Villamayor-Tomas, Sergio (*in press*), Polycentricity in the Water-Energy Nexus: a comparison polycentric governance traits and implications for adaptive capacity of water user associations in Spain, *Environmental Policy & Governance*.

Abstract:

This paper assesses the merits of polycentricity by looking at the water-energy nexus in the Spanish irrigation sector. In the last decades, the Spanish electricity and water governance systems have transitioned from relatively monocentric, top-down arrangements to arrangements that exhibit traits of polycentricity. This paper characterizes both governance systems against a series of polycentricity traits and provision and production activities. Then the paper assesses the merits of the featured systems against the capacity of water user associations (WUAs) to adapt to water and electricity supply dynamics. The study relies on quantitative and archival data collected from a set of 38 irrigation systems located in the Northeast of Spain as well as secondary data from the broader water, energy and irrigation sectors. As illustrated in the analysis, WUAs can play a key role in integrating the management of water and electricity. They do so locally, via a diversity of institutional and operational adaptations. This role, however, requires sufficient levels of autonomy, clear rules that shape the interactions of WUAS with other water and electricity authorities, and a relatively competitive environment.

Key words: polycentricity, framework, water energy nexus, Spain, irrigation, water user associations

Word count (without appendix, abstract and references): 8290

1. Introduction

The nexus approach has inherited from the long-standing Integrated Water Resources Management (IWRM) paradigm a concern over the need to integrate policy decisions across sectors and organizations (Benson et al., 2015). However, while the IWRM paradigm prescribes the organization of resource management at the river basin scale, the nexus approach emphasizes the need of multi-level governance systems. The interest in multi-level governance is indeed one of the most genuine features of the nexus approach. As of now, however, nexus scholarship has not offered normative principles or theory about how such governance shall occur (Benson et al., 2015). This paper aims to start filling the gap by introducing polycentricity theory and testing it against the capacity of local authorities to cope with water-energy couplings (Scott et al., 2011). For this purpose, the paper unfolds into a case study of the way irrigation associations in Spain have adapted to changes in water and electricity supply dynamics, and the extent to which their adaptive capacity can be explained by polycentricity traits of the broader water and electricity governance systems.

Polycentric governance systems can be distinguished from markets and centralized and decentralized governance systems. In markets, individual citizen-consumers are responsible for their own provision of goods and services, and each must seek out the producers that supply them. In centralized systems, a government makes decisions over the supply of public goods and services (e.g., water and energy networks) on behalf of citizens and shall in turn be accountable to said citizens-consumers (e.g., via representative democracy). In decentralized arrangements, significant amounts of independent legislative and fiscal authority (i.e., provision decisions) are allocated to subnational (e.g., regional, local…) governments. In polycentric governance systems, different authorities, whether central and local governments, agencies, self-governed user groups, firms or other hybrid organizations participate in both markets and planning processes horizontally across the territory and vertically across geographical scales to co-produce public goods (Ostrom et al., 1993).

Polycentricity theory has been successfully used to make sense of the "organized chaos" of metropolitan governance in the US (McGinnis, 1999b; Ostrom et al., 1961). Such "sense-making", however, runs the risk of being too normative if applied as a blueprint and not as a hypothesis across other contexts. This study relies on and aims to contribute to two research strands within polycentricity studies that have mobilized polycentricity theory beyond normative claims. The first strand has focused on the merits of polycentric governance as compared to centralized and market governance systems (Andersson and Ostrom, 2008; Baldwin et al., 2015; Galaz et al., 2012; Gruby and Basurto, 2013; Herrfahrdt-Pähle and Pahl-Wostl, 2012; McCord et al., 2017; McGinnis, 1999a; Ostrom, 2010). In theory, polycentric governance systems are more flexible and less vulnerable, reflect local conditions and preferences better, and are more conducive to experimentation and learning take place than alternative systems (Carlisle and Gruby, 2017; Morrison et al., 2017). This study aims to test the theory from the perspective of WUAs and their capacity to adapt to water and energy crises The second stand is concerned with the conceptualization and operationalization of polycentric governance traits. This research responds to several motivations, including a concern about the challenges of testing the merits of polycentricity without a clear analytical grid (Aligica and Tarko, 2012), the need to distinguish polycentricity from similar paradigms (Hooghe and Marks, 2003; Huitema et al., 2009), and an interest in developing theory on varieties of polycentric governance (Aligica and Tarko, 2012; Galaz et al., 2012). This strand has been much less developed, partially due to the difficulties of constructing a meaningful and operational analytical grid. This study aims to contribute to fill the gap by operationalizing and expanding Aligica and Tarko's (2012) framework.

Few scholars have paid systematic attention to the governance of water-energy interactions, and even fewer have looked at the efforts made by local self-governed user groups to manage water and energy in an integrated manner (Scott et al., 2011; Villamayor-Tomas et al., 2015). A paradigmatic example of local such groups are irrigation water user associations (WUAs). In the irrigation sector, water is used to produce crops, and energy is used in many cases to produce (i.e., withdraw) and distribute water (i.e., via pressurized irrigation technologies). Additionally, water can be also used to produce energy (i.e. via turbines in the irrigation canals and reservoirs). Thus, farmers are potentially exposed to both water and energy events and policies, and may need to adapt accordingly.

Spain is internationally recognized for the strength of its irrigation sector and long tradition and autonomy of its WUAs (Blomquist et al., 2005; Ostrom, 1990). The Spanish irrigation sector represents almost a third of the total irrigated area in the European Union. Irrigation in Spain accounts for 80% of total farm exports in the country, but also consumes 70% (around 21,000 Mm3 in 2013) of total water resources in a typical year (Hardy et al., 2012; López-Gunn et al., 2012). In the last 20 years, a series of severe droughts and the growth of cities and industry in Spain have resulted in a concern about the sustainability of the sector. One of the responses of farmers and WUAs to the new scenario has been the transition from flood to sprinkler and drip irrigation. The measure, heavily promoted by the government since the early 2000, has in turn aggravated the dependence of the sector on energy. The energy consumption share of the sector is not particularly high (less than 3% of total energy use; 70% of which is electricity); however, energy consumption has been growing without stop for the last 50 years, reaching the peak of close to 6,600 GWh in 2007, (Berbel et al., 2014; Hardy et al., 2012). The increasing dependence of the sector on energy became a problem from the 2008 on, when the government eliminated subsidies to electricity prices in the sector as part of its energy liberalization reforms.

The water and electricity governance systems in Spain display some traits of polycentricity. The water sector resembles a centralized system, i.e. one that centers around the authority of River Basin Organizations (RBOs); however, WUAs and other local authorities have strong autonomy and are effective integrated in the planning and operations of the RBOs. The electricity governance system has been traditionally under the control of the central government; in the late 1990s, however, the government introduced competition in the production and commercialization stages.

The sections that follow include: an introduction to polycentricity theory (2), a description of the methods used to assess polycentricity (3); an overview of the water and electricity governance systems in Spain and the WUAs under study (4); an account of the relative adaptation capacity of the WUAs against droughts and high electricity prices (5); a discussion linking adaptation capacity to polycentricity traits of the water and electricity governance systems; and some final reflections (6).

2. Theory

Traits of polycentric governance systems

An important distinction associated to the polycentricity paradigm is that between provision and production decisions. Provision involves decisions about how much and in which qualities to consume and how to organize the payment of production. Production decisions include how, when an at which cost to produce the good (Ostrom et al., 1993). Thus, it is not necessary that the organizations that make provision decisions are also involved in the production of the good. Production decisions can be contracted out to other organizations.

