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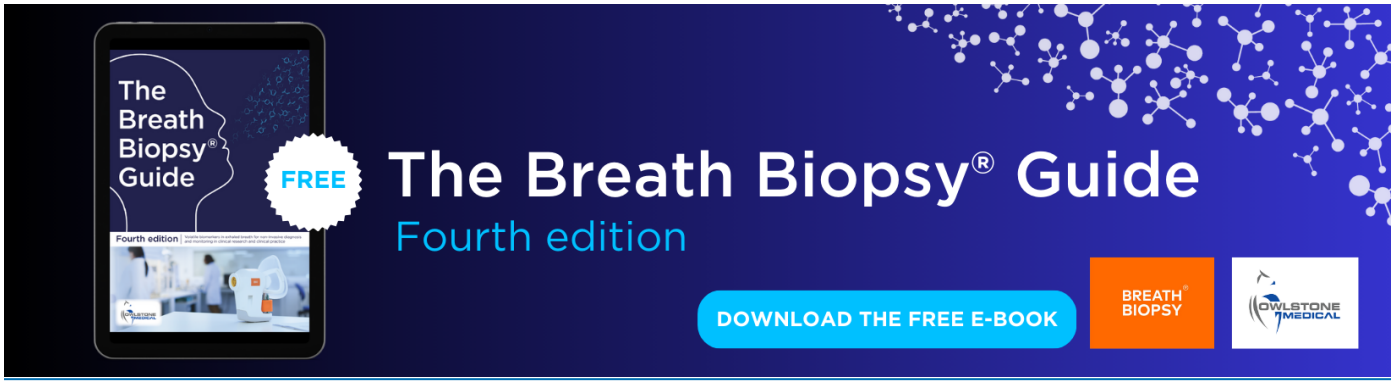

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Using reclaimed water to cope with water scarcity: an alternative for agricultural irrigation in Spain

Mario Ballesteros-Olza[1,*], Irene Blanco-Gutiérrez[1,2], Paloma Esteve[1,2], Almudena Gómez-Ramos[3] and Antonio Bolinches[4]

[1] CEIGRAM, Universidad Politécnica de Madrid, Senda del Rey 13, 28040 Madrid, Spain
[2] Department of Agricultural Economics, Statistics and Business Management, ETSIAAB, Universidad Politécnica de Madrid, Campus Ciudad Universitaria, Av. Puerta de Hierro 2-4, 28040 Madrid, Spain
[3] Department of Agricultural and Forestry Engineering, Universidad de Valladolid, Av. de Madrid 57, 34004 Palencia, Spain
[4] Universidad Politécnica de Madrid, Ramiro de Maeztu 7, 28040 Madrid, Spain
[*] Author to whom any correspondence should be addressed.

E-mail: mario.ballesteros@upm.es

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Abstract

In water-stressed agricultural regions, reuse of reclaimed water has emerged as a promising alternative that improves supply reliability, alleviates water scarcity and contributes to circular economy. The European Union has recently launched several initiatives to facilitate the adoption of water reuse for irrigation. However, its adoption is still far below its potential in most areas. This is the case of the Western La Mancha aquifer, in central Spain, where reclaimed water reuse is considered an alternative source to groundwater that may contribute to reduce overexploitation. A stakeholder-based fuzzy cognitive map (FCM) was developed to provide insights into the current situation of reclaimed water reuse in this area, as well as to explore the outcomes of different simulated scenarios (*cost recovery, agricultural transformation, social awareness* and *political will increase*). The FCM-based dynamic simulations showed that political will increase would generate the highest increase of reclaimed water reuse in agriculture in the study area, providing the highest increase of water reuse in agriculture. Agricultural extensification and increased social awareness delivered similar positive outcomes, however, only public awareness campaigns would increase water reuse, with agricultural extensification outcomes being more oriented towards the reduction of water abstractions and pollution. The cost recovery scenario was the only one that resulted in non-desired changes, mainly caused by reduced farmers' income due to higher costs of reclaimed water. Finally, the analysis also evidenced the key role that the newly enacted EU Water Reuse Regulation may play in promoting reclaimed water use, even reversing the negative outcomes of the cost recovery scenario.

1. Introduction

In a context of growing pressures over water resources, reclaimed water reuse emerges as a promising solution for irrigation agriculture that may result in a more sustainable use of water resources [1]. In addition to preserving freshwaters, reclaimed water can provide supply reliability and contribute to nutrient recycling and circular economy [2, 3].

Several international initiatives, like the UN 2030 Agenda for Sustainable Development [4] or the EC Circular Economy Action Plan [5], set among their goals the expansion of reclaimed water reuse. Also, the recently approved *EU Regulation 2020/741* [6] aims to contribute to the wider and safer adoption of the practice for irrigation agriculture by homogenizing the reclaimed water quality standards and water risk management systems across all EU Member

States [7]. However, despite a significant effort has been made in the EU, especially in water scarce countries such as the Mediterranean [8–10], only a small part (around 2.4%) of treated wastewater is currently being reused [11].

Numerous barriers, shaped by complex interrelationships between technological, economic, and socio-political factors, still prevent the widespread implementation of water reuse [12]. Technical difficulties to implement a water reuse infrastructure, including the choice of treatment technologies and the distribution of wastewater and its storage, can hinder the uptake of reclaimed water use [13]. In addition, trade barriers for food products grown with reclaimed water and the high cost of reclaimed water compared to natural water resources often make water reuse more expensive and less attractive to farmers [14, 15]. Along these lines, many studies underline that the main challenges associated with reclaimed water are social and institutional rather than technical or economic [16, 17]. Empirical evidence suggests that the lack of supportive institutional frameworks, poor leadership and concerted policy efforts may jeopardize the implementation and upscaling of water reuse schemes [18, 19]. Moreover, public concern over pathogens and risks (real or perceived) to public health and the environment are a serious obstacle to greater acceptance of water reuse [20, 21].

The existing literature on reclaimed water use have tended to be context-specific, underscoring the need to consider local contexts in the design and development of water reuse projects [12]. Nevertheless, most studies are scattered on individual cases that ignore the multiple relationships between barriers (and drivers) and stakeholder views in the decision-making process [16]. In particular, previous studies investigating public attitudes towards the use of reclaimed water for irrigation have been based on the perceptions of certain groups of stakeholders, like farmers (e.g. [20, 22]), consumers (e.g. [21, 23]) or both [24], overlooking the vision of other key stakeholder groups (e.g. policymakers, business companies, and environmental groups). Very few studies consider more integrated approaches that include the perceptions of all relevant stakeholder groups [7, 25].

The objective of this study is to examine the perceptions of major stakeholders (public administration, environmental groups, farmer associations, food retailers, consumer organizations, water treatment companies and water reuse experts) concerning the direct or indirect interactions of variables influencing the current and future state of water reuse in the Western La Mancha aquifer. By using a multi-stakeholder perspective, the study aims to provide a comprehensive overview of reclaimed water use in agriculture and thus complement the existing literature.

In particular, we use participatory fuzzy cognitive maps (FCMs) to outline the many interconnected factors affecting water reuse as a water management strategy. FCMs are powerful tools for modeling casual relationships, such as those inherent to complex water systems [26, 27]. In addition, they can simulate a wide range of policy scenarios and decision processes and combine different stakeholder opinions to better represent domain knowledge [28].

In this study, FCMs have been applied to the region of the Western La Mancha aquifer, in the Upper Guadiana basin (central Spain). This is an emblematic region where agricultural development has largely contributed to the overexploitation of the aquifer and the degradation of the associated wetland ecosystems [29]. Previous studies in the area have investigated the potential of reclaimed water to replace groundwater extractions and alleviate pressure on water resources [13], in line with the Guadiana River Basin Management Plan, which only allows the use of reclaimed water when it substitutes existing groundwater withdrawal rights [30]. However, no study has yet examined the different factors affecting water reuse, including barriers and drivers. This paper addresses this issue and analyzes how specific (simulated) changes at economic, agricultural, social, institutional, and normative level may affect water reuse in the Western La Mancha aquifer.

The study provides an integrated perspective, and locally relevant and contextual information on the potential use of reclaimed water for irrigation to enhance water security and environmental sustainability. In addition, although this is a context-specific study, findings can be extrapolated to other settings. The dynamic analysis of the FCM and the assessment of alternative scenarios provides solid scientific evidence to support water policy decisions for the promotion of reclaimed water reuse for agriculture, and may contribute to improve knowledge and awareness about water reuse in agriculture and increase stakeholder acceptance. Furthermore, the study provides insights into practical implementation issues and enablers that can support the development of water reuse projects. It helps to identify the most important aspects to check before launching a water reuse project as perceived by stakeholders, emphasizing the need for transparent and quick administrative procedures.

2. Case study

The study is applied to the case of the Western La Mancha aquifer, in the Upper Guadiana Basin, in central Spain (figure 1). The aquifer has been the focus of many previous water management research works (e.g. [29, 31–34]). It is a paradigmatic example of conflicting interests between agricultural development and environmental conservation that led to social and institutional dissension [32]. In this

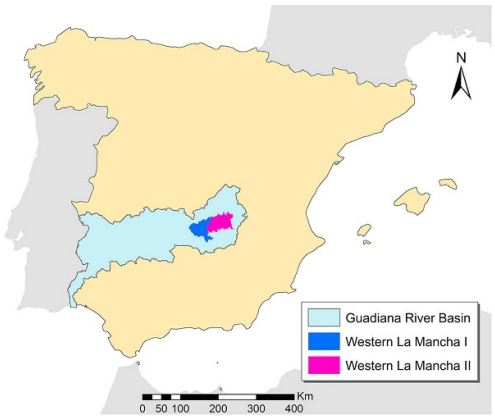

Figure 1. Location of the study area.

region, groundwater-based irrigation development over the second half of the 20th century fostered rural socio-economic development [29]. However, it led to the overexploitation of the two groundwater bodies, Western La Mancha I and Western La Mancha II, included in the aquifer, and severely damaged the associated wetland ecosystem of Las Tablas de Daimiel [34].

The lowering of groundwater level forced the Water Authority to legally declare the overexploitation of the aquifer and to restrict water abstraction for irrigation, effectively reducing water rights held by irrigators [31]. According to this new regime, a quota-based scheme was established with water allotments ranging between 2000 and 2200 m^3 ha yr^{-1} for herbaceous crops and 1500 m^3 ha yr^{-1} for permanent crops [33]. These quotas have been subsequently reduced due to drought conditions down to 1800 m^3 ha yr^{-1} and 1350 m^3 ha yr^{-1} for herbaceous and permanent crops respectively in 2021. Farmers' unrest and opposition has increased as they claim to bear the whole burden of the measures, resulting in significant reductions in farm profitability [33]. This makes it difficult for the Water Authority to enforce the policy and to control compliance, resulting in delays in the recovery of the water table and ecosystems.

In such a water stressed environment, and in a context where European and national policy initiatives encourage the adoption of water reuse, the River Basin Management Plan allows the reuse of reclaimed water to substitute agricultural or industrial groundwater rights [30], i.e. the total amount of consumed water would remain constant, but sources would diversify. Even if the potential for reclaimed water reuse in this inland area is small [13], there are two successful initiatives in the area (Los Auriles and La Serna) that exploit reclaimed water for the irrigation of permanent crops (vineyards and olives). These initiatives show that water reuse for irrigation presents clear advantages for users in this region [13]: (a) reclaimed water flows are constantly produced from urban wastewater, and allotments are constant (e.g. 1500 m^3 ha yr^{-1} in the case of Los Auriles) as they do not depend on precipitation; and (b) nutrient concentration in reclaimed water reduces crop fertilization needs and thus, saves costs to farmers. As a result, many farmers in the study area are calling for the expansion of water reuse projects and have gained the support of water companies and farmers associations. Despite this, the water authority remains reluctant to increase water reuse in the area. Environmental groups warn that, in inland basins, reduced surface water flows due to decreased return flows from wastewater treatment plants may threaten downstream ecosystems.

