increase (*positive*)
	Water reclamation capacity	Increase (*positive*)
	Use of reclaimed water in agriculture	Neutral
	Availability of conventional water resources for farmers	Neutral
	Use of desalinated water in agriculture	Neutral
	Maintenance of current allocations from the conventional water resources	Neutral
	Subsidies for desalinated water	Neutral
	Lack of new desalination projects	Neutral
	Wastewater treatment fee	Neutral
Environmental	Good status of water bodies	Increase (*positive*)
	Fertilizer needs	Decrease (*negative*)
	Quality of reclaimed water	Increase (*positive*)
	Quality of desalinated water	Increase (*positive*)
	Waste discharge	Decrease (*negative*)
	Lack of renewable energy projects	Neutral
Socio-Institutional	Social acceptance of reclaimed water	Increase (*positive*)
	Health and environmental risks	Decrease (*negative*)
	Lack of training	Neutral
	Research in desalination techniques	Neutral
	Lack of implementation of new wastewater treatment and reuse policies	Neutral

Table S5. Centrality (indegree + outdegree) of the components

Components	Outdegree	Indegree	Centrality
Use of desalinated water	0.80	3.00	3.80
Use of reclaimed water	1.00	2.60	3.60
Cost of desalinated water for farmers	1.20	2.00	3.20
Availability of conventional water resources for farmers	1.80	1.00	2.80
Cost of reclaimed water for farmers	1.00	1.60	2.60
Quality of reclaimed water	1.60	0.60	2.20
Energy cost	1.40	0.80	2.20
Desalination production	1.40	0.80	2.20
Supply guarantee	0.80	1.20	2.00
Health and environmental risks	1.00	1.00	2.00
Research in desalination techniques	2.00	0.00	2.00
Social acceptance of reclaimed water	0.80	1.00	1.80
Quality of desalinated water	0.80	1.00	1.80
Agricultural income	0.00	1.80	1.80
Waste discharge	0.20	1.40	1.60
Good status of water bodies	0.00	1.20	1.20
Maintenance of current allocations from the conventional water resources	1.00	0.00	1.00
Wastewater treatment fee	1.00	0.00	1.00
Lack of implementation of new wastewater treatment and reuse policies	1.00	0.00	1.00
Lack of renewable energy projects	0.80	0.00	0.80
Lack of new desalination projects	0.80	0.00	0.80
Water reclamation capacity	0.40	0.40	0.80
Fertilizer needs	0.20	0.60	0.80
Subsidies for desalinated water	0.60	0.00	0.60
Lack of training	0.40	0.00	0.40

B. Methodological details of the evaluation of NCW as an alternative to traditional water source

Table S6. Other Data of crops of CRCC.

Crop	Yield (t/ha)	Price (€/t)	Basic payment (€/ha)	Cost[2] (€/ha)
Artichoke	4315 (12%)	8223	3871	0.64
Cauliflower	4154 (11%)	7175	2396	0.17
Lettuce-Melon[1]	7078 (19%)	13989	5434	0.40
Pepper	2347 (6%)	40618	5397	1.48
Lemon tree	6878 (18%)	4792	5733	0.60
Fallow	12493 (34%)	0	0	

[1]Data averages between the two crops were considered.

[2]Cost does not include labor or water costs.

Sources: CARM (2024), MAGRAMA (2016), MAPA (2022) and Del Villar García et al. (2020)

Table S7. Monthly Distribution of Crops in Soil (CRCC).

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Artichoke	1	1	1	1	1	0	0	1	1	1	1	1
Cauliflower	1	1	1	0	0	0	0	0	1	1	1	1
Lettuce-Melon	1	0	1	1	1	1	1	1	0	1	1	1
Pepper	1	1	1	1	1	1	1	1	0	0	1	1
Lemon tree	1	1	1	1	1	1	1	1	1	1	1	1
Fallow	1	1	1	1	1	1	1	1	1	1	1	1

Source: Guerrero et al. (2019)

Analysis of salinity (based on (Instituto Valenciano de Investigaciones Agrarias, 2010)

The salinity of irrigation water affects crop yield. In the case study of the CRCC, water sources have the following salinities:

Table S8. Salinity of water sources.