Four key aspects of polycentricity are co-production, local self-governance capacity, subsidiarity and coordination (Aligica and Tarko, 2015). Co-production refers to the idea that citizens are a key part of the process of providing public goods. Local self-governance, whether in the form of "indigenous" communities, cooperative organizations, or local governments, can pave the way for co-production. More frequently than not, however, decisions by local organizations are undermined by those of higher level organizations. That is why polycentricity scholars have also emphasized the importance of the subsidiarity principle, according to which any particular task should be decentralized to the lowest level of governance with the capacity to conduct it satisfactorily (Marshall, 2008). Finally, there is the need of coordination among the different authorities of the system. In this regard, authors distinguish polycentric arrangements, which do not include the existence of an overarching set of rules that coordinates interactions between the authorities, from polycentric governance systems, which do include it (Marshall, 2016).

Polycentric governance systems and Performance

The adaptation benefits of polycentric governance systems have been highlighted from both the transaction cost approach and complexity science. As pointed by Williamson (Williamson, 2002) hierarchies, or centralized institutional arrangements are good at adaptation when changes are sudden and consequences relatively predictable. In those occasions, command-and-control can quickly promote coordination in the right direction. Alternatively, market and decentralized arrangements are good at adaptation in the advent of progressive but uncertain changes. In these occasions, the sequential decision making and contracting among a multiplicity of agents shall provide for flexibility and learning (Williamson, 2002). Polycentric governance systems are decentralized but still coordinated and thus potentially combine efficiencies of both markets and hierarchies (Marshall, 2016).

A similar reasoning emerges from a complex systems perspective (Galaz et al., 2012; Wilson, 2001). The autonomy granted to governmental units, agencies, NGOs, cooperatives firms and other organizations within their jurisdictions promotes creativity and entrepreneurship. Coordination, in turn, facilitates the adjustment of innovations and learning across such self-organized processes.

The benefits of polycentric governance systems have been associated to three necessary conditions. The first of them is the "active exercise of diverse opinions and preferences" of the different authorities within their jurisdictions. The second is the "alignment between rules and incentives", meaning that rules and their consequences are relatively transparent and considered useful by the authorities. The third condition is "autonomy", or the capacity of authorities at lower levels to make operational decisions independently from higher levels if they wish so (Aligica and Tarko, 2012).

3. Case study background

The water sector: multiple provision and production centers around RBOs

Much of the current water governance system in Spain has its origins more than a century ago. The Water Act of 1979 and subsequent regulations prescribed the organization of water governance into river basin organizations (RBOs) with the goal of guaranteeing reliable water production and distribution, mostly for irrigation. This goal was accomplished via the establishment of water use rights systems and the planning of big storage and conveyance infrastructure (Perez Picazo and Lemeunier, 2000). The Law prescribed a decentralized system for irrigation management. Farmers would be granted collective use rights and full authority to self-organize into water user associations (WUAs) to distribute the water and maintain the infrastructure.

The transition to democracy and growth of cities and industrial poles in the 1970s, and the regional decentralization, advent of the environmental discourse and social contestation against dam building in the 1980s, all led to a change in the water management paradigm. The change materialized in new Water Laws in 1986 and 2001, and a number of subsequent reforms aiming to integrate the new interests around water. Currently, both regional and local governments, as well as urban and industrial users enjoy, along with the irrigation sector, representation and full voting rights in the RBOs. Planning now includes a number of affairs other than hydro-agricultural infrastructure building, and is carried through the organization of stakeholder participation processes.

The electricity sector: a differentiated market of buyer and sellers

The energy sector has historically been managed as a public monopoly by the central government for both the provision and production of electricity. In the late 1990s the government approved a reform to introduce competition in the production, distribution and commercialization of electricity. The central government kept the ownership over the distribution grid and the regulatory power (shared with the Congress). A joint public-private operator controlled by the central government (*Red Electrica Española*) rents the distribution grid to electricity distribution firms. Retailer firms obtain the energy from electricity generation firms in a wholesale energy market and sell it to consumers in a retailer market. Currently, there are more than 200 retailer firms {CNMC, 2016 #2328}. The number of generation firms has decreased over time, from over 35 in 1990 to only five in 2002 (Serrallés, 2006). Electricity generation firms are currently the same as the electricity distribution firms.

Over time most regional governments have gained authority over energy taxing and planning (Jefatura de Estado, 2013). Still the main planning tool is the National Electricity Plan (NEP), which is elaborated by the central government (in consultation with the regional governments). The plan includes previsions of investments in distribution infrastructure as per estimations of electricity demand and supply (MINETAD, 2015).

The Riegos del Alto Aragon project

The RAA project is a paradigmatic example of the hydro-agricultural policy in the region of Aragon, and Spain. It was designed in the early 20th Century and progressively implemented over the decades, becoming the largest irrigation project of its kind in the country. The project is located in the Ebro river valley (see Appendix 1), and consists of two big canals that divert water from the Gállego and Cinca rivers (Ebro tributaries), and convey it to 135,000 has, 115 small municipalities, 650 cattle ranches and 10 industrial complexes (RRAA, 2012). Irrigation is organized into 50 systems (see Appendix 2 for descriptive statistics). Most of them were designed to use flood irrigation. In the last decades, however, the government has intensively promoted a transition to pressurized irrigation via subsidies. As a result, the area covered by pressurized irrigation has increased from less than 20% in the early 2000s to more than 50% in 2015 (Villamayor-Tomas, 2016). The most notable increase took place from 2006 to 2009 (see also Appendix 2). In 2016 (last data officially available), the project consumed 798 Hm3 of water and around 50Mwh of electricity (RRAA, 2016).

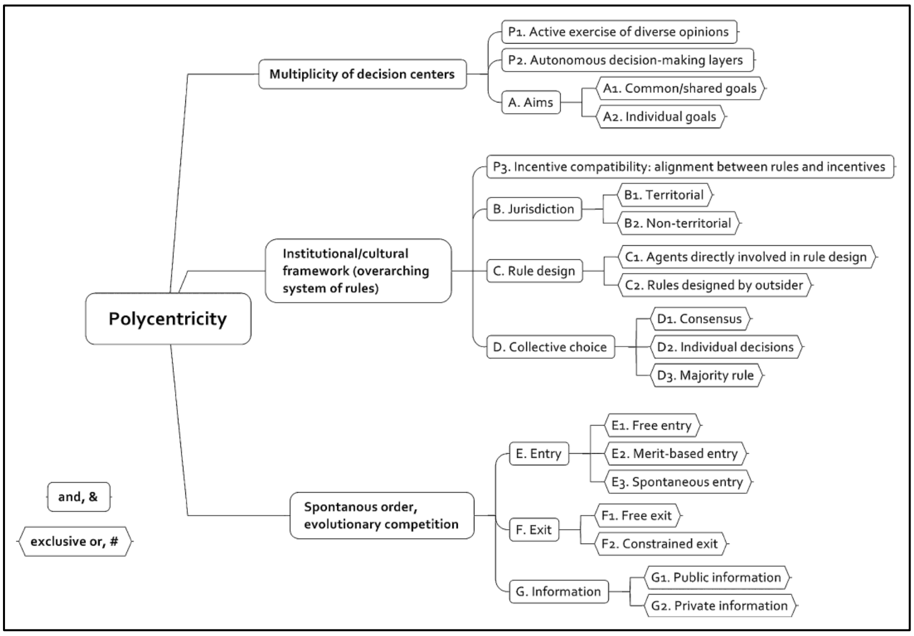
Each of the 50 irrigation systems is managed by a water user association (WUA). The 50 WUAs are in turn coordinated by an umbrella organization (hereafter the RAA organization). The project is supplied by two reservoirs that are managed by the Ebro river Basin Organization (E-RBO). The main canals are jointly managed by operators from the E-RBO and the RAA organization. Once the water enters into the irrigation systems, it is the responsibility of the WUAs to manage it.
In recent times, the project has been confronted with threats of different kind and the need to adapt. Two of the most recent stimuli for adaptation have been the drought of 2005-2006 and the financial crisis that followed the government decision to eliminate subsidies to electricity use in the sector from 2008 on.

4. Methods

Methodologically, the analysis included two stages. The first stage consisted on the assessment of the responses that the WUAs under study have developed to cope with water and electricity supply crises. Qualitative data were obtained via semi-structured interviews as well as through the revision of secondary documents (i.e., mostly yearly reports elaborated by the WUAs) and used to identify how WUAs have responded to the 2005-2006 drought and the rise in electricity prices; and the extent to which they have relied on other authorities for that purpose. A total of 23 interviews were carried out with officials from the WUAs, RAA organization, the E-RBO, and the National Federation of Irrigation Associations (FENACORE). Quantitative data on water and electricity use was obtained from the WUAs and the RAA organization, and processed to explore the extent to which the WUAs have successfully coped with the disturbances. Adaptation to droughts, was assessed by looking at "irrigation performance", which was computed as a ratio between water available and crop water needs in the RAA project (Villamayor-Tomas, 2014). Adaptation to the rise in electricity prices was evaluated by looking at the evolution of the electricity costs generated in the project, i.e., whether WUAs and the RAA organization were able to contain such costs and decouple them from changes in electricity prices. The choice of these two outcome variables was suggested by farmers themselves.

The second stage consisted on a characterization of the water and electricity governance systems through the polycentricity lenses[1]. The characterization relied on the framework developed by Aligica and Tarko (2012). According to these authors the "active exercise of diverse opinions and preferences", the "alignment between rules and incentives" and "autonomy" are core factors of performing polycentric governance systems. Additionally, there are number of other factors that are not necessary but still important for performance (Aligica and Tarko, 2012) (see Figure 1). Those factors allow observers to distinguish varieties of polycentricity, and can help move current research from a narrow comparison between "polycentric vs. monocentric systems" to an exploration of the conditions under different polycentric governance systems perform better.

Figure 1. Logical structure of polycentricity: traits for assessment



Note: P1, P2 and P3 are necessary conditions of performing polycentric governance systems.
Source: Aligica and Tarko (2012).

As an innovation to Aligica and Tarko's analytical grid, this study added the distinction between provision and production of public goods. Thus the 10 polycentricity traits (i.e., P1-

[1] This study understands water and energy networks as public goods of relatively similar characteristics (Kimmich 2013).

P3, and A-G from Figure 1) were used to feature the water and electricity governance systems both with regard to production and provision decisions (see Table 1 and Appendix 3).

Table 1. Guiding questions to assess polycentricity traits

Autonomous centers of authority	
P1. Active exercise of opinions	Do authorities (*e.g., WUAs*) have the capacity to collectively make and implement provision/production decisions within their jurisdictions? *(Yes/No)*
P2. Autonomy	Do authorities have autonomy to make autonomous provision/production decisions in their jurisdictions? Is the decision making capacity of local authorities (*e.g., WUAs*) complemented (and not undermined) by higher level authorities? *(Yes/No)*
A. Goals	Do authorities have *common/individual* goals?
Overarching rules	
P3. Incentive compatibility	Do authorities consider useful the overarching set of rules that shape their incentives and interactions? Is the connection between rules, behavior and consequences clear for all authorities? *(Yes/No)*
B. Rule design	Are the decisions to design/reform the overarching set of rules taken by *insiders/outsiders* of the system?
C. Jurisdiction	Are the jurisdictions of authorities *territorial/non-territorial*?
D. Collective choice	How are decisions among multiple authorities taken? (*majority rule, consensus, individually*)
Evolutionary competition	
E. Entry	Is the entry of new authorities in the sector *merit based/free/spontaneous*?
F. Exit	Is the exit of authorities in the sector *merit based/free/spontaneous*?
G. Information	Is relevant information for provision/production decision making *public* (shared among all authorities) or *private*?

Based on: Aligica and Tarko (2012) and Marshall (2008)

Associations between capacity of the WUAs to cope with the water and electricity crises and polycentricity traits of the water and electricity governance system were drawn via comparison.

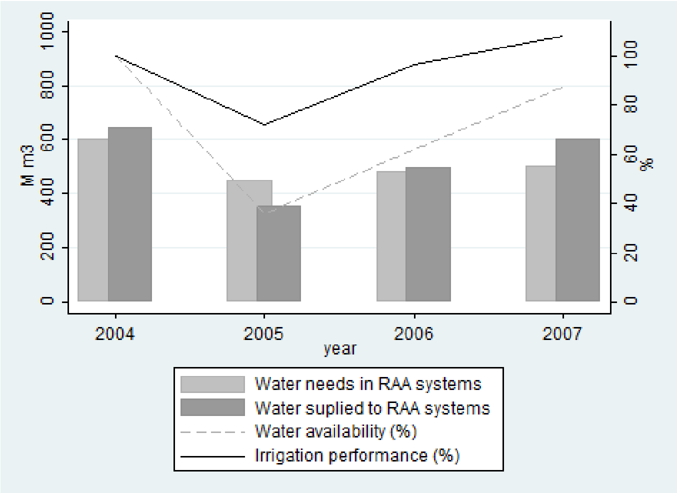
5. Results: Adaptive capacity in the Riegos del Alto Aragon project

Adapting to (the 2005-2006) drought

In the last 20 years a series of severe droughts in Spain have seriously threatened the sustainability of the irrigation sector (Roldán, 2007). The drought of 2005-2006 (see Figure 2) was particularly severe in the Ebro basin and the Gallego-Cinca sub-basin. The Water Law gives priority to urban uses over irrigation and industrial users, meaning that the RRA project, main non-urban user in the Gallego-Cinca sub-basin, was confronted with the need to reduce consumption drastically.

The 2005-2006 drought triggered responses at all levels of governance in a relatively coordinated fashion. At the sub-basin level, the E-RBO held meetings with representatives of the RAA project and other user groups to allocate the water proportionally to each group's rights. To distribute the allocated water across WUAs, the RAA organization implemented a transferable quota policy and also strengthened monitoring efforts (Villamayor-Tomas, 2014). To manage the quotas, the WUAs used a diversity of measures, including "emergency" water allocation rules, strengthened monitoring mechanisms, and the temporal use of wells and reuse of drained water. The authorization to use the drainage system was granted by the RAA organization, while the right to use the wells was given by the E-RBO. The quotas were transferable so a farmer with land in two WUAs could request water to be sent from one WUA to another. Thus, many farmers ended up concentrating their water rights in the systems that enjoyed higher water productivities, i.e., dominated by sprinkler irrigation and high water-demand crops (see table in Appendix 5).

Fig. 2. Evolution of total water available, average water received, average water needs and average performance in the RAA systems (2004–2007)



n=38
Note: The base year for water availability and irrigation performance (right Y axis) is 2004 Water availability is based on reservoir inflows. Water received is the total water sent by the Ebro RBO to the RAA irrigation project. Water needs are estimated based on crops cultivated in each of the irrigation districts within the RAA project. Irrigation performance was computed as an averaged ratio between water received and water needs at the irrigation district level. A decrease in the performance indicates that farmers were less able than usual (i.e, 2004) in adjusting their water needs to water availability.
Source: Own elaboration based on data from the E-RBO and Villamayor-Tomas (2014).

To compensate farmers for their water conservation efforts, the E-RBO cancelled the water fee they charge to the WUAs. Also, the regional and central governments mediated with the EU to lessen the conditions under which farmers can receive the European Common Agricultural Policy subsidies. The central government also approved a series of Royal Drought Decrees that provided a selection of RBOs, including the E-RBO, with budget and regulatory power to invest in emergency supply and water efficiency infrastructure, enable temporal water markets and look for alternative water sources, among other operations (Hernandez Mora et al., 2012; Sánchez et al., 2006). Permanent Drought Commissions, including representatives of basin authorities, regional, local and user authorities, were responsible for following implementation of the Decrees. The government subsidies to promote pressurized irrigation can be also understood as a measure to adapt to droughts (Lecina et al., 2010; MAGRAMA, 2015). Many WUAs in the RAA project used the subsidies to build in-system pools and pave ditches. Many others invested in pumped irrigation.

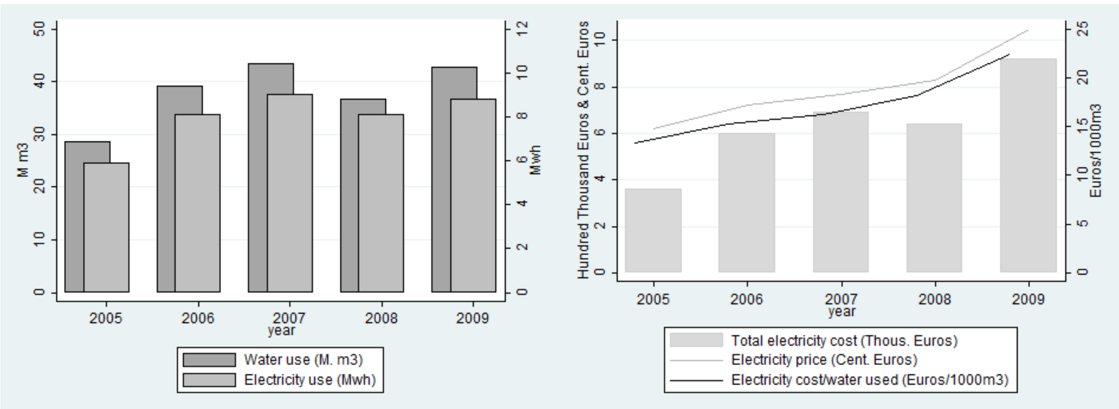
Overall, the joint actions taken by the E-RBO and RAA organization contributed to build adaptation capacity and buffer the effects of the drought. Despite the 60% decrease in water availability, "irrigation performance" only decreased by 20% (see Figure 2). (Villamayor-Tomas, 2014).

Struggling with (the 2008-to date) electricity price crisis

The year 2008 set the start of an electricity and financial crisis in the irrigation sector that still continues. Traditionally the sector had benefited from a reduced (i.e., subsidized) electricity tariff but, in 2008 the tariff was eliminated and the sector had to face actual market prices, which had been progressively increasing since the liberalization reform. Additionally, the government decided to introduce changes in the market price structure, making electricity more expensive in summer time (peak of irrigation campaign) and some periods of the week (e.g., weekends). As a result of all these changes, electricity costs in many Spanish irrigation systems increased dramatically (Berbel et al., 2014; García de Durango, 2014; RRAA, 2009). In 2008, 16 out of the 50 WUAs in the RAA project applied sprinkler irrigation (55,000 hectares, 41% of the irrigable area). An internal study carried out by the RAA for a selection of those WUAs in 2008 estimated an increase of 50% in electricity consumption and more than 150% in the electricity bill from 2005 to 2009 . A detailed look at those numbers illustrates the influence of the rising electricity prices on the electricity bill (Figure 3b), even if partially mediated by water –and energy- use (see decrease of the electricity bill from 2007 to 2008, in Figures 3a and 3b). Electricity use grew at This put the RAA project in a difficult situation and triggered a number of responses.

Figure 3. Evolution of water and electricity use, and electricity price and bill for a sample of irrigation systems with RAA project.

a **b**



n=5

Note: Production and consumption are measured in Gigawatts per hour (left Y axis in graph a). The cost of electricity use (right Y axis on both graphs) is the result of first multiplying the electricity consumption times the price of electricity paid in the project (left Y axis in graph b), and then adding it to a fix cost that depends on the power term contracted.

Source: Own elaboration based on data from the E-RBO.

One of the first responses of most of the WUAS in the RAA project and elsewhere to the crisis was the redesign of irrigation schedules to fit the periods when electricity prices are lower. A number of WUAs also commissioned electricity audits to better estimate their consumption and adjust their contracts with retailer companies accordingly. A few WUAs were also able to sign contracts with electricity retailer companies just for the irrigation campaign (otherwise WUAs are obliged to contract electricity for the full year).

The RAA organization has played an important role to facilitate the implementation of efficiency measures. The organization has organized informative meetings and workshops regularly and also promoted a real-time online system for data collection on water and electricity use. Additionally, the RAA organization has coordinated the collective bargaining and contracting of energy between the WUAs and the retailer companies to reduce costs (RRAA, 2010). According to estimations by the National Federation of Irrigation

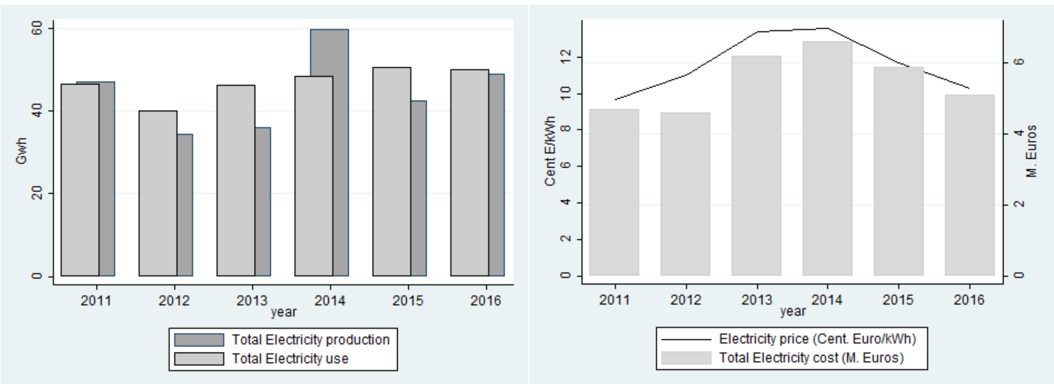
Associations (FENACORE), collective bargaining could save the ensemble of Spanish irrigation communities around €56M (FENACORE, 2013); however, the scaling up of collective bargaining should not be taken for granted. Neither WUAs nor second order organizations like the RAA enjoy a "Public Administration" status in the energy sector that would allow them, for example, to have first-hand access to information compiled by the regional and central governments, enjoy enforcement authority for electricity-related affairs within their jurisdictions, or be compensated for investments in the distribution infrastructure in case of contract failure.

The other key role played by the RAA organization has to do with the strategic use of electricity production capacity. The RAA project counts on 7 turbines located in the main canals of the project. To recover costs, the RAA organization had been selling the energy at market prices (before the crisis it did it at a flat, regulated rate). To be registered as an electricity generator, the RAA organization has to commit with the government to a particular amount and timing of supply, which requires a careful planning of irrigation to guarantee constant water flows into the turbines.

Additionally, the RAA organization has explored the option of using its production capacity for self-consumption (Retema, 2015). The amount of electricity produced is rather sufficient to satisfy the needs of all WUAs on average, but it fluctuates a lot from year to year (see Figure 4.a). Moreover, there are institutional barriers. Auto-production make sense in the context of "net balance" systems, which allow auto-producers to deliver energy surpluses to the grid in exchange of discounts in the electricity bill or of energy during periods of production deficit (Energia y Sociedad, 2014); however, current regulations do not contemplate that option. Also, according to a Royal Decree signed in 2015, auto-producers have to pay a tax associated with the public maintenance of the distribution system regardless of the use they make of the grid (BOE, 2015), and it is forbidden that auto-producers self-organize to pool production and demand. This context stays in stark contrast with that of many other European countries, where the system of Net Balance not only is allowed but also promoted (EC, 2015; Ropenus and Skytte, 2005).

Figure 4. Evolution of total electricity production, consumption, cost and prices in the RAA project

a **b**



Note 1: 2011 is the year when most of the measures developed by the RAA organization and WUAs were fully implemented.

Note 2: The cost of electricity use (right Y axis on both graphs) is the result of first multiplying the electricity consumption times the price of electricity paid in the RAA project (left Y axis in graph b) and then adding it to a fix cost that depends on the power term contracted.

Source: Own elaboration based on data obtained from the RAA organization

Overall, the measures of the WUAs and the RAA organization had some effect although maybe not as much as needed. As shown in Figure 4.a, the increase in electricity consumption has decelerated. The electricity produced in the project amounts to around 46Mwh/year on average since 2011 which is very close to the averaged electricity consumption for the same period (48Mwh/year). That said, electricity production is quite volatile (standard deviation of 8Mwh/year and range of 24Mwh/year over the period). More importantly, the influence of electricity prices on electricity costs is still quite strong (Figure 4.b), which illustrates the pervading vulnerability of the project to market dynamics.

Supplementary to the measures taken by the WUAs and the RAA organization, there are also actions implemented by the regional, basin and national authorities. The E-RBO has sold the hydroelectricity produced in the basin to WUAs at reduced prices (CHE, 2015). At some point, the government of Aragon also explored with WUAs the construction of large scale, renewable energy projects within the systems; however, the lack of sufficient funding and a sudden decision by the central government to cut subsidies to renewable energy production, prevented the venture from materializing (RRAA, 2010). Finally, the central government has also implemented electricity tax and price deductions (RRAA, 2012), funded programs to disseminate measures to increase energy efficiency in the irrigation sector, and initiated some planning measures to better integrate irrigation and energy policies (Mayor et al., 2015; Rocamora et al., 2008).

A number of the measures put in place by the government were implemented in response to the lobbying activities carried by the RAA organization in Aragon and the FENACORE in Spain. These included from formal complaints to demonstrations and meetings with politicians. Despite the changes, there are a number of other requests that the government has resisted to make, such as giving priority to WUAs in the approval process for electricity production, more flexibility in the contracting of power term, further tax reductions, a special tariff for the irrigation sector, or the suppression of the tax to self-production.

6. Discussion

WUAs in Spain operate in the interface of a water governance system and electricity governance system. Both systems display traits of polycentricity but not necessarily the same (see Table 3). A comparison of those traits can help to understand why the RAA project WUAs have tended to cope better with droughts than with the rise of electricity prices. .

Differences that explain WUA adaptive capacity across the water and energy sectors

Relevant differences in polycentricity traits across the water and electricity sectors concentrate mostly on the production activities, and are related to the autonomy (*exercise of diverse interests*, *formal authority* and *subsidiarity*) granted to the WUAs, the *clarity* and *openness to WUA participation* of regulations and policies, and the degree to which evolutionary competition (i.e., via proper *information* sharing and lack of *entry* barriers) is guaranteed.

WUAs display in both the drought and electricity crises a diversity of adaptation responses (see *Active exercise of diverse interests* in Table 3 and Appendix 4 for a detailed account of the evidence). Some of those responses are adjusted to the specific features of each irrigation system and carried out by the WUAs themselves (i.e., different irrigation rules and schedules depending on irrigation technology). Other responses have been developed and carried out by the RAA organization (e.g., transferable quota policy, collective bargaining with electricity generators). In comparative perspective, the responses were less diverse in the electricity crisis than in the water crisis. To cope with the rise in electricity prices, WUAs focused exclusively on demand management measures (e.g., adjustment of irrigation schedules); however, to cope with the drought, WUAs used both demand and supply (new sources of water) measures.

Table 3. Polycentricity traits in the water and electricity sectors from the perspective of WUAs

	Water		*Energy*	
	Provision	**Production**	**Provision**	**Production**
Autonomous centers				
P1. *Exercise of diverse interests*	Yes	Yes	Yes	*No*
P2. *Autonomy: Formal authority & subsidiarity*	Yes & Yes	Yes & Yes	Yes & Yes	*No & No*
A. *Goals*	Common	Common & Individual	Common	*Individual*
Overarching rules				
P3. *Clear consequences of rules*	Yes	Yes	*No*	*No*
B. *Rule design and redesign*	Outsider	Outsider	Outsider	*Insider*
C. *Jurisdiction*	Territorial	Territorial	Territorial	Territorial & Non-territorial
D. *Collective choice*	Majority rule	(None)	Individual	*Consensus*
Evolutionary competition				
E. *Entry*	Merit based	Merit based	*Free*	Merit based
F. *Exit*	Constrained	Constrained	Constrained	*Free*
G. *Information*	Public	Public	Public	*Private*

The diversity of local strategies can be related to the autonomy of the WUAs to organize affairs within their jurisdictions (see *Autonomy: Formal authority* in Table 3). The associations are owners of their own irrigation infrastructure and enjoy rights over provision activities (i.e., planning and financing), as well as production activities (e.g., water extraction, allocation, enforcement and conflict-solving) within their jurisdictions. Additionally, the WUAs are formally recognized as Public Administration authorities, which grants them with access to special sanctioning and conflict solving mechanisms, first-hand information about water availability, and procedures to pool water rights, to mention a few. None of these privileges hold when WUAs have to manage electricity. This not only hampers local initiative but also hinders successful ventures (e.g., collective contracting and production) to scale up.

In both the water and electricity crises, the governments have played a subsidiary role (*Autonomy: Subsidiarity*), but this is much more patent in the water situation. In both crises the WUAs have benefited from information and economic resources provided by the E-RBO and governments at different scales. Additionally, the WUAs have benefited from important "modernization" subsidies and the support of the E-RBO in the coordination of water allocation within the sub-basin and monitoring of the quota policy. As pointed by the RAA organization and FENACORE, such a level of governmental support would be desired to better cope with the electricity situation (RRAA, 2012).

Another relevant difference between the water and electricity governance systems has to do with the clarity of the regulations that govern interactions between the WUAs and other actors (*Overarching rules: Clear consequences*). In the water situation, rules (e.g., priority of urban rights over irrigation rights, water allocation and drought management rules) are clear and accepted by the WUAs. In the electricity sector the decisions by the central government to organize the electricity market and the setting of prices have been contested by WUAs and other actors of the sector in different occasions. Also, the government has reformed the system in numerous occasions and this has aggravated the uncertainty generated around the cost of electricity and the feasibility of long term investments. The failed attempt by the RAA (in partnership with the regional government of Aragon) to invest in renewables illustrates the point.

Also, there are differences in the level of participation of WUAs in resource allocation decisions (*Overarching rules: Collective choice*). On the one hand, the WUAs, represented by the RAA organization, enjoy full voting rights in the E-RBO. Such rights are shared with other water user groups and grant the WUAs with a voice in the reservoir release and right reallocation decisions. On the other hand, decisions in the electricity sector are made via the market. Here, the provision side is quite atomized; however, the production side is rather oligopolistic, with a handful of firms dominating both the generation and distribution stages. This not only goes in detriment of the bargaining power of WUAs (indeed forcing them to act collectively), but undermines also the capacity of the system to evolve (see next section).

The two systems are also different with regard to *Evolutionary Competition*. In both sectors, new production activities (i.e., the use of new water sources, or the building of new power plants) require the approval by the government. In the electricity sector, however, the participation of WUAs as producers in the market (*Evolutionary Competition: Entry*) is hampered by taxes and the lack of distribution infrastructure. Also information about availability and prices is more accessible in the water than in the electricity sector (*Evolutionary Competition: Information*). Information of water availability estimations, storage and demand is easily accessible online. Similarly, the fees charged to the water users by the three RBOs are announced every year by March and opened to amendment proposals by users. Alternatively, the structure of the price of electricity is quite complex, involving a number of components, fees and restrictions that have been updated from year to year with limited preannouncement and publicity. Additionally, supply contracts made by retailer companies vary depending on the deals reached between the companies and the end user (e.g., WUAs), which aggravates the opacity to the retailer market. Such opacity adds to the lack of public forecasts of power supply and demand, making contracting particularly difficult and subject to abuses (Garrido, 2017).

Similar barriers to adaptation in the water and electricity sectors

An aspect that is similar in both the water and electricity governance systems and points to adaptation issues is the over-allocation of "production rights" and the difficulties to rationalize them (*Evolutionary Competition: Exit*). On the one hand, there is an issue of under-used water use rights in the irrigation sector (e.g., in the Ebro basin). This is due to a progressive process of land abandonment and concentration of irrigation activities in the hands of professional farmers who are heavily investing in water efficient irrigation technologies (CESA, 2012). The central government launched the program "Alberca" to adjust water use rights to actual water uses and efficiencies (MAGRAMA, 2012). The program has made some progress; however, this has been mostly accomplished by targeting abandoned agricultural land and outdated water uses such as old mills. A full update of those rights would facilitate adaptation planning in the sector and across sectors; however, RBOs lack the means to accomplish such a comprehensive update, and it is unlikely that landowners who invested in new irrigation technologies to increase productivity are going to give away their rights easily.

In the electricity sector, there is an excess production capacity of 40% and this has created a problem of financial sustainability. The central government is in charge, among other operations, of maintaining the distribution system, subsidizing renewable electricity production, and compensating fossil fuel generators for maintaining a number plants operational as a back-up when climatic conditions for solar and wind production are not suitable. All this should be financed via fees to electricity distribution and consumption; however the revenue is not sufficient to offset the costs of such an oversized system. Successive increases in the electricity fees (which partially explain the electricity price crisis) have not been sufficient and, as a result, the government has accumulated a debt with fossil fuel power generators that grows year after year. The lobby of generators has opposed the debt-accumulation strategy and claimed for financing the deficit via higher fees and the public budget, but the government has resisted due to obvious political costs. Until now, and despite warnings from the EU (Rejon, 2017), the central government has not only ignored the option of closing fossil-fuel power plants down but also kept the compensation payments to many of those plants under the argument that they provide a necessary back up to the system.

As it happens, the government does not have information about the maintenance and operation costs actually incurred by fossil fuel generators and lacks legal tools to force them to reveal that information (*Evolutionary competition: information*). Having this information would not only facilitate an update of the actual costs of the system and a revision of the compensation payments, but would also make using the public budget to pay the deficit politically more feasible.

More generally, the production capacity stalemate in the electricity sector can be associated to the strong lobby of generators (*Overarching rules: rule design/redesign*). Generators are not only entitled to the compensation payments, but also benefit from a peculiar system to set market prices. Whole sale market prices are set at the cost of the most expensive electricity sources, which are coal and gas. This mechanism guarantees returns to capital to generators but has the consequence of rising prices as demand increases. Also, it provides incentives to generators to artificially inflate prices by restricting supply, as has already happened in the past (El Pais, 2015). Overall, the benefits of generators have grown at an average of around 3.3% since the reform of the sector (Energia y Sociedad, 2012).

The irrigation (i.e. farming) lobby has lost much of its influence over water governance decisions (Downward and Taylor, 2007), and this has forced the sector to adapt. That said, irrigators are still quite powerful.Not without reason, for example, the Drought Decrees included important investments in water supply infrastructure and infrastructure improvement subsidies for the irrigation sector (BOE, 2005). Although positive and probably necessary, such a focus on technological fixes, has brought many WUAs into a dynamic of water an energy intensification of uncertain results (see next discussion section below).

Local institutional interplays across sectors

The RAA project case also illustrates the relevance of institutional interplays in several ways. First, the current vulnerability of WUAs to the rise in electricity prices partially owes to the massive promotion of pressurized irrigation by the government in the past decade with the aim of increasing the robustness of the sector to droughts (López-Gunn et al., 2012). As indicated by interviewees, many farmers welcomed the program quite enthusiastically as an opportunity to reduce maintenance costs and/or increase water productivity (not necessarily conserve it); others were progressively bought into the "modernization" programs by public consulting firms and contractors, and WUA leaders The "modernization" subsidies reached up to 60% of total projects costs in many cases (MAPA, 2001). Overall more than 8,800ME were invested in the program, including both public and private funds (Aunion, 2014).

Second, the dependence of the irrigation sector on electricity and its vulnerability to electricity prices could be ameliorated if the water efficiency improvements were accompanied by a thorough revision of water use rights in the sector. The new pressurized technologies have not always translated in water savings due to now well-known rebound effects (Berbel et al., 2015) . In the Ebro basin, improvements in water productivity did not offset the expansion of irrigated land or the intensification of irrigation, resulting in net water use increases and/or decreases in irrigation returns (Lecina et al., 2010). More efforts from water use authorities (including WUAs) to rationalize water use rights could ameliorate said rebound effects; however, it is important to note that the effects are the result of complex dynamics and motivations (Dumont et al., 2013). As illustrated in the RAA project (see Appendix 4), droughts may end up concentrating water use in those systems that are sprinkler irrigation-dominated, and thus electricity use-intensive. Also, farmers may not be interested at all in reducing water use even if that would decrease electricity costs or future water availability. As pointed above, one should not assume that farmers invested in infrastructure improvements to conserve water. Moreover, as also indicated by interviewees, reducing water use is not an option for farmers who still have to pay the bill of such investments.

Third, a number of the electricity management measures developed by the WUAs to cope with the price crisis owes to the WUA's autonomy and capacity for collective water management. The rescheduling of irrigation, collective bargaining and electricity production are clear examples of it. The capacity to adjust irrigation schedules owes to the authority of the WUAs over water allocation affairs. Compliance by farmers with the schedules is not trivial. Farmers that do not depend on electricity shall resist to such adjustments. Also, the electricity bill in each district is shared by all irrigators equally regardless of when they irrigate. The common history of cooperation for water management among farmers and the active monitoring of water use carried by the WUA staff paved the way for cooperation in this occasion. A similar logic applies in the case of collective bargaining and electricity production. The RAA organization does not have authority to enforce collective electricity use and production contracts. Overuse and underproduction are penalized in the market. Thus, it is important that the RAA organization makes reliable estimations of electricity needs and production capacity, which require cooperation among all WUAs. Again, the prevalence of a common understanding of the benefits of cooperation in this context contributed to the success of the initiative.

7. Conclusions

This study advances our understanding of institutional problems and solutions in the management of water-energy interactions by introducing and testing polycentricity theory.

According to the findings, Water User Associations (WUAs) can play a key role in integrating the management of water and electricity. They do so mostly locally, via a diversity of institutional and operational adaptations. That said, such integrative capacity depends on features of the broader governance context. In the RAA case, WUAs showed a lower capacity to adapt to electricity supply dynamics (i.e., rise in electricity prices) than to water supply dynamics (i.e., droughts), and this can be traced back to differences in polycentricity traits across the water and electricity sectors. As far as the comparison of the two sectors shows, the adaptive capacity of WUAs (and seemingly other local water-energy user groups), requires sufficient levels of autonomy, clear rules that structure interactions with other water and electricity authorities, and a relatively competitive environment.

The above findings align with previous studies showing the advantages of polycentric governance in certain contexts (Baldwin et al., 2015; Binder et al., 2013; Herrfahrdt-Pähle and Pahl-Wostl, 2012). Additionally, this study links those advantages to specific polycentricity traits, illustrating the existence of different varieties of polycentric governance and thus potential paths to adaptive capacity. Most of the empirical works on polycentricity to date have tended to assess polycentricity as differences in degree ("more or less polycentric") and rather ignored the exploration of differences in kind (different types of polycentricity). Such tendency has in turn reinforced a rather unsophisticated view of polycentricity and its benefits. In response, this study has featured two governance systems as representing different configurations of polycentricity traits. As shown, many of the differences across the two configurations relate to the way production activities are arranged. Whether these configurations actually reflect more general types is a question for further research. Such "configurational" research is important from the perspective of water-energy nexus research. Water-energy trade-offs and synergies are a good illustration of the complexity and idiosyncratic nature of human-environmental interactions. Addressing such complexity is an imperative for the advancement of water-energy nexus governance scholarship and social environmental science more generally; however, such goal should not jeopardize the ultimate interest of accumulating knowledge and building relatively generalizable theory (Cox, 2008). As illustrated here, the "polycentricity traits" lenses offer a way to start moving in that direction.

The above reflection has also significant policy implications. The Spanish water sector displays more polycentric traits that the electricity sector, but this does not mean that the water governance system is a panacea or that it should be just copied and pasted as a blueprint in the electricity sector. Although similar in some respects, each sector has also its own history and challenges. The water governance system has gained in transparency and diversity of interests and authorities over time. Although highly reliant on the coordinating and planning role of RBOs, the autonomy and voice of local authorities (i.e. WUAs) and thus their adaptive capacity have so far been guaranteed; however, a policy challenge remains in the adjustment of water use rights to increases in water use efficiencies so investments and subsidies in infrastructure investments ameliorate and not aggravate the trade-off between water use efficiency and electricity costs. The electricity governance system was reformed to operate as a spot market, and has increasingly hosted local production and consumption initiatives where the pricing system is substituted by cooperation and planning The scaling up of these initiatives and other adaptations will likely depend on the authority granted to the cooperative actors that feature them as well as on the capacity of the government to improve transparency and remove market barriers in the sector.

Also, the study shows important institutional interplays across the water and energy sectors, and the potential of moving beyond the single-sector analyses that have so far dominated the polycentricity scholarship. The role played by the WUAs to cope with the electricity crisis cannot be understood without looking at the autonomy and capacity for cooperation they enjoy in the water governance system. At the same time, the progressive concentration of production capacity in the Spanish electricity sector and the influence of generators on regulatory decisions have jeopardized the WUAs' efforts to decouple their electricity bill from electricity price dynamics . These interplays illustrate ongoing tensions between polycentricity and centralization forces. As pointed by Aligica and Tarko (2012) "the structure and dynamics of a polycentric system is a function of the presence of polycentrism in the governance of the other related and adjoined systems… any island of polycentric order entails and presses for polycentricism in other areas, creating a tension toward change in its direction" (p. 247). Further research on such cross-sector tensions can notably contribute to expand polycentricity theory, and water-energy nexus studies are particularly well positioned for that purpose.

To conclude, the study of varieties of polycentricity and their performance is probably the most promising inroad to further theory building around polycentricity. Progress on this matter has been hindered for quite long by the lack of effective analytical grids. This study has aimed to fill the gap by operationalizing Aligica and Tarko's (2012) framework in the context of water and energy governance and adding a distinction between provision and production activities. Further methodological and theoretical steps shall include the development of additional polycentricity traits, the use of more fine grained measuring scales of those traits, or the development of propositions about interactions between traits within and across sectors.

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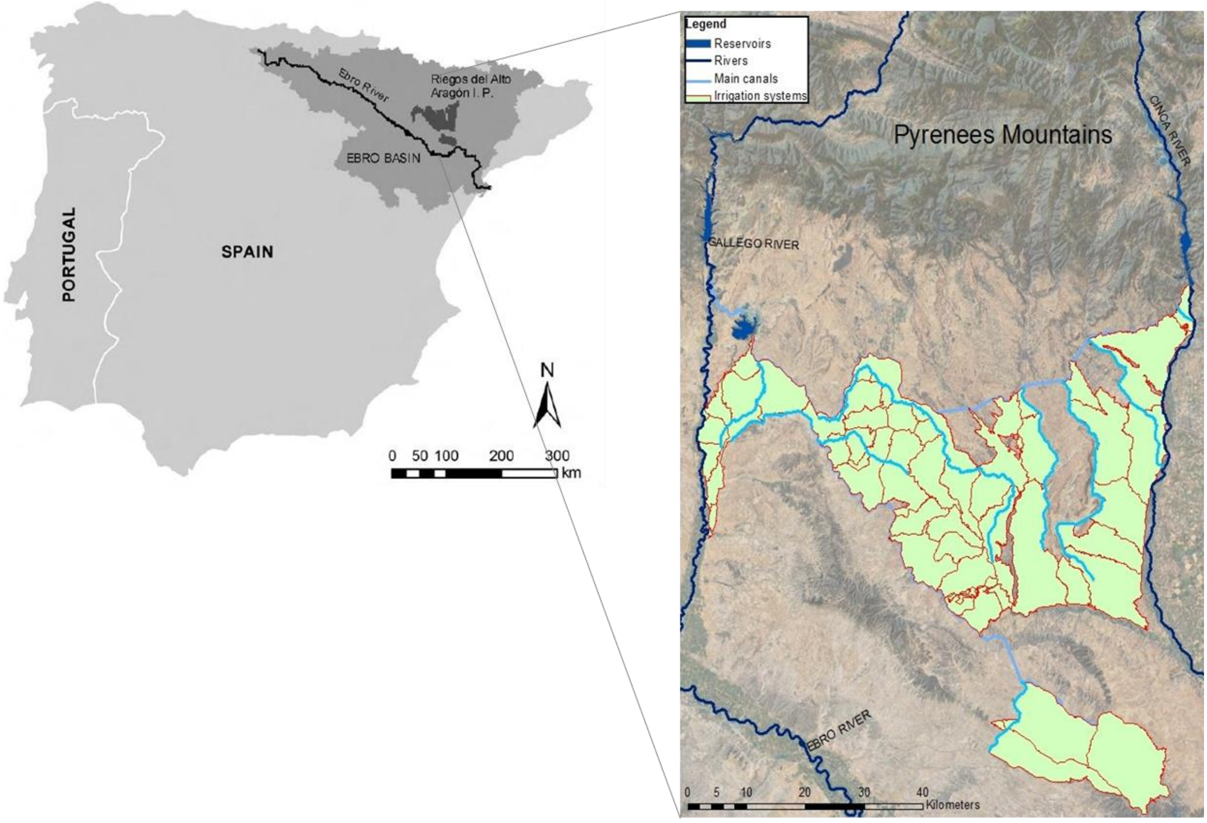
Appendix 1. Location of RAA project

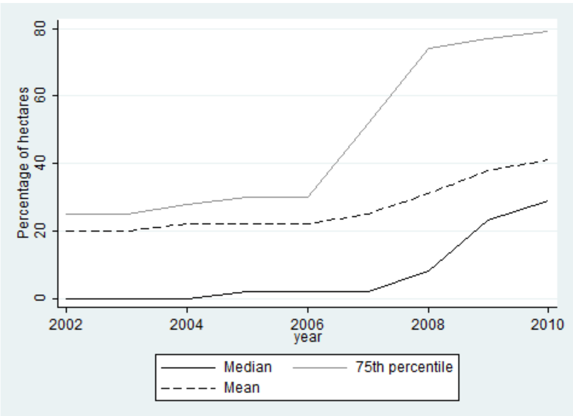


Appendix 2: Averaged descriptive statistics of irrigation systems within RAA project (2001-2010)

	Mean	sd	Min	Max
Area of system (has)	2,395	1,856	142	9,797
Number of farmers	140	88	11	399
Average plot size (has)	40	24	7	148
Percentage of sprinkler irrigation	26%	36%	9%	100%
Summer crops (has)	64	15	22	93
Winter crops (has)	24	13	1	69
Fallow (has)	11	8	1	50

Source: Own elaboration with data obtained from RAA organization

Presence of sprinkler irrigation in the RAA project over time



Note: the measure is an averaged percentage across irrigation systems

Appendix 3: Guiding questions to assess provision and production decisions in the irrigation sector

	General question	*Decisions in the irrigation context*	
		Water	***Electricity***
Provision decisions	How much water/energy should be consumed?	Allocation of water use rights; cropping	Electricity contracting
	How should the production and distribution of water/electricity be financed?	Financing of infrastructure (reservoirs, canals, in-system pools, pumping stations…)	Financing of electricity generation plants and distribution grid
	When/how should water/electricity be consumed?	Water allocation within sector and across sectors	Amount, timing and intensity of pumping
	Which qualities of water/electricity should be prioritized?	Quantity vs. Quality priorities	Fossil fuel vs. Renewable electricity priorities
Production decisions	How should water/electricity be produced?	Design, construction and maintenance of infrastructure	Construction and maintenance of power plants and distribution grid
	When should the water/electricity be produced?	Operations management of infrastructure	Operations management of plants and distribution grid

Based on: Ostrom et al. (1993)

Appendix 4. Polycentricity traits in the Water and Electricity governance systems from the perspective of WUAs

	Water		Energy	
	Provision	Production	Provision	Production
Autonomous centers				
P1. Active exercise of diverse interests	*Yes* From quota policy to land leveling or investments in sprinkler/drip irrigation → Reduction in water use during droughts	*Yes* Temporal reliance on wells and drainage canals; investment on in-system pools →Reduction of crop loses	*Yes* From collective electricity contracting to audits and irrigation rescheduling →Reduction in electricity bill	*No* WUAs have limited capacity as generators; electricity produced by RAA is sold in the market (see also *authority* and *entry*)
P2a. Autonomy: Formal authority	Yes Self-organization of water use among farmers and across WUAs (see RAA); Public Administration status of WUAs →Reduced water use during droughts	Yes Water distribution carried by WUAs within their jurisdiction; Public Administration status of WUAs → Satisfactory implementation of quota policy; adjustment of irrigation to electricity prices	*Yes* WUAs can self-organize into electricity retailer cooperatives →Collective bargaining and contracting	*No* WUAs can produce and sell based on their choice energy and mode of production; however, pooling of electricity and net balance are forbidden → Self-production experiences
P2b. Autonomy: Subsidiarity	*Yes* Central and regional government subsidies for infrastructure improvements →Increase in water productivity	*Yes* Monitoring and information sharing by RBO; drought emergency supply investments by central government; approvals for temporary use of wells and drainage canals by RBO and RAA → Satisfactory implementation of quota policy; reduction of crop loses	*Yes* Preferential selling of electricity by RBO; tax reductions and training on efficiency by governments →Reduction in electricity bill	*No* Failed partnerships between WUAs and regional governments due to lack of funding

A. Goals	*Common* Efficient and equitable water allocation across uses	*Common & Individual* Efficient and equitable water allocation across uses; maximize net capital return	*Common* Efficient and equitable electricity allocation across uses	*Individual* Maximize net capital return → Sent seeking behavior of generators
Overarching rules				
P3. Clear consequence of rules	*Yes* Clear priority ranking of water uses; transparent water use rights system →Lack of conflict between RAA and other uses, and within RAA during droughts	*Yes* Drought protocol at RBO level →Effective implementation of quota policy	*No* Market regulation agency is not independent: opaque and volatile decisions → Uncertainty and controversy around pricing system; 2008 shock	*No* Lobbying activities carried by energy generators/distributors → Uncertainty and controversy around auto-production rules
B. Rule design and redesign	*Outsider* European Water Directive and Spanish Water Law questioning water supply and hydro-agricultural paradigms. →Push for adaptation to increase water use efficiency and conservation	*Insider* Pervasive supply infrastructure subsidies; massive pressurized irrigation subsidies; difficulties to rationalize water use rights →Many WUAs locked in intensive water and electricity use dynamic	*Outsider* European Energy Directive and central government Electricity reform; Regulatory agency but questioned independence from Department of Industry; sanctions to generators due to collusion	*Insider* Pervasive subsidies to fossil fuel generation → Constrained competition and rationalization of system
C. Jurisdiction	Territorial	Territorial	Territorial	Territorial & Non-territorial
D. Collective choice	*Majority rule* WUAs and other user groups have full vote rights in reservoir release commission and in operations committees at sub-basin level. → Satisfactory apportionment of reservoir waters between RAA project and other uses and	*(None)* Water use rights system is managed by the RBOs officials	*Individual* Atomized electricity retailer market	*Consensus* Oligopolistic electricity generation/distribution market (zoning) → bargaining power of generators/distributors

	implementation of quota policy			
Evolutionary competition				
E. Entry	*Merit based* Mandatory formation of WUAs for the management of collective use rights; irrigation water use rights are linked to land ownership; WUAs have to be recognized by basin authorities	*Merit based* Water production (wells, diversions) by WUAs are subject right concession approval by the RBO	*Free* (but transaction costs) → WUA collective bargaining	*Merit based* Need of approval by government and binding forecast of production capacity; tax to self-production, lack of distribution infrastructure, transaction costs, experience and financing barriers → Self-production not used as a strategy to cope with electricity crisis
F. Exit	*Constrained* Irrigation water use rights are linked to land ownership; difficulties to rationalize water use rights → Constrained water use conservation	*Constrained* Lack of sufficient monitoring by RBO of water sources other than reservoirs → Difficulties of long term adaptation by reallocating rights	*Constrained* WUAs cannot contract for variable power term → Barrier to adapt to prices and demand	*Free* Strategic behavior by fossil fuel generators despite regulations → Rise of prices in peak demand periods
G. Information	*Public* Historical and real time information of water use processed by RAA organization. →Effective implementation of quota policy	*Public* Public registry of water use rights; real time information of water availability processed by RAA organization →Effective implementation of quota policy	*Public* Public advertising of contract conditions by retailers processed by RAA organization; real time information of market prices → WUA collective bargaining	*Private* Generators are not obliged to reveal their costs → Difficulties to rationalize production system and prices

Note: green color: positive impact on adaptation; red color: negative impact on adaptation

Appendix 5: Correlations among WUA features during 2005 drought

	1.	2.	3.	4.	5.	6.	7.
1. % high water crops	1						
2. % low water crops	-0.823*	1					
3. Farm size hetero†	0.258	-0.452*	1				
4. % small farms	-0.231	0.415*	-0.985*	1			
5. Average farm size	0.345*	-0.489*	0.929*	-0.935*	1		
6. Transfer inflows	0.124	-0.308*	0.195	-0.169	0.232	1	
7. % sprinkler	0.192	-0.211	0.256*	-0.485*	0.514*	0.312*	1

n=38 (sampled from the 50 irrigation systems of the RAA project)

†Farm size Heterogeneity is measured as a fractionalization index. The fractionalization index measures the chances that two random hectares in an irrigation district belong to a small farm (< 30 hectares) and to a big farm (>30 hectares) respectively.

Note: as shown there is a strong correlation between the grow of high water-demand crops and the reliance on sprinkler irrigation during droughts (as well as on farm size and farm size heterogeneity). As pointed by interviewees, a relatively small number of big landowners who have recently invested in new land acquisitions, the mechanization of agricultural labor and sprinkler irrigation tended to stick to high-water demand crops, while a large number of part-time, small landowners tended to switch to lower demand crops and fallow land.