The presence of different perspectives over the use of reclaimed water for agricultural irrigation evidence the need to improve understanding on the water reuse system in the Western La Mancha aquifer. FCMs can contribute to this as they can be developed through stakeholder participation incorporating the distinct perspectives of different groups into a single vision.

3. Methodology

3.1. Development of FCM

FCMs are weighted directed graphs used to represent causal relationships among variables (or concepts, *C*) within a system, as perceived by a person or a group of people [26]. These relationships among the system's concepts are weighted with fuzzy values ranging from −1 to +1 [35], where negative values close to −1 represent a strong negative influence, positive values close to +1 illustrate a strong positive connection, and values close to 0 mean that there is a weak relationship between the linked concepts.

This mapping technique has been applied to numerous disciplines, such as engineering, medicine and politics [36]. Recently, it has also been used to analyze socio-ecological systems [37], as well as to support water management [27, 38]. In the last years, they have gained relevance because of their simplicity, flexibility to model design, and capacity to be integrated with quantitative models and stakeholders' views [36, 37]. FCMs can also support scenario development and enhance communication by representing in a simple manner complex issues including feedback loops and system dynamics [28].

In this study, a FCM was developed to visualize the perceptions of stakeholders concerning the interactions of variables that influence the current and future state of water reuse in the Western La Mancha aquifer. The steps implemented as part of the methodology are illustrated in figure 2. The FCM was built based on the contributions offered by representatives of key stakeholder groups, linked in different ways to the use of reclaimed water for irrigation in the Western La Mancha aquifer. A total of 20 stakeholders were involved, representing the following groups:

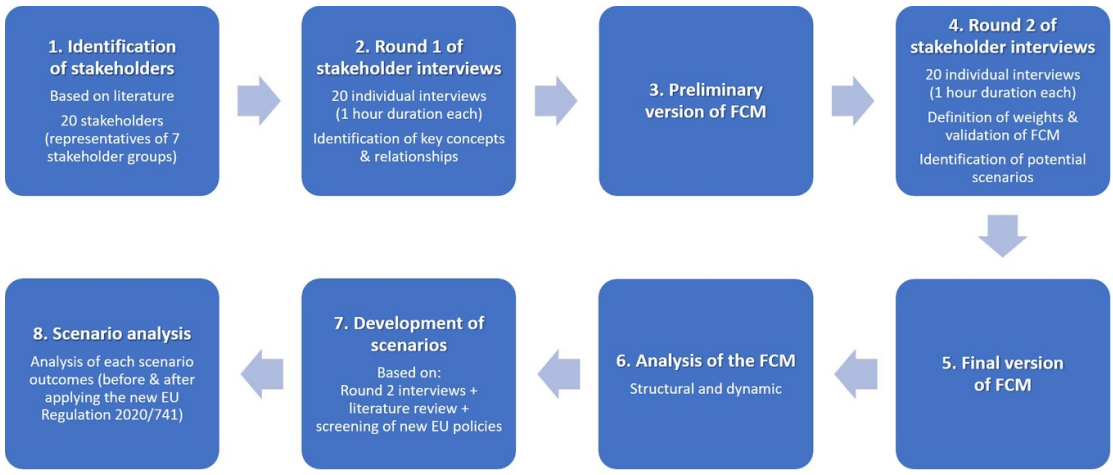

Figure 2. Methodological steps in the research.

public administration, environmental NGOs, farmer associations, food retailers, consumer organizations, water treatment companies, as well as water reuse experts. These groups were identified based on literature review [7] and previous experience in the study area [13, 39]. Table S1 presents the stakeholder groups consulted, including their representatives.

The next step of this process consisted in a round of interviews, which took place during March 2022. The individuals involved in the interviews did not feel obligated to participate in the process and verbal consent was asked. The interviewees were informed that their responses were being used for the specified purpose of representing the current water reuse system in the basin. They were also informed that their responses would only be presented in an aggregated way and not be used in any way that would allow the identification of individual responses. Interviews lasted about an hour each.

In this first round of interviews, the stakeholders were individually asked to identify the key concepts that could have an impact on (or be impacted by) the state of water reuse in agriculture in the Western La Mancha aquifer (table S2). Stakeholders were also asked about the direction (from C_i to C_j or vice versa) and sign (positive or negative) of the connections among these concepts. Based on the information gathered during these interviews, a preliminary version of the FCM was built, which included the concepts and connections identified by the stakeholders, with connections weight still missing.

A second round of 1 h interviews with the same stakeholders was carried out during May 2022, where the stakeholders were asked to review and validate the preliminary version of the FCM, as well as to determine the weight of each connection by using a Likert scale [40] from 1 to 5 (or −1 to −5) to measure the strength of these connections (table 1), as per Solana-Gutiérrez *et al* [38]. The final weight (w_{ij}) for each connection was calculated as the average value of each stakeholder group's medium values (to avoid the FCM being biased by the visions of stakeholders' groups with more interviewees). During this second round of interviews, stakeholders were also invited to offer their perspectives on possible futures, serving as input for scenario development and simulation.

Table 1. Interpretation of the causal connections established by stakeholders among the system's concepts.

Connection's strength (by stakeholders)	Linguistic weight	Interpreted crisp weight
−5	Negatively very strong	−1
−4	Negatively strong	−0.8
−3	Negatively medium	−0.6
−2	Negatively weak	−0.4
−1	Negatively very weak	−0.2
0	No causal relationship	0
1	Positively very weak	0.2
2	Positively weak	0.4
3	Positively medium	0.6
4	Positively strong	0.8
5	Positively very strong	1

As a result of this participatory process, the graph's $n \times n$ adjacency matrix (**W**) was obtained (formed by every w_{ij}) (table S3), where n represents the total number of concepts included in the FCM.

