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Milestone 9: Working paper on motives and barriers of collective action to reduce the impact on water resources

Testing design principles of collective action schemes to enhance sustainability of water resource use

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Executive summary

Water resource management at the landscape scale is vital for addressing environmental and hydrological challenges in European agriculture. Due to fragmented land ownership, management must extend beyond individual properties and align with hydrological systems, requiring collaborative governance involving farmers and other stakeholders. This study uses Elinor Ostrom's design principles (DPs) as a diagnostic tool to assess institutional robustness in three cases: irrigation management in Spain and Hungary, and catchment-based nitrogen regulation in Denmark. The Spanish case shows strong alignment with DPs, featuring nested, user-driven organizations and legal recognition of collective rights. The Hungarian case shows strong top-down control, but lacks the capacity to implement complex and collective water management initiatives, as well as the necessary bottom-up cooperation, coordination and professional guidance. The Danish case diverges notably from DPs due to limited stakeholder involvement and user autonomy. These findings demonstrate how institutional context and governance design affect legitimacy and effectiveness in water management. While Ostrom's principles offer a valuable institutional benchmark, they provide limited insight into behavioral factors influencing farmer participation. We propose that future research on Ostrom's principles need to incorporate behavioral perspectives to better understand successes and failures of collective agri-environmental schemes for sustainable water resource use. