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Changes in institutional and social-ecological system robustness due to the adoption of large-scale irrigation technology in Navarre (Spain)

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Abstract

Many regional and national organisations promote the modernisation of agriculture by supporting new technologies to increase their territory's competitiveness in a free-market context. Such technologies and their associated intensive land management practices are geared towards obtaining higher yields. However, their application also entails changes in water and land management institutions that could alter interactions among multiple components of the agrarian social-ecological system and potentially weaken the system. Here, we assess how these components and their relations change in a village situated in Navarre (Spain) after the uptake of large-scale irrigation infrastructure. Specifically, we analyse such changes by comparing how the design principles for robust social-ecological systems manifest before and after the adoption of large-scale irrigation . Our findings indicate that an unequal distribution of water and land induces some farmers to abandon their agrarian activities. Our case study also shows how irrigation communities have partially lost their autonomy to self-organise and make agrarian management related decisions. We suggest that the adoption of large-scale irrigation in this region contributes to a decrease in cooperation among resource users, and between users and infrastructure providers. This is due to a decline in the capacity to achieve collective-choice arrangements and higher external control and monitoring of water use. We argue that the current agrarian management changes may damage social-ecological system robustness and affect the sustainable use of common-pool resources, leading farmers to maladaptation to climate and market variability.

KEYWORDS

institutions, technological change, large-scale irrigation, robustness of social-ecological systems, maladaptation

1. INTRODUCTION

The agricultural commons—i.e. common access to arable land— were essential components of early modern agriculture in many parts of Europe until the 19th century. The global expansion of capitalism caused their disappearance through the phenomena of "enclosures" the legal process of consolidating small landholdings into larger farms (Moore, 2000). Contrary to Hardin's famous "tragedy of the commons" which warned of the risk of unregulated natural resource management, the "enclosures" of the commons are still a current phenomenon characterized by new agricultural contracts and regulations that encourage a different tragedy. A tragedy that is not for all, as Hardin proposed, but this time only for some: small land-holders with less power over land (Boyd et al., 2018).

There is, worldwide, an increasing pressure on agricultural land to supply food to face population growth and changes in diet induced by rapid economic growth in much of the developing world (Bruinsma, 2017). Energy demand pressure also drives large-scale buyers and processors to allocate growing amounts of food crops to provide biofuels as a solution to high fuel prices and energy insecurity (Boserup, 2017; Bruinsma, 2017). Consequently, global agriculture has intensified and expanded over the past decades to increase yields (Foley et al., 2005; Dias et al., 2016).

Since the late 1990s and particularly over the last decade, this global expansion has been possible through land-grabbing processes promoted through speculative financial investments (Von Braun and Meinzen-Dick, 2009). Recently, in South East Asia, it has also been practised as a response to climate change (Corbera et al., 2017). Land grabs are deeply shaped by historical legacies but can also emerge and expand from new global rule-making regimes, where States facilitate processes of land grabbing by 1) justifying the need for large-scale land investments; 2) defining or reclassifying marginal lands; 3) identifying these "kind" of lands, 4) appropriating these lands and 5) reallocating these lands to investors (Margulis et al., 2013). Climate adaptation discourses also politicize the necessity to foster new technologies and innovation (Swyngedouw, 2010). In contexts where there is a widely recognised requirement to undertake urgent action to secure sustainable futures and avert environmental catastrophe, populist manuvers can take advantage of popular sentiment to promote agricultural development infrastructure policies in the name of sustainability (Swyngedouw, 2007; MacNeil and Paterson, 2012).

A global need for increased crop production, intertwined with the emergence and consolidation of a narrative regarding the unquestionable necessity of modernisation to face globalization consequences creates conditions that facilitate the enclosure of the commons. This kind of strategy is associated with not naming other causes of current and future socio-ecological problems (Swyngedouw, 2010) and has led to the intensification of agricultural practices and the modernisation of water management infrastructure to increase trade crops (Elliott et al., 2014).

Modern agricultural intensification practices replace traditional irrigation systems that have been used for centuries that supply water via canals or channels to crops in the field (Fernald et al., 2007) with modern methods of irrigation such as drip systems and sprinkler systems. Large-scale irrigation projects are, thus, promoted with the aim to increase water availability and therefore produce higher yields, allowing farmers to compete in international markets (Playán and Mateos, 2006; Nakawuka et al., 2018).

Both systems, the traditional and the modernised large-scale irrigation systems, rely on a sustainable supply of water for irrigation. This water can be considered as a common pool resource (CPR) (Wong et al., 2017). A CPR is defined as a "natural or human-made constructed system that generates a finite flow of benefits, in which: 1) exclusion of beneficiaries through physical and institutional means is especially costly, and 2) exploitation by one user reduces resource availability for others" (Ostrom, 1993).

Sustainable use of CPR depends on cooperation of resource users (irrigators) that behave in a socially optimal way restricting their individual extraction to avoid overharvest (Schlüter et al., 2016). Therefore, CPR implies a shared common resource but also specific institutional conditions that allow for its joint management, considering them as both common objects and social relations (Ostrom, 2005). We, therefore, understand the commons as institutional spaces that frame the relationship between the CPR and the system of rules, norms and social conventions that allow their collectivisation and co-production (Ostrom, 2005; Bollier, 2007).

Following this theoretical approach, sustainable management of irrigation water will need to involve the direct participation of local communities in the allocation, use, and exploitation of the resources in question (Ostrom, 2015). Therefore, collective management involve resource users with common interests and voluntary actions to pursue these interests (Markelova et al., 2009; Ostrom, 2009; Scott and Marshall, 2009; Vanni, 2014). This self-governed collective action aims to avoid the overexploitation of CPR, preventing environmental degradation and safeguarding people's livelihoods.

In the European context, and more specifically in Spain, access to irrigation water remains a challenge, and, therefore, self-governed collective action is crucial for water management. Through a case study, this article aims to analyse how the adoption of large-scale irrigation transforms the agrarian social-ecological system (ASES), especially in terms of the norms and rules-in-use regarding irrigation water. To do so, we assess and compare the two stages of an ASES in Navarre, Spain.

First, we describe the ASES, before and after the adoption of large-scale irrigation. The analysis of the ASES's characteristics is grounded on the analytical framework of the robustness of social-ecological systems (SES) from an institutional perspective developed by Anderies et al. (2004). This framework allows us to study this evolution by characterising each component of the ASES as well as the types of links between them (e.g. between resource users and infrastructure providers), and by reflecting on potential tensions that may arise after the adoption of a large-scale irrigation project. We then analyse how the adoption of such irrigation infrastructure affects the eight design principles of institutional robustness adapted from Anderies et al. (2004), based on Ostrom's (1990) principles for common-pool management. We, finally, discuss how the adoption of large-scale irrigation technology has transformed the characteristics of the ASES, relating the design principles for institutional robustness with the ASES robustness framework.

The following sections present the analytical framework applied in this case study (section 2); the main characteristics of the case study in Navarre, Spain (Section 3); the field methods (Section 4); the results of the qualitative analyses. Results include the main perceived changes after the adoption of large-scale irrigation technology in the region and their effects in the design principles for the robustness of irrigation management institutions after adopting this large-scale infrastructure (Section 5). A discussion of the main results (Section 6) follows; and conclusions and implications of this case study (Section 7).

2. ANALYTICAL FRAMEWORK

Agrarian systems are complex SES, i.e. ecological systems linked with and affected by various social systems (Anderies, 2014). The agrarian system, its biological conditions, social interactions, and structures are all interdependent. Individuals invest time and effort in developing forms of physical and institutional infrastructure, which affect natural system functions over time (Janssen and Ostrom, 2006). An ASES includes other interconnected sub-components: resource system (e.g. the agrarian ecosystem), resource units (e.g. crops, organic matter, nutrients), users (e.g. farmers, society), and governance systems (e.g. organisations and rules that guide farming in a given context). The outcomes of the mentioned sub-components' interactions at the ASES level influence the subsystems and their components, but also other SES (Janssen and Ostrom, 2006). Within the framework of Anderies et al. (2004), subsystems are represented by sub-components of the irrigation system, specifically the resource (irrigation water), resource users (farmers), infrastructure providers (the government or a private firm) and the infrastructure itself. The external environment, including climate factors, as well as economic and political systems also influences all of these entities.

We acknowledge that various alternative analytical frameworks for the study of institutional changes exist. For instance, the institutional resource regime (IRR) framework helps to analyse the transformation of regulatory measures and other resource management practices by combining property rights theory and policy analysis. This framework describes the configuration of regimes and changes in order to predict their ability to assure the sustainable use of a given resource (Gerber et al., 2008). The IRR analyses institutions from a political economy perspective at a macro-level, but pays less attention to the characteristics of CPR, as institutional spaces of co-management and co-production of environmental commons. Another alternative framework is the institutional analysis and development framework (IAD) from Ostrom (2005) that identifies functional characteristics and interactions encouraged by a given policy instrument. The IAD is used especially to describe the different types of rules and norms in-use and to understand the institutional setting in which action situations take place. Even though the IAD framework has been designed to study the management of CPR, it is limited in this function in that it only focuses on different types of rules and norms and does not help to describe the evolution of the relations between resource users and the CPR.

For this case study, we compare SES changes through an assessment of ASES components and their relations, as well as institutional changes caused by the adoption of irrigation technology (from traditional to large scale). We understand institutions as "the conventions, norms and formally sanctioned rules of society that provide expectations, stability, and meaning to human existence and coordination. Institutions regularise life, support values and protect interest (Vatn, 2005, p. 60). Therefore, changes in governance structures will cause changes in the relationships and outcomes of an ASES.

After a general description of the case study ASES components and a brief exploration of the changes in their relationships, we compare two stages of the ASES based on the principles for robust SES as proposed by Anderies et al. (2004). These principles find their roots in the principles of collective and adaptive governance proposed by Ostrom (1990) and Dietz et al. (2003) that highlight a strong link between reciprocity norms, democratic management, and active participation. According to the authors, the co-production of commons is based on feedback between information, monitoring, and participatory decision-making. These foundations are reflected in the Anderies et al. (2004) framework for the enhancement of the robustness of SES. Robustness here refers to the maintenance of some desired system characteristics despite fluctuations in the behaviour of its entities or its environment (Carlson and Doyle, 2002). We understand robustness as the capacity of SES to overcome environmental disruption over time. The robustness of a SES is highly influenced by the institutions that govern its management and exchanges (Anderies et al., 2004).

The Anderies et al. (2004) framework outlines eight design principles for robust SES. First, there should be *clearly defined boundaries* of the resource system where the rights of users to harvest resource units, such as irrigation water, are clearly designated. Second, there should be *equivalence between benefits and costs* defined by allocation rules. Such institutions define and allocate the number of resources according to local conditions, as well as the labour, or any other type of input involved in the allocation. Third, there should exist *collective-choice arrangements*. Individuals affected by the rules in use could modify these arrangements. The fourth concerns *monitoring*, where monitors audit ecological conditions and the type of user behaviour in regard to resource management. Monitors are accountable to resource users, and they can also be users themselves. The fifth concerns *graduated sanctions,* where if users violate rules they will receive sanctions according to the context and seriousness of the fault. Sixth, the existence of *conflict-resolution mechanisms* that guarantee equal access to discussion arenas between users and officials at a low cost. Seventh, a recognition of the *right to self-organise*, where users operate indepentely of external governance authorities, are autonomous in crafting their own institutions and have tenure rights over the shared CPR. If the resource is part of a larger system, an eighth principle arises involving *nested enterprises*, which involve the appropriation, provision, monitoring, enforcement, or conflict resolution. Nested enterprises are organised at a multi-scale level, linking resource users with those in higher or lower governance levels.

The size of a SES influences the operation of its design principles. In smaller and simple SES, it is easy to perceive changes, as the providers and users of resources are more likely to have strong social links which allow them to observe each other's daily behaviour as well as the impacts of resource use (Sarker and Itoh, 2001; Anderies, 2015). In these cases, conflict or problems might be resolved based on trust and reciprocity linkages (Baggio et al., 2016; Dhakal et al., 2018). Also, as Baggio et al. (2016) claim, the application of SES design principles could depend on the nature of the SES infrastructure. For instance, SES monitoring will be easier when infrastructure is static, as is the case for water contained within a centralised irrigation system.

3. ITOIZ-CANAL DE NAVARRA CASE STUDY

Spanish agriculture is of high importance in terms of the extent of its coverage -more than twenty-five million hectares, representing approximately 50% of Spain's total agricultural area is classified as useful agricultural lands (SAU). Moreover, the Spanish agricultural sector generates around 7% of the total country's employment and benefits from high public subsidies (MAGRAMA, 2013).

Water scarcity has been a reoccurring theme in Spain's public policy rhetoric during the last century, and the search for water sources persists (Swyngedouw, 2004). As a result, nearly every river basin in Spain has been altered, engineered, and transformed in persuit of water security. Only the countries of China, the USA, and India contain a greater number of dams than Spain, where thehighest number of dams per square kilometre per capita in the world can be found (Mendez, 2001). Within Spain, the building of dams is justified on the grounds of producing hydroelectricity, securing water availability in drought periods and, more recently, tackling climate change-related concerns, such as buffering infrastructures to mitigate temperature rise and to regulate extreme flooding events (Bruckner et al., 2011).

Relatedly, in Spain, irrigation infrastructure is also promoted as a measure for climate change adaptation as long as stored water is available (Field et al., 2014). In this context, a shift from traditional irrigation practiced in Spain to currently widespread pressure systems — such as sprinkler irrigation methods— has been facilitated through policy measures subsidising farmers' adoption of irrigation infrastructure and guaranteeing low water prices (Baldock et al., 2000).

The study community is located in the region of Navarre, situated in the district of Ribera Alta, in the Ebro River Basin, Spain. The name of the village will remain anonymous to protect the identity of the participants in the study. Following the trends of the regional area, this village has undergone a process of agrarian transformation through the adoption of a large-scale irrigation project known as Itoiz Canal de Navarra (Albizua et al., 2019a, 2019b). The main cash crops that grow in the area of study are irrigated and rainfed corn and rotations of winter wheat and barley.

Figure 1. Location of Navarre and the case study in Spain

The study area contains different types of farmers, who can be classed according to their crops and land management practices. Small-scale farmers work on small plots (< 1 hectare) of vegetables and woody crops such as olive and almond trees, sometimes under traditional irrigation systems. Normally small-scale farmers do not relly only on agriculture, but have other sources of income or are retired farmers. On the contrary, large-scale intensive farmers cultivate extended farmlands (>50 ha) of rain-fed and irrigated cereals and maize, mixing the use of organic and conventional fertilisers. Within large-scale intensive farmers, we also observe some farming types variants within the 'cash-crop' category; for instance, some farmerstend towards more organic practices or others have vineyards as a complementary crop (Albizua et al., 2019a, 2019b). The studied community is representative of the patterns experienced by other villages in Navarre affected by the adoption of large-scale irrigation.

In 1999, the government of Navarre introduced the Navarre Irrigation Plan (Foral Law 7), followed by the Foral Law 1/2002, which required the local government to subsidise approximately 40–50% of investment costs to farmers adopting large-scale irrigation. In addition, the Foral Law 6/1986 —repealed by Foral Law 6/1990— favoured the transformation of communal lands and provided a higher subsidy for the installation of the large-scale irrigation if municipal councils prioritized full-time farmers when allocating communal lands, accelerating the adoption of the new technology.

The adoption of large-scale irrigation has caused multiple changes in the rural landscape of Navarre, including an increase in the cultivated land area per farmer through a land re-parcelling process. The types of crops grown then shifted towards predominantly corn (*Zea mays*) and forage, as well as some biofuel production (Diario de Noticias de Navarra, 2017). Consequently, farming practices have begun to rely on an increased amount of synthetic fertilisers and pesticides. The average yield per year is higher; winter wheat increased on average 5900 Tm between 2013 and 2014 in the whole Ribera Alta (Gobierno de Navarra, 2016). However, the new irrigation system implies higher farm-level costs when compared to traditional irrigation systems (see Table 1).

The study village held a non-binding referendum in June 2014 to surface farmers' views about adopting the Itoiz-Canal de Navarra project in their traditionally irrigated lands. The result of this referendum showed that most residents opposed the implementation of the proposed large-scale irrigation system. However, a second democratic process conducted in December 2014 had the opposite outcome: a majority favoured the large-scale irrigation project. By this time, some owners had already sold their lands, and the council voted in favour of large-scale irrigation. It needs to be noted that the village council is in charge of large communal lands and votes are weighted based on the amount of usufructed land, and therefore the council was able to strongly influence the voting result. Hence, institutional changes in communal land tenure and irrigation enabled this project to move forward, and the consequences of such changes in farming practices were tangible in the regional landscape after a period of fewer than 5 years.

4. FIELD METHODS

To answer our main question regarding how institutions and, consequently, the ASES relationships have changed with the adoption of large-scale irrigation, this research adopted a case study approach combined with qualitative research methods including semi-structured interviews and focus groups.

4.1. Semi-structured interviews

During May-June 2015, 19 interviews were conducted with a sample of farmers, stratified based on their land management practices (N=17), and with actors of government officers (N=2). The aim was to explore the changes in institutions and SES robustness resulting from the transformation from a traditional to a large-scale irrigation system in the community. Recruitment of participants was done using the snowballing technique. Conversations were structured around three main themes concerning water access over time: (1) a comparison between traditional irrigation institutions and the large-scale irrigation system (2) the socio-economic pressures that led to irrigation modernisation, and (3) the implications of large-scale irrigation on rural livelihoods. Most interviews provided insights on the existing social relations in the village as well as personal opinions of, feelings about, and experiences with institutional changes. The results of the interviews helped to understand the context in which the large-scale irrigation project took place, and to provide a detailed characterization of both systems in relation to their components and their relations as well as the eight principles for robust SES suggested by Anderies et al., (2004). Documents, newspapers, and other written sources were also assessed as a way of triangulating the information.

4.2. Focus groups

In June 2015, the lead author and two research assistants conducted a focus group discussion in the village to determine outcomes of Itoiz Canal de Navarra large-scale irrigation project and how it affected institutions and stakeholders. Participating farmers were selected based on their land management practices, focusing on whether or not they had adopted large-scale irrigation. Recruitment of participants was done using the snowballing technique. Seven participants initially committed to the group, though ultimately five people partook. They were: two members of the traditional irrigation community (who eventually became members of the large-scale irrigation community), a local environmental activist, an owner who refused to uptake large-scale irrigation, and an INTIA[1] technician who guided the village's involvement in the land re-parcelling and the resulting land redistribution process. In December 2016, a second focus group (N=8), composed only of landowners and farmers deliberately selected based on their land management practices, was conducted in the village. The aim of this focus group was to validate initial results and gain an interpretation of initial findings from interviewees and previous focus groups.

5. RESULTS

5.1. Characterizing the social-ecological system components and the evolution of their relations

Interviews and focus groups revealed that the adoption of large-scale irrigation produced important changes in respect to land access for farmers. Farmers who did not invest in the new irrigation technology felt forced to abandon their farming activity due to a lack of access to communal land and irrigation water. Through the comparison between the traditional and the new irrigation communities' member lists —i.e. counting how many people appeared in such lists before and after the adoption of large-scale irrigation —, we found that the number of landowners had decreased by 28% in just one year (2015-2016), suggesting a transition towards fewer farmers with larger property entitlements. This point was also highlighted by some of the respondants. Some of the affected farmers lent their lands to the local rural cooperative who then contracted this land to other farmers. In this way, the lenders did not lose their property rights, but they did abandon their farming activity. Those who did not lend their lands through the cooperative sold or rented their farms, resulting in a concentration of land ownership among fewer farmers.

New land tenure and labour dynamics in this region, created some tensions among farmers by clearly excluding small-scale farmers' communities from large-scale farmers fully involved in the irrigation project. This dynamic was clearly reflected by interactions during the focus group. When asking interviewed farmers to suggest suited candidates for the group discussions most of them discouraged the researchers from conducting the focus groups. Farmers stated that this exercise should be postponed, once tensions between those adopting large-scale irrigation and those abandoning their farming activity decreased. Low participation in the focus groups by stakeholders also reflected this conflictual dynamic within the community.

336 Meanwhile, the governance of communal irrigation, organised in "irrigation communities", also changed. Now, irrigation communities cover more than one village, now called "irrigation sectors", while in the past there was one irrigation community per village. Therefore, decision-making bodies became more aggregated, resulting in a less participative collective-choice process (see Table 1). Landowners who abandoned farming stopped participating in irrigation communities, and some irrigators, who still laboured their land, also stopped participating in irrigation community assemblies.

343 Finally, it was also highlighted that in the past, traditional irrigators would pay the River Basin Agency a low fee for long-term water use concessions. This agreement had lasted for approximately 75 years. In the new system, water consumption is measured by a meter located next to the hydrants. As a result, farmers pay not only for the fixed quota but also for water consumption (0,03069 €/m^3 in 2014 and 0,03400 €/m^3 in 2018), the maintenance service, and the canal construction.

350 **Table 1.**

352 In characterising the SES components and comparing the traditional and new systems, we found that farming practices were more homogeneousin the traditional system. Farming strategies were similar because flooding irrigation[2] offered fewer farming options. Another difference is that, in the traditional system, there was no single infrastructure provider, and irrigators had a higher autonomy, reflected by a direct connection with the watershed basin agency. Likewise, farmers had more control over resources—irrigation water—and the infrastructure—the *acequias*[3]. In contrast, in the new system, we found two contrasting farming livelihoods: small-scale farmers and large scale more market-oriented producers. However, this duality of livelihoods is tending towards an homogenization as some small-scale farmers are inclined to abandon farming. Currently, sprinkler irrigation is the most widespread type of irrigation system. The infrastructure in the new system involves more complex and long-lasting physical structures, making infrastructure itself a more relevant resource since users cannot access water if such infrastructure does not operate. On the contrary, in the traditional system, farmers could still find ways to irrigate even with small breakdowns in infrastructure (see Figure 1 in the appendix).

[2] Traditional irrigation technique where the irrigated area is flooded, and surrounded by small dikes that regulate the entrance of water

[3] Small canals that transport water from the river. This infrastructure is part of a century old system

Table 2.

Figure 2 Comparison of entities and their links in the traditional and new irrigation social-ecological systems.
Note: The numbers of the arrows refer to links between entities, explained in Table 3

Figure 1 in the appendix and Figure 2 show that the ASES evolved from a horizontal and widely representative governance system to a more hierarchical and aggregated structure where only some representatives have the opportunity to voice concerns about irrigation. Figure 2, based on Anderies et al., (2004), portrays additional components of the system, where the size of each component represents its relative importance. Figure 2 details the different connections between all the entities composing the ASES. Each entity and its connections are further explained in tables 3 and 4 that summarise the potential tensions and problems identified by participants in this study for each entity of the ASES, as well as their relations to the introduced large-scale irrigation project.

Table 3 illustrates the links between the entities and shows how they have changed with the adoption of large-scale irrigation.

Table 3.

Note: Numbers refer to the connections shown in Figure 2

5.2. Comparing the robustness of traditional and large-scale irrigation systems

Of the eight design principles of Anderies et al. (2004) framework, we focused our analysis on six, as these were the relevant themes that arose from the qualitative codification of the interviews and focus groups. Such principles were: 1) the necessity to clearly define the boundaries of the resource system; 2) the establishment of proportional benefits and costs that a user is allocated; 3) collective-choice arrangements that individuals use to modify rules; 4) monitoring and 5) sanctioning means to secure proper use of resources, and; 6) conflict-resolution mechanisms among users or within relationships of users and officials. We coupled monitoring and sanctioning to better outline our results.

First, concerning the need for *clearly defined boundaries*, irrigation rules and norms were clearly defined in both the traditional and large-scale irrigation systems in Navarre. Moreover, the area in which irrigation can be used also was well delineated and determined by the existing water distribution infrastructure, e.g. *acequias*, that continues to serve as a pipe-irrigation system. However, in terms of the defined boundary for the amount of water consumed, respondents revealed a lack of knowledge and higher uncertainty in the new system. First, water flow and pressure remain a concern as the initial design of the large-scale irrigation system encompassed a smaller region than what has later really been developed. There has been an expansion of the project in which the second phase has been put on hold, and respondents did not know whether or not it will be developed in the future. Second, in both systems, the CHE[4] provided a fixed volume of water concessions. However, in the past this concession was directly given to the local irrigators' communities and, based on past experiences, communities knew of supply shortages in advance (during a few months in summer). Respondents also showed that in the traditional system, farmers had a clearer idea of the total amount of available water at any one time and broader access to water. In contrast, in the large-scale irrigation system, irrigators felt that the volume of water used was unclear based on limited experience with the system and a disconnection from resource management.

Moreover, in the traditional system, irrigators paid a fixed low quota regardless of consumption levels, whereas in the modern system, financial capital seemed to gain importance, since irrigation water is measured and charged. Therefore in the new system, water consumption is influenced by price. Irrigators need to make an initial high investment for the irrigation system transformation, and this financial concern is accompanied with with the uncertainty attached to the continuously increased water quotas over the years (Diario de Noticias de Navarra, 2016). Focus groups' participants and most of the interviewed farmers recognised that a water consumption system based on price encourages water efficiency. However, they also mentioned that extensive farming practices and the cultivation of water demanding crops were increasing in the region as a consequence of the implementation of the large-scale irrigation project. This could suggest a possible rebound effect resulting in the overall increase in water consumption[5].

In respect to the second design principle, the *establishment of balanced benefits and costs* of water irrigation systems, farmers adopting large-scale irrigation stated that an increase

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[4] CHE Confederación Hidrográfica del Ebro (English: Ebro River Basin Agency)

[5] We could not get quantitative data about how much such consumption had changed due to the lack of counters before the large-scale irrigation project. Moreover, there were also differences in the modern system regarding the types of crops they selected that make comparability more difficult.

in crop yields compensated for new irrigation-related expenses, such as the cost of large-scale irrigation installations and water quotas that were partially subsidised by the regional government. Respondents universally aknolwedged that the traditional system did not allow commercialising crops in the international market, due to insufficient yields. This situation has evolved following the introduction of the new system, as farmers perceive they can more easily compete in the food market. However, as large-scale irrigation replaced traditional water access, farmers unable or unwilling to invest in large-scale irrigation infrastructure lost their water concession rights. As one farmer explained: "*The costs of adopting large-scale irrigation supposes concentrating land ownership in very few people. By increasing costs many people have been forced to sell the land*" (FG1-3). This was also revealed by another respondent explaining that "*The land has gone from 60 to 6 plots. Moreover, before the average area was 0.6-0.5 hectares and now the average is around 7-8 hectares*" (SI2-1).

Small-scale farmers also stated that a loss of concession rights had resulted in the loss of other cultural services linked to traditional land management practices, such as ecological local knowledge, often used for environmental education, and other relational benefits tied to respondents identity as farmers (e.g. self-esteem and self-improvement feelings related to land labouring). In this regard, the distribution of costs and benefits of the new system can be considered to be uneven. One of the farmers questioned whether the small-scale farmers referring to cultural values were really farmers at all, thereby reducing all farming relations into financial terms: "*we should define what we understand as "farmers" because maybe we are calling farmers to small-scale owners who are not farmers*" (FG1-4). In addition, he added later "*For me, benefits are defined by the market*" (FG1-4).

According to the third principle, users need to have the *capacity to design their own institutions* in the long term. In the new system, decision-making is not a community-based process and this could compromise potential collective action in the future (Anderies et al., 2003; Dakos et al., 2015). Some interviewed farmers perceived bureaucracy (e.g. paperwork required to deal with government administration) as a restraint to addressing problems or to decide how to organise the irrigation system according to their practice: "*Irrigators do not have the same power as before. For example, to make the modern irrigation extension we had no option to say how we wanted it*" (SI2-14).

In repect to the fourth principle, *monitoring*, the control of biophysical conditions and users' behaviour to secure the proper use of resources is performed differently in both systems. A few[6] respondents complained that in the traditional system, the guard used to avoid conflict, and this led some users to break norms (e.g. not cleaning their *acequias* when it was their turn). One of the current irrigators stated: "*This way of monitoring was a conflict source and there was abuse in the ways people used water.*" Another participant specified "*There were two months per year (during the summer) that were especially problematic but the rest of the year the system worked fine*" (FG1-5). Focus group participants expressed that having external monitoring, by a licensee enterprise, could increase compliance with rules and norms due to the lack of personal involvement of those in charge of monitoring. Additionally, participants also perceived a higher control of water consumption due to its measurement and the proper management of the firm in charge of the irrigation system.

[6] 'Few', 'some', 'many' and 'most' are used consistently to mean less than 25 percent, up to 50 percent, up to 74 percent and 75 percent or more of the corresponding sample, respectively.

These examples suggest that positive social relations between the monitor and other community members might have allowed some farmers to take advantage of water consumption (Ribot and Peluso, 2003). Easier access to authorities and negotiations through friendship, trust, and reciprocity influenced positively farmers' perspective on water access and management, as social networks showed to be more relevant in the past than in the current system.

Lastly, it is necessary to establish *conflict-resolution mechanisms* among users or between users and officials. Nearly half of the respondants expressed that in the past, there were few conflicts, and arguments were often due to non-compliance of farmers with irrigation turns, especially during the drier months. Dialogue was the primary mediation tool, and formal complaints were avoided. In the new system, participants are uncertain about how conflicts may be addressed by the external company. One of the irrigators in the focus group stated: "*at least, for the issue of payment defaults, the law allows the irrigation communities to go to the executive and claim water cuts or foreclosures*" (FG1-4). There was also uncertainty about other types of potential future conflicts.

Table 4 summarises how each phase of the studied ASES operationalised the design principles for robust SES, and how this robustness has evolved. Symbols in the "principles" categories refer to whether the agrarian social-ecological system robustness is enhanced (+), reduced (-), equal (=) or if it remains uncertain (?) after the adoption of the large-scale irrigation based on participants' experiences in the studied area.

Table 4.

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6. DISCUSSION

In this work, we assessed how the changes in the management of irrigation water in Navarre, Spain, influence social and ecological interactions of agrarian systems, resulting in new relations between resource users, the resource, infrastructure, and management structures. We observed that according to actors' perceptions the boundaries of the resource became more abstract creating an impression of efficient water use but also allowing the expansion and intensification of agriculture practices. Such a rebound effect might cause a severe impact on the environment in the long run (Baldock et al., 2000) as explained by theories linked to the Jevons Paradox (Swyngedouw, 2004).

Simultaneously, relations among resource users, as well as between irrigators and public infrastructure providers changed in concern to the maintenance and monitoring of the resource. Although sprinkler systems allow for irrigators' better control of water use, the new exercised control of an external firm over water consumption and infrastructure has led to a perceived decrease in communication, reciprocity and social sanctioning dynamics, which were frequent in the past.

Consequently, local users feel disconnected from the resource and infrastructure as well as from the rules involved in the management and co-creation of the CPR– the irrigation water. Users are then becoming less aware of external forces, such as climatic hazards that will affect water reservoirs and the infrastructure. Overall, the governance structure of the system became more aggregated where only some actors had space to voice concerns about irrigation. In such a context, infrastructure played a bigger role and should be considered as a resource itself, as farmers cannot access water, or farm, without access to the modern irrigation system.

These new dynamics influence users' perception of their legitimacy to farm (Schlüter et al., 2016). Some farmers claimed that only those who lived mainly from agriculture and generated a financial income should be considered "real farmers". This perception excludes farming livelihoods shaped by cultural and relational values, such as education, knowledge related services, which are slowly eroded by technological change. This dynamic increases the ongoing tension between different types of farmers, due to the accelerated abandon of farming activity and the sale and rent of lands.

The institutional changes caused by the introduction of a large-scale irrigation project not only present implications for relations between resource users and the resource but also influence the robustness of the agrarian SES in the context of climate change adaptation. First, large-scale institutional arrangements, rather than being a win-win solution for CPR management, present unequal outcomes in terms of water access. Large-scale farmers intensified and extended farming practices due to greater access to land and water, creating inequality in access to agricultural resources and an uneven distribution of the costs and benefits of large-scale irrigation infrastructure in the region. Even though policies promoting large-scale irrigation in this region portrayed the project and its outcomes as beneficial for all, they failed to acknowledge the heterogeneity of rural communities in the region. Moreover, when the actions of intensive farmers impact small-scale farmers by restricting access to communal land and water, maladaptation to climate variability is uncovered (Barnett & O'Neill, 2010) due to the improvement of one farmer's condition that damages the condition of another type of farmer.

This new resource configuration, resulting from the institutions governing the introduction of large-scale irrigation technology, reflects an unequal distribution of influence and power between the different types of farmers in the region. The role of social relationships in shaping resource management cannot be ignored (Cleaver, 2007) since rule systems are not the product of deliberation between equal actors, but rather the result of negotiations influenced by existing power relationships (Cleaver, 2007; Harribey, 2011). In this case study, power relations exist among the different types of farmers, as large-scale farming systems are better aligned with the aims of large-scale irrigation projects, and, therefore, with a pro-industrial agriculture policy agenda. Farmers' access to irrigation water is then a reflection of socio-technical and institutional dependencies, village hierarchies, and the pressure of global agrarian production trends to intensify production in order to increase yields. Although power relations are not an explicit proxy of the design principles to assess SES robustness, our results suggest that their incorporation should be considered.

Secondly, our case showed that monitoring and control over water consumption improved with new irrigation technology (principle 4). However, farmers lost their capacity to influence the norms and rules governing water use (principle 3) and they developed a dependency on a private firm and the government subsidies by paying for water consumption. As Anderies et al. (2004) already emphasised, the link between resource users and public infrastructure providers is a key variable affecting the robustness of SES and has frequently been ignored in past studies. The replacement of local and collective power structures to administer water use by an external and hierarchical power apparatus means that farmers are "deprived of knowledge of their own systems and understanding on how to engage with one another in organising collective action" (Ford et al., 2007).

According to principle 3, for the institutional robustness of the SES, users should be autonomous and have control over the management and allocation of resources. However, large-scale intensive farmers seem to accept the loss of their autonomy over the resource and its management as long as their access to water is not compromised. This relation shows a short-term and utilitarian vision where irrigators attach more importance to their financial gain, through crop trade rather than long-term food security. However, this short-term vision does not allow them to prepare for the long-term risk of an increase in water use in the region in the context of increased climate variability (IPCC, 2014) and stronger development pressures (Sanchis-Ibor et al., 2017; Albizua et al., 2019a).

In line with the compromised capacity to self-organise, our results also raise concerns about resource privatization or common enclosures. As Sanchis-Ibor et al., (2017) described in their analysis of the community of Senyera in Valencia (Spain), since the early 2000s, many regions have experienced penetration of service companies into irrigation water management. This does not always imply the privatization of the resource *per se* as the companies may merely provide operational services, as seems to be the case in this region. However, in other communities, service companies are in charge of constructing irrigation networks and allocating resources among users. This intervention of the private sector into water management and access might increase as farmers' autonomy and their capacity to organise their own rules diminish.

Overall, the analysis of the evolution of the principles for robust socio-ecological systems showed trade-offs between principles, contrasting those associated with control and surveillance with those associated with irrigators' autonomy and self-governance capacity. In the context of climate urgency and agricultural uncertainty, these trade-offs might be presented as inevitable by policymakers, justifying an increase in command and control by a desired efficient use of the common resource. However, this search for only technical efficiency might be compromised in the long run, as there are no important changes in the overall political and economic market structures that continuously encourage an increase in production and economic growth as an inevitable aim of food production (Schneider et al., 2010). Moreover, autonomy is an important, if not the main, institutional feature to assure a polycentric, decentralized and adaptive management of a CPR (Ostrom 2005). Without this feature, even the concept of the CPR, as a collective space to co-manage a common resource, is compromised, leading to a potential enclosure of the CPR and a transition to a hierarchical, centralized management system.

The potential loss of the commons (the space and the resource) in a context of uncertainty remains an important thread to the self- organizing capacity of farming communities. Commons contribute to building robust SES to confront future ecological and economic risks. Meanwhile, motivated by the forecasted water scarcity (IPCC, 2014), neoliberal policies continue to gain influence in resource management and water control could become a new profitable market. The influence of such economic dynamics might not be ignored in a context where agricultural market expansion continues to be nurtured, as in the case of Europe (Pacheco, 2006), contributing to increase farmers' vulnerability, decreasing their adaptive capacity, and reinforcing a maladaptation of agriculture to global change.

We recognise some caveats when applying a combination of the SES robustness framework and the design principles to assess SES robustness. First, these approaches fall short for a multi-scale analysis; it does not allow relating contextual and specific characteristics of the SES with broader political and economic contexts as the principles for the robustness of SES do not reflect the influence of global or political dynamics on maladaptation. The IRR framework could help to further analysis the role of formal rules and resource regimes, such as policies encouraging intensification and modernisation of agriculture, and their impact on maladaptation patterns. Second, Anderies et al. (2004) presented the design principles as a way to explore SES robustness while paying less attention on the basis of such principles, such as the way they could better encourage cooperation against the threat of overexploitation. One of our contributions is in illustrating how SES entities' cooperative relations are altered and consequently weaken the capacity of farmers to influence norms and rules governing water use and farmer's self-organisation capacity. Still, the application of the CPR institutional robustness framework could shed light on the relations between entities, the system's dynamics, and factors influencing collective action and co-management of CPR.

7. CONCLUSIONS

Our study shows that even if large-scale irrigation systems allow for more market access and better water consumption monitoring, there are still challenges when operationalising SES robustness principles. Special attention should be paid to the distribution of cost and benefits, the influence of power relations on the distribution of resources, and the decrease of the capacity of the users to self-organise. All of these issues are symptoms of maladaptation that results from the multiple shocks and stressors that rural communities face in Europe, such as climate variability and crop price volatility (Albizua et al., 2019).

These compromise the robustness of the ASES by creating feedback loops, where farmers' behaviour shifts to increase their use of water in a context of water scarcity, increasing inequalities between types of farmers.

Applied frameworks are not explicitly conceived to disclose maladaptation, although this dynamic was revealed during the qualitative interviews and focus groups, and the maladaptation concept is key to understanding and comparing the importance of the design principles. Patterns of maladaptation of CPR allow us to explain how institutional changes influence SES robustness. Moreover, this work illustrates the on ground consequences of populist manoeuvres that infuse post-political and post-democratic conditions (Swyngedouw, 2010). In other words, certain types of farmers—small landowners—are ignored in favour of those who can use efficient modern irrigation for a more 'sustainable' future agriculture. Such a trend might create conditions for further enclosure of agricultural commons, compromising resource access in a context of climate vulnerability.

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Table 1. Changes from the traditional to the new irrigation governance systems

Features	**Traditional system**	**New system**
Land access	Land distributed between a higher number of heteregenous types of farmers	Land distributed among fewer homogenous farmers
Governance levels	Local and autonomous irrigation communities (1 village/1 community) Decisions at the local level	Aggregated irrigation communities by irrigation sector (1 community/several villages) All sectors are further aggregated in a unique General Community (GC)
Costs	Long-term concession between farmers and the river basin agency Low fee for long-term water use	Short-term contracts between farmers and the concessionaire firm Farmers pay for water consumption, for maintenance and for conservation of the infrastructure

Table 2. Resulting ASES entities, components of the entities, and potential tension due to the modernisation of the irrigation system (from (Anderies et al. 2004))

Entities	Components	Potential problems
Resource	Labour, land, irrigation water	Unequal access to resources. Greater uncertainty about resource availability
Resource users	Farmers	Weaker social ties at the local level
Infrastructure providers	AguaCanal, Canasa, Government office (INTIA[7])	Need for higher coordination. Internal conflict, indecision, information loss
Infrastructure	Engineering firms	Break-downs, maintenance

[7] INTIA Tecnologías e Infraestructuras Agroalimentarias. Public company attached to Navarre Government that projected Itoiz-Canal de Navarra canal

788 **Table 3.** Links between entities

Link	Example	Past and present situation comparison and potential problems identified
(1) Between resource and resource user	Availability of water at the time of need/availability of crop	• The past system was limited to fewer crops and management practices • Farmers now are satisfied using automatic and remotely activated sprinklers • The area planned for irrigation has been progressively extended, increasing water demand • Farmers now are concerned about water availability in the future during high demand periods, due to the capacity of the dam, the higher water demand from new crops, and the lack of norms regarding irrigation turns. • The new management practices that may cause potential environmental impacts (erosion, pollution, pests)
(2) Between users and public infrastructure providers	Voting for providers Contributing resources Recommending policies Monitoring performance of providers	• In the past, there was no interaction with any infrastructure provider but rather a concession provided by the River Basin • Monitoring and sanctioning worked through internal social sanctioning (local guard and irrigation community assembly). The dialogue was a tool for decision-making and sanctioning. Few interviewed farmers also reported some abuse by a minority • Now, there is uncertainty about how the firm will manage sanctions and conflict resolution • Some farmers fear more control and less flexibility (dialogue) on mangagement issues.
(3) Between public infrastructure providers and public infrastructure	The building, maintenance, monitoring and enforcing rules	• In the past, the public infrastructure provider was mainly absent regarding infrastructure's management and there was a direct relation between users and infrastructure • Now, users are no longer involved in building, maintenance, and monitoring of infrastructure. Instead, an external firm is in charge of all this

(4) Between public infrastructure and resources	Impact of infrastructure on resource levels	• The new system has a higher environmental impact from the building large canals
(5) Between public infrastructure and resource dynamics	Impact of the infrastructure on the feedback structure, Harvest dynamics	• No percolation of water back to the system • There are proved effects of river regulated by dams such as lack of sediments, channel narrowing and river incision (Kondolf, 1997; Vericat et al., 2006)
(6) Between resource users and public infrastructure	Maintenance, monitoring, and sanctioning	• In the past, resource users were in charge of the well function of the infrastructure. • Now, there is a disconnection between users and infrastructure. Farmers no longer maintain the infrastructure
(7) External forces on resource and infrastructure	Climatic hazards	• Now, climate variability is less felt by farmers • Consequences of long-term climate change are uncertain in this region (e.g. water scarcity, extreme events such as floods)
(8) External forces on social actors	Political changes, migration, commodity prices	• Now, there is a higher dependence on subsidies for the installation and payment of water quotas • There is an increase in prices of irrigation quotas • High volatility of the international crop market

Note: Numbers refer to the connections shown in Figure 2

Table 4. Comparison of farmers' interpretation of large-scale and traditional irrigationsystems and their implications for robustness

Principles	**Traditional system**	**Large-scale system**	**Implications**
1. Clearly defined resources boundaries			
Physical boundaries (-)	Direct access to water from the river, close to the irrigated land (<10 km)	Water coming from Itoiz dam and transported through a 187 km canal	The physical boundaries of the infrastructure are clear in both systems. Water volume boundary is poorly defined in both systems but it seems to remain more unclear in the large-scale system
Water volume (?)	Contracted water volume: 1200–3000 m^3/sec for about 75 years. A low fee equal for all irrigators	Water consumption is not fixed, it depends on the demand and it has a fixed fee. Overall volume consumed remain unclear for farmers	
2. Equivalence between benefits and costs			
Financial (=/+)	Low-cost infrastructure. Low crop yields Long-term concession between farmers and the river basin agency, which involved low fees for long-term water use	Higher cost infrastructure, higher crop yields Short-term contracts between farmers and the concessionaire firm Farmers pay for water consumption and for maintenance and conservation of the infrastructure	In financial terms, benefits and costs are balanced in both systems–i.e. *a priori*, if farmers invest more, they gain more
Cultural (-)	High level of cultural services such as traditional knowledge, educative	Reduction of most cultural services	The new system suppresses some cultural services while provisioning services (yield) increase

	services and other services related to relational values such as self-stem of farmers and rural identity		
Market options (+)	Reduced access to international markets	Access to international markets	The traditional system did not allow large-scale farmers high enough yields for commercialization on the international market
Irrigation water access (-)	All types of farmers had access	Small-scale diversified farmers lose their access	The new systems lead to the abandonment of farming by some small-scale farmers
3. Monitoring and graduated sanctions			
Surveillance (+)	Local surveillance and a designed monitor —maintenance person —at the village level	External company (regional level)	Access to governmental bodies in charge of water allocation was easier in the past and hence everyone benefitted from greater water access. However, this could mean an inefficient use of water. The monitoring-scale (water management) increases along with the use of technology and human resources
Control (+)	No consumption meter boxes	Consumed water is measured	
Sanctions (+)	A local guard was in charge of reporting infractions or other issues to the assembly. The assembly was in charge of sanctioning. There was normally absence of formal sanctions	Higher remote control perceived	
4. Collective choice arrangements / Recognition of rights to organise			
Autonomy (-)	Higher local autonomy Each community discussed issues in the local community assembly	Top-down bureaucratic governance Less representation of farmers in the General Community level, composed of representatives of the different irrigation sectors Increase control of an external concessionaire firm	The community's decision-making autonomy has been reduced. In the traditional system, most individuals affected by the rules were included in the decision-making process. In the new system, farmers lose this power as decisions are made at a higher and more integrated level

		Irrigators are uncertain about how sanctioning will work	
5. Conflict resolution mechanisms			
Mechanisms (?)	The dialogue was used when infractions occurred. They normally adopted strategies of reciprocity	Notification of infractions by enforcers external to the community, and legal processes when infractions occur	The mechanisms seem similar in both phases of the system. However,in the new system those mechanisms are external to the communityand their effectiveness is still uncertain since they have been in operation for a few years

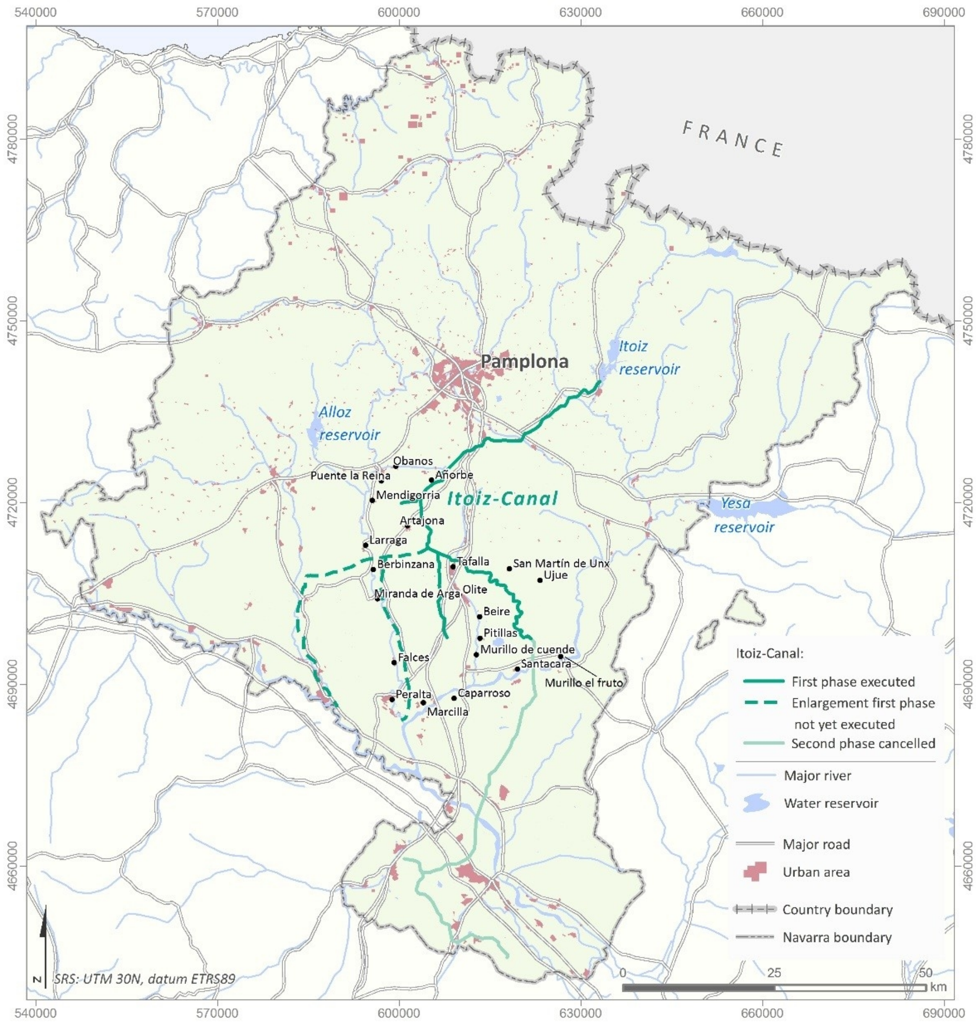
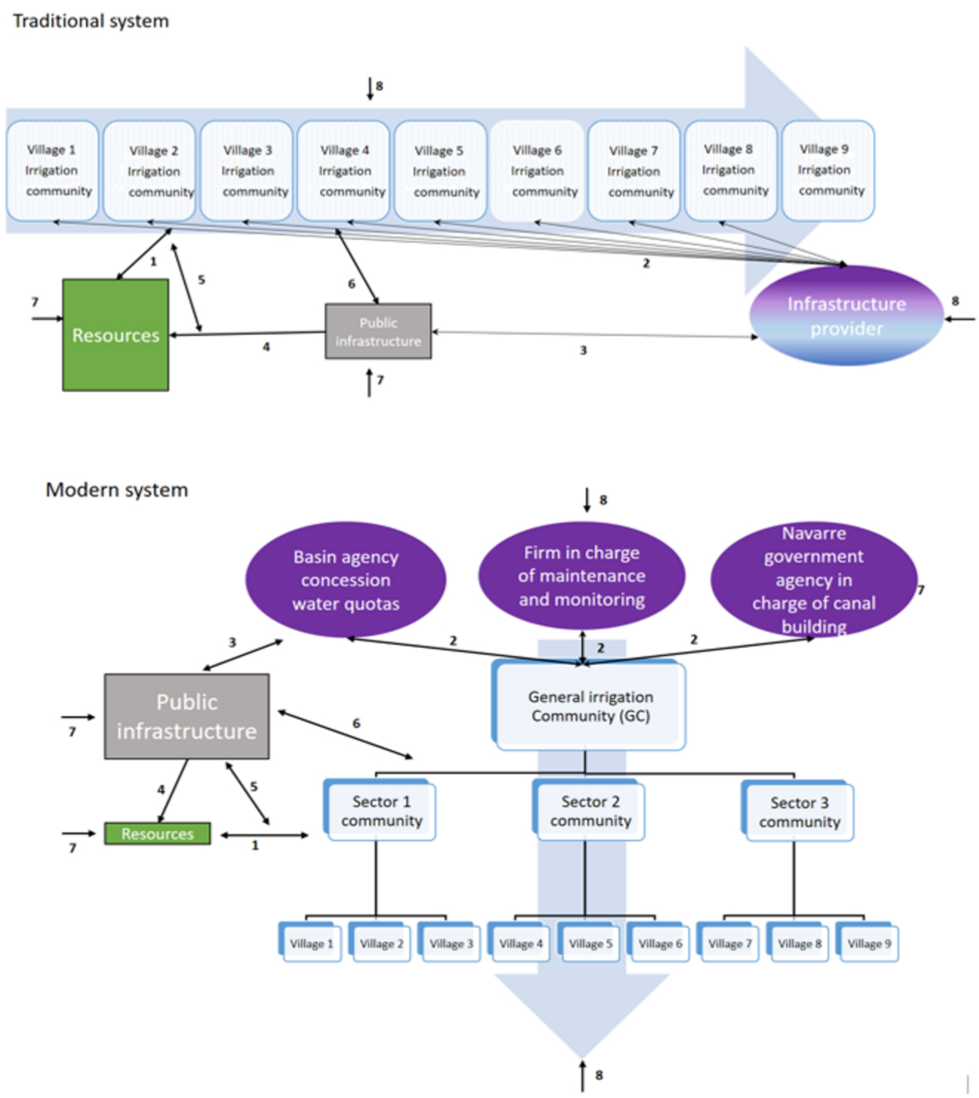


Figure 1. Location of Navarre and the case study in Spain

139x142mm (220 x 220 DPI)



Comparison of entities and their links in the traditional and new irrigation social-ecological systems