3.2. FCM analysis

To begin with the analysis, the map structure was reviewed based on typically used FCM indices, such us number and type of concepts, number of connections, connections per concept, density,

complexity, indegree, outdegree and centrality (table S4).

Second, FCM was used to make predictions on how the studied system performs or operates [41], therefore supporting scenario development [28]. These predictions are made by carrying out an inference process in which the adjacency matrix is multiplied by a $1 \times n$ state vector ($\mathbf{A}$) over multiple iterations (k). For this iteration process, Kosko's activation rule with self-memory (equation (1)) was applied, as proposed by Stylios and Groumpos [42]:

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

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

Also, a sigmoid function (equation (2)) was applied to facilitate the convergence of the system in each iteration step. This function squashes its content in the interval [0, 1], which hinders quantitative analysis, but enables qualitative comparisons between concepts and among scenarios [43]:

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

where λ is a real positive number that determines the slope of the function. In this case, the value is set to $\lambda = 1$.

This dynamic behavior of FCMs allows to: (a) analyze how the concepts interact between them, over multiple iterations, until the system reaches a new steady state at equilibrium (steady state condition or baseline scenario); and (b) simulate different scenarios to assess how the system responds (compared to the baseline scenario) to specific incentives, impacts and transformations, which might be related to economic, institutional, environmental and/ or social aspects, among others.

To calculate the baseline scenario, the concepts' starting values (or activation vector, $\mathbf{A}_0$) can either be set to one (unit-vector) or set according to assumptions about each concept's current state [48]. In this case, the unit-vector was used as the activation vector, as per Wildenberg *et al* [49], as all concepts were defined considering their current state.

Furthermore, in order to simulate the different scenarios, the values of specific concepts (generally, drivers of the system able to provoke changes with an increase/decrease of their baseline values) were fixed throughout all iterations [49]. Following Reckien [50] and Blanco-Gutiérrez *et al* [37], these values were fixed between 0 and 1, according to the magnitude of the simulated change in each scenario (i.e. fixed values close to 1 represent strong increases, those close to 0 indicate strong decreases, while intermediate values denote less intense changes in the altered concepts). In this study, four different scenarios were simulated: (a) *Cost recovery*; (b) *Agricultural transformation*; (c) *Social awareness*; (d) *Political will increase*. These scenarios were proposed based on the information gathered during the second round of interviews (stakeholders were asked 'what changes in the system could have an impact in the level of water reuse for agriculture in the region?', and most mentioned topics were considered as potential scenarios), existing prospects or guidelines from the new EU policies, and previous related findings in the literature. Table 2 presents a brief description of each scenario, as well as the concepts and values used to represent the changes in the system with respect to the baseline scenario. Additionally, the effects of the compliance with the EU Regulation 2020/741 on minimum requirements for water reuse [6] were analyzed for every simulated scenario. This driver was fixed to 0.1 (baseline value >0.6), to represent a strong decrease of the lack of compliance with this regulation due to its application.

To analyze the outcomes of each simulated scenario, the relative changes of the system concepts were presented both individually and in an aggregate form. To aggregate these changes, concepts were categorized as positive (an increase in their value is perceived as positive for the system), negative (an increase in their value is perceived as negative for the system) or neutral [50] (table S2). Following Blanco-Gutiérrez *et al* [37], the aggregate values were obtained by subtracting the relative changes' sum of negative concepts from the relative changes' sum of positive concepts. The FCMapper tool, developed by Wildenberg *et al* [49], was used to carry out the dynamic and scenario analysis. It should be noted that FCMs are considered a semi-quantitative method, meaning that their outcomes can only be interpreted in relative terms [28]. Thus, observed effects during the analysis can only be compared within the system and not with absolute indicator values [37, 50].

4. Results

4.1. Structure analysis of FCM

The resulting FCM is presented in figure 3. It has been graphed using the Mental Modeler tool [51], where blue and orange arrows indicate positive and negative relationships, respectively. As shown in table 3, the stakeholders identified 26 variables and established 36 connections to characterize the system under study, and, as a result, the FCM presents 1.385 connections per concept.

According to the variables' indegree (id) and outdegree (od) values (figure 4), the system is characterized by eight drivers ($id = 0$; $od > 0$), 2 receivers ($id > 0$; $od = 0$) and 16 ordinary concepts

Table 2. Summary of all the simulated scenarios.

Scenario	Description	Concept	Value change (compared to baseline scenario)	Fixed value
Cost recovery	This scenario aims to accomplish the principle of full cost recovery, in line with Article 9 of the EU Water Framework Directive [44], by removing from the system agricultural subsidies associated to water reuse. Stakeholders considered this a key issue as it could increase the cost of reclaimed water for famers.	Agricultural subsidies related to water reuse	Decrease (−0.66)	0.0
Agricultural transformation	This scenario reflects a transformation of the current agricultural model towards a more extensive one (less water-consuming crops, etc.). Following the prospects of the new EU policies (e.g. the Green Deal [45], and the Farm to Fork strategy [46]), stakeholders indicated that the current model of agriculture intensification should be transformed and made green again. Water reuse is considered part of this transformation.	Agricultural intensification	Decrease (−0.36)	0.3
Social awareness	This scenario simulates the implementation of advertising and media campaigns to raise awareness of the benefits of water reuse. In line with Saliba *et al* [24] and Po *et al* [47], stakeholders believe that there is room for improving public awareness and that this is key to increase the acceptance of reclaimed water use.	Lack of social awareness campaigns	Decrease (−0.56)	0.1
Political will increase	This scenario simulates a political will increase oriented towards easier and quicker paths to request and implement water reclamation projects. In line with Reymond *et al* [18], stakeholders highlighted that water reuse projects are often hampered by a lack of institutional coordination and weak political support. Increased political will could reverse this situation and help promote water reuse.	Lack of political will	Decrease (−0.56)	0.1

($id > 0$; $od > 0$). The low complexity score (0.25) denotes a reduced number of receivers (compared to drivers) identified by stakeholders, which could be interpreted as the system being notably hierarchical.

The stakeholders identified concepts related to the institutional and legal framework, the costs of water reclamation, the overexploitation of the Western La Mancha aquifer, the environmental condition of water bodies, the social acceptance of reclaimed water for irrigation, and other variables related to farmers' income, among others (figure 3). The centrality (CT) ranking provided in figure 4 highlights the water reuse in agriculture concept as the most important within the system (CT = 6.3), which was expected considering it is the variable under study, followed by the farmers' income (CT = 3.9), as well as other variables like the cost of reclaimed water for farmers, the good status of water bodies and those related to the aquifer water abstraction (all of them with centrality values over 2.5).

4.2. Dynamic analysis of FCM

4.2.1. Baseline situation

Figure 5 presents the steady state value of all the system concepts after 20 iterations. The baseline situation of the system is mainly characterized by the poor status of water bodies (Good status of water bodies <0.4), and low levels of water reuse in agriculture (≈0.2).

A more in-depth look at the results reveals how this poor environmental condition of water bodies is strongly related to a high aquifer overexploitation (>0.8), which, in turn, is caused by high water demands from the intensive agriculture (>0.6), as well as the effects of clime change (>0.6), such as the increase of droughts' intensity and periodicity.

In addition, the results show that the low level of water reuse in agriculture in the aquifer relates to a lack of political will (>0.6), which hinders the implementation of this type of projects, and to a

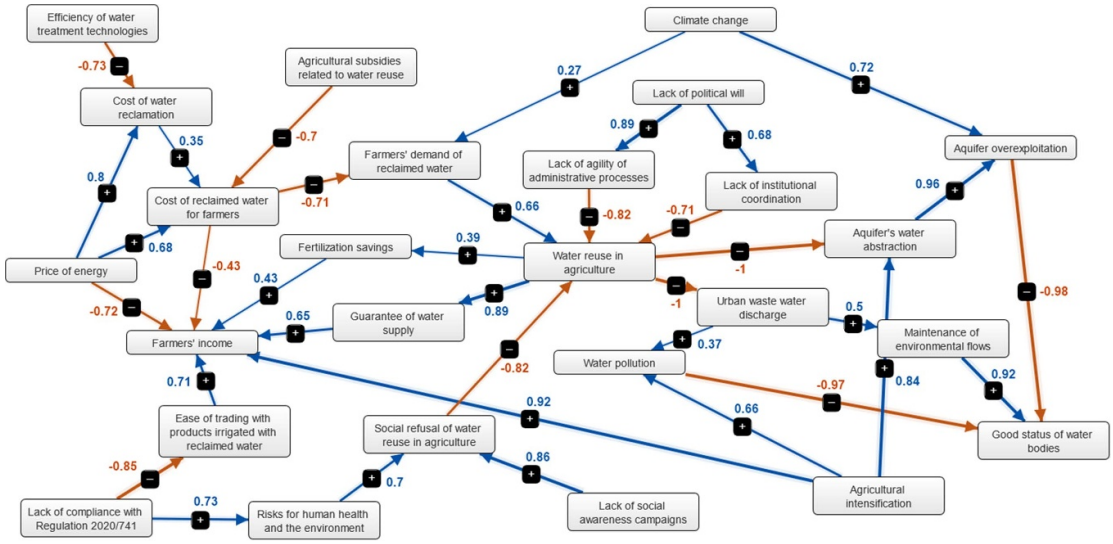

Figure 3. Fuzzy cognitive map developed by stakeholders in the region of the Western La Mancha aquifer. Blue lines represent positive connection weights and red lines negative connection weights.

Table 3. FCM structural metrics.

Index	Value
Concepts	26
Connections	36
Density	0.055
Connections per concepts	1.385
Drivers	8
Receivers	2
Ordinary concepts	16
Complexity	0.25

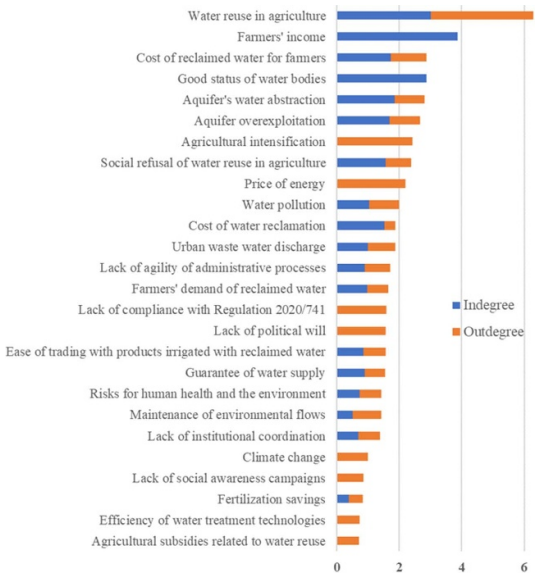

Figure 4. Concept importance in the system, according to their centrality (indegree + outdegree).