Water Sources	Salinity (ds/m)
Surface water	2.41
Tagus-Segura Transfer	0.8
Reclaimed water	3.6
Desalinated water	0.51
Assignment of rights	2.76
Brackish water desalination plant	5
Groundwater	4.24

Source: Soto García (2020), Soto García (2015), Martínez-Alvarez et al. (2023) and Sadhwani Alonso & Melián-Martel (2018)

To study how salinity affects yield, Maas & Hoffman (1977) carried out a classification of crop tolerance based on the threshold value of ECe (Electrical Conductivity measured in the saturation extract) from which production begins to decrease significantly and also on the degree of production reduction depending on the increase in soil salinity. With the idea of quantifying, this relative yield can be expressed as a function of the electrical conductivity in the saturation extract, ECe, by the following mathematical equation:

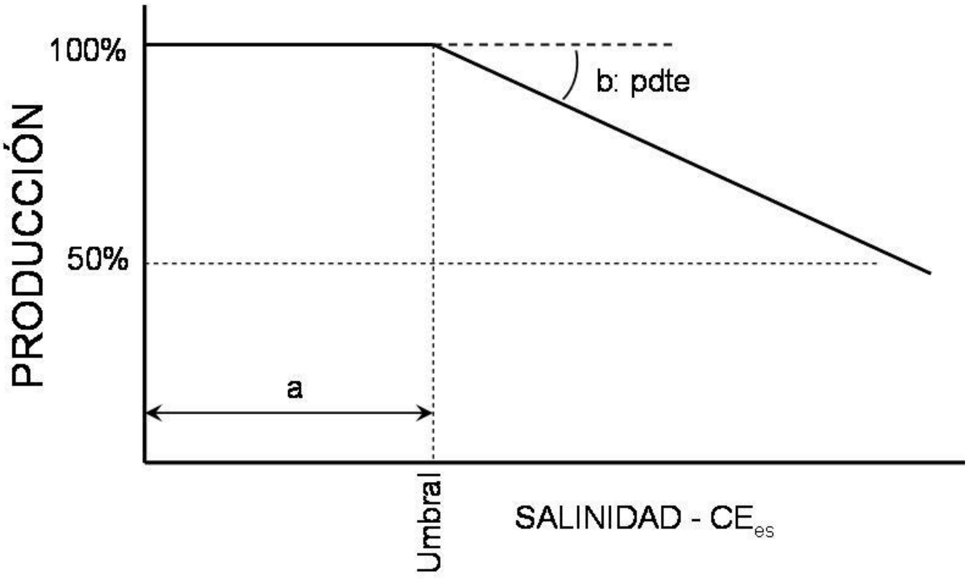

Figure S1. Effect of irrigation water salinity on crop yield reduction. Source: (Instituto Valenciano de Investigaciones Agrarias, 2010)

Where:

a: is the threshold electrical conductivity of the soil (ECe) beyond which the crop starts losing yield due to salinity.

b: is the slope of the line, indicating the percentage of crop yield loss as a function of the increase in soil salinity.

Table S9. Salinity of crops.

Crop	a	b	Type of tolerance
Artichoke	6.1	11.5	Moderately sensitive
Cauliflower	2.3	7.7	Moderately sensitive
Lettuce-Melon[1]	1.48	11.09	Moderately sensitive
Pepper	1.5	11.04	Sensitive
Lemon tree	1.5	19	Moderately sensitive

[1] Data averages between the two crops were considered.

Source: Soto García (2015; 2020), Martínez-Alvarez et al. (2023) and Sadhwani Alonso & Melián-Martel (2018)