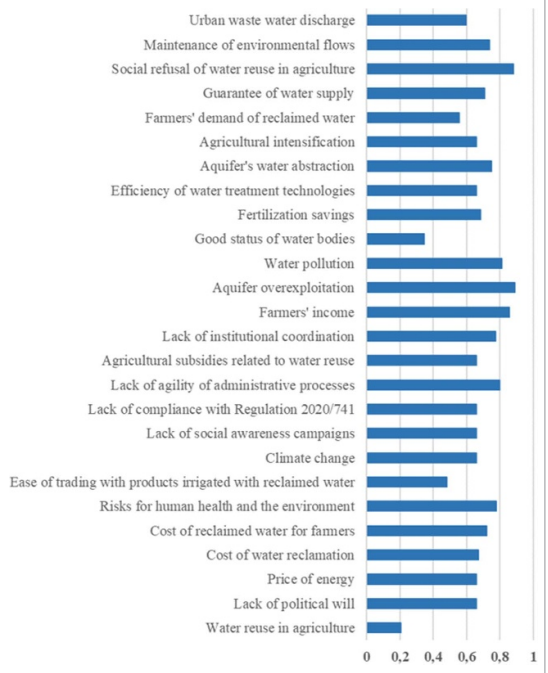

Figure 5. Steady state values of the variables under baseline conditions.

high social rejection of reclaimed water (>0.8). At the same time, this low acceptance of reclaimed water is associated to the lack of social awareness campaigns (>0.6), as well as to the perceived risks for humans and the environment (≈0.8) that derive from the current non-application of the EU Regulation 2020/741.

4.2.2. Scenario outcomes

For each simulated scenario, the relative changes of each concept (compared to their baseline values) are presented in aggregate (figure 6) and individual form (figure 7). Both figures 6–7 show scenario outcomes, without ('Before R. 2020/741') and with ('After R. 2020/741') the compliance of the EU Regulation

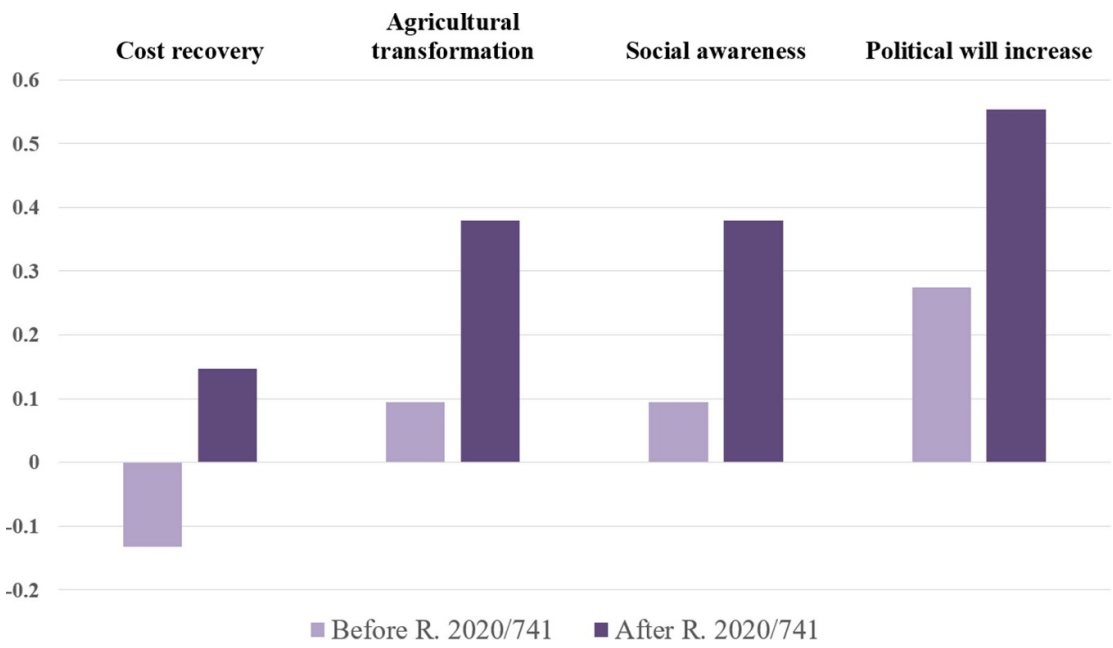

Figure 6. Aggregate relative changes in the system in each simulated scenario, compared to the baseline scenario. Light-purple bars refer to scenario outcomes before the application of the new EU Regulation 2020/741 ('Before R. 2020/741'), while dark-purple bars refer to the outcomes that include the effects of compliance with this new regulation ('After R. 2020/741'). Positive values indicate desired changes and negative values denote non-desired changes in the system.

2020/741 to simulate the effect of its soon-to-be mandatory application (from June 2023). Besides, the relative changes of the driver variables that were fixed to simulate each scenario were excluded from these figures, to narrow down the analysis to just the concepts that were affected by the simulated changes in each scenario.

As shown in figure 6, the *cost recovery* scenario is the only one that presents a negative aggregate change (−0.13) (i.e. a non-desired change for the system). On the opposite side, the *political will increase* scenario has the biggest desired change in the system (+0.27). The other two scenarios (*agricultural transformation* and *social awareness*) also provide desired systemic changes (both +0.09), but three times smaller than the *political will increase* scenario.

Looking at the effects of compliance with the EU Regulation 2020/741 (dark-purple bars in figure 6), the four scenarios present positive changes. Each scenario maintains its relative ranking: the *political will increase* scenario at the top (+0.55); the *cost recovery* one at the bottom (+0.15); and the other two in the middle, with similar values (+0.38). Further, the four scenarios received a similar boost in absolute terms (between +0.28 and +0.29) because of compliance with the new regulation, which shortened the differences among their outcomes in relative terms. Thus, while the aggregate positive change in the system driven by the *political will increase* scenario is three times bigger than that by the *agricultural transformation* and *social awareness increase* scenarios, when the new water reuse regulation is applied, the aggregate positive change driven by the *political will increase* scenario becomes 1.4 times bigger than that of the other two.

Figure 7 presents the values of relative change compared to the baseline scenario for each concept and each simulated scenario. As it can be seen, the *cost recovery* scenario shows a sharp increase in the cost that farmers pay for the reclaimed water, which has a negative impact on both their income and demand for water reuse projects, leading to a slight decrease in water reuse in agriculture. However, the implementation of the new regulation mitigates the negative effect on farmers' income caused by the augmented cost of reclaimed water. This is due to the homogenization of water quality standards for water reuse in agriculture in all EU Member States and, consequently, to the greater ease of regional (EU) trade with products irrigated with reclaimed water.

In addition, when the new regulation on water reuse is applied in this scenario, the decrease in water reuse in agriculture is slightly reduced due to an improvement of social acceptance resulting from reduced risks for humans and the environment.

The scenario of *agricultural transformation* originates desired changes in the environmental part of the system, mainly thanks to the reduction of water abstraction from the aquifer, as well as to the decrease of water pollution, both contributing to the improvement of the environmental status of the water bodies. Nonetheless, as a trade-off for these environmental benefits for the system, farmers' incomes decrease because of the less intensive agricultural activity. Looking at the effects of compliance with the EU Regulation 2020/741 for this scenario, the decrease in

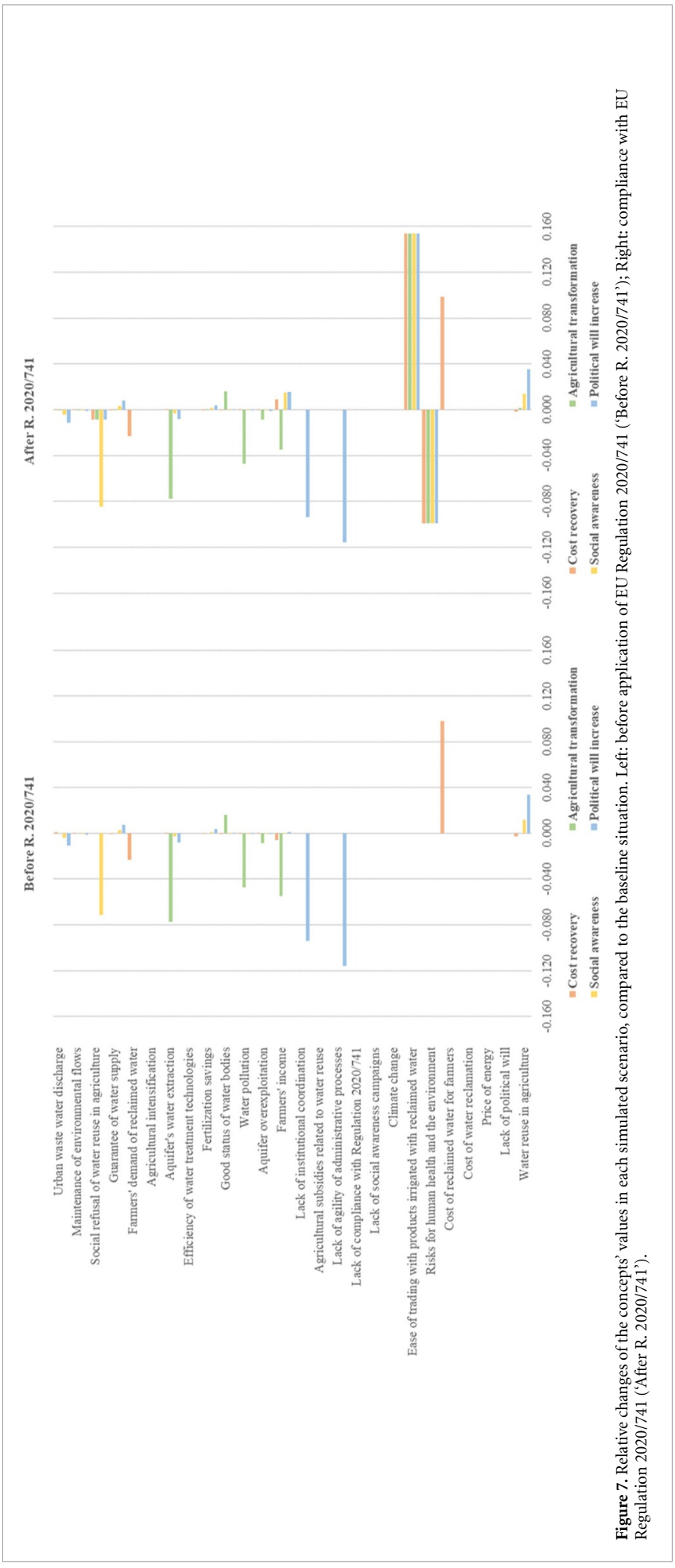

Figure 7. Relative changes of the concepts' values in each simulated scenario, compared to the baseline situation. Left: before application of EU Regulation 2020/741 ('Before R. 2020/741'); Right: compliance with EU Regulation 2020/741 ('After R. 2020/741').

farmers' income is mitigated by the ease of trading products irrigated with reclaimed water with other EU countries.

The *social awareness* scenario focuses its impact on the variable related to the social rejection of reclaimed water for irrigation, reducing it thanks to the simulated social awareness campaigns. By improving public acceptance, water reuse in agriculture shows the second largest increase of the four scenarios. Moreover, if the effects of the compliance with the new European regulation are added, this increase in water reuse in agriculture in the system is even higher.

The *political will increase* scenario presents the highest increase in water reuse in agriculture. This in turn translates into positive changes in concepts like the increase of the guarantee of water supply and fertilization savings, and the decrease in the aquifer water abstractions. This can be explained by the fact that political will is one of the drivers most directly and strongly related to water reuse in agriculture, due to the key role that the Administration can play in promoting and implementing water reclamation projects for irrigation. In addition, as in the case of the *social awareness* scenario, the implementation of the new regulation on water reuse in agriculture further increases water reuse in agriculture.

5. Discussion and conclusions

We developed a participatory FCM to examine stakeholder perceptions towards reclaimed water use in agriculture, with the aim of providing a better understanding of the state and the prospects of this resource in the region of the Western La Mancha aquifer, in the Upper Guadiana Basin. This is particularly relevant in this water-stressed area, where water reuse in agriculture may contribute to partially alleviate the pressure on the overexploited aquifer and its associated wetland ecosystems. The analysis used the combination of knowledge from major stakeholder groups, offering locally relevant and contextual information on the potential use of reclaimed water from urban wastewater treatment plants for irrigation to enhance water security and environmental sustainability.

Our findings reveal that reclaimed water is seen as a promising alternative supply source to balance water for rural livelihoods and water for conserving ecosystems. However, its use is deemed to be low as it is hampered by institutional aspects, public resistance, and high costs. This supports recent research suggesting that water reuse for irrigation is so far deployed below its potential in the region of the Western La Mancha aquifer [13].

The importance of lack of institutional coordination, the complexity of regulations and the delays imposed by administrative procedures is congruent with the contemporary literature. These recent works suggest that the lack of supportive frameworks and unclear institutional arrangements make it difficult to implement reclaimed water reuse projects [18, 19]. In line with Haldar *et al* [25], our results indicate that political support for water reuse would facilitate the bureaucratic process and foster reclaimed water use. The *political will increase* scenario showed the largest aggregate desired change of all simulated scenarios.

Moreover, the low level of social acceptance and the high cost of reclaimed water are often identified as two major barriers preventing a wider spreading of this practice [7, 52]. Stakeholders in the region of the Western La Mancha aquifer recognized the 'yuck factor', which refer to the disgust reactions at the idea of using recycled water [53], and the sanitary risk perception by consumers as critical points for advancing in the use of reclaimed water for irrigation [12, 21]. However, the skepticism of farmers about using reclaimed water, which is mentioned in many articles (e.g. [20, 54]), is not identified in our study. The results show that farmers are aware of the ability of reclaimed water to secure water supply and to fertilize and provide nutrients [55], thus saving costs and increasing their income [56]. In line with Saliba *et al* [24] and Dery *et al* [22], our findings reveal the importance of communication and awareness campaigns (*social awareness* scenario) to debunk myths about the quality of reclaimed water and disseminate information on the various benefits of water reuse. This scenario provided the second largest increase in water reuse in agriculture in the system, and the second largest aggregate desired change (along with the *agricultural transformation* scenario).

In addition, our study indicates that climate change and its negative impacts (water scarcity and water stress) triggers farmer demand of reclaimed water. However, Hristov *et al* [14] suggest that reclaimed water costs are very high and even climate change effects may fail to induce higher use. Mesa-Pérez and Berbel [7] reveal that the development of new wastewater treatment technologies could have a positive impact on the cost of reclaimed water. Nevertheless, energy costs should be overcome. Our study supports these findings and show that a change in the financing model, without subsidies related to water reuse and with a greater emphasis on water tariffs to ensure compliance with the cost recovery principle (*cost recovery* scenario) could significantly increase the cost of reclaimed water for farmers and decrease their demand for reclaimed water [14, 15].

Stakeholders also suggested that prospects in water reuse should be accompanied by a transition to more sustainable and less resource-intensive farming systems to effectively achieve the good status of water bodies. The difference in desired change between this scenario (*agricultural transformation*) and awareness campaigns (*social awareness*) was minimal, suggesting its potential. These results support the vision of the

scenario analysis developed by Mack *et al* [57], which shows how even under negative future scenarios agricultural extensification can result in improvements in ecological status. These results are also in line with the spirit of the new EU policies (the Green Deal [45], the Farm to Fork strategy [46], the Circular Economy Action Plan [5], and the Common Agricultural Policy 2023–2027). Furthermore, our findings reinforce the notion that water reuse projects should only be implemented after a careful consideration of their potential environmental externalities [13]. It has been noted that in inland regions (as it is the case of our study area) excessive reuse could jeopardize environmental flows [58], and increase the offer putting further pressure on natural resources [14]. In this context, stakeholders stressed that the use of reclaimed water should be linked to the decrease in the exploitation of the aquifer, supporting the long-term sustainability of the water use, in line with the Guadiana River Basin Management Plan [30].

The study also evidences the role of policies, and in particular the new EU Water Reuse Regulation [6] to foster reclaimed water use in agriculture. The implementation of this regulation is expected to have many benefits. According to our study, it could increase the desired change in all scenarios and reverse the negative outcomes of the *cost recovery* scenario. These results support previous findings that evidenced stakeholders' concern regarding (a) barriers to trade of agricultural products, (b) potential significant gains derived from the establishment of harmonized minimum requirements for water quality [59], and (c) higher social acceptance due to improved risk management processes [23]. However, more research is needed to assess the full scope and impact of the new water reuse regulation. Among others, Bolinches *et al* [13] suggest that complying with regulation could also imply important transaction costs (e.g. in terms of negotiation and adoption of risk assessment plans). Not only technical barriers, but also economic and institutional barriers may hamper compliance with regulation as seen in the past in Spain, with the implementation of EU regulations on urban wastewater treatment and reuse [15]. Moreover, previous research in the case study region points to high transaction costs and limited enforcement capacity of the Water Authority when dealing with water abstractions for irrigation in the context of compliance with the aquifer's Water Abstraction Regime [29, 31, 32].

Among the practical implementations of the study, the results strongly advocate for the definition of a streamlined and transparent administrative procedure before any authority embarks on a water reuse program. According to the perception of the stakeholders, a particular region (be it country or river basin) willing to reclaim water for agriculture should beforehand revise all required formalities and ensure the proactive action of all the implied levels of administration.

Finally, further research could explore the potential of combining the different scenarios presented in this study, as they are not mutually exclusive. This could help uncover synergies and provide valuable insights to decision-makers and water authorities.

Data availability statement

The data generated and/or analyzed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

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ORCID iDs

Mario Ballesteros-Olza https://orcid.org/0000-0003-1756-7727
Irene Blanco-Gutiérrez https://orcid.org/0000-0002-6105-3339
Paloma Esteve https://orcid.org/0000-0003-1216-9156
Almudena Gómez-Ramos https://orcid.org/0000-0003-1419-5454
Antonio Bolinches https://orcid.org/0000-0002-7447-6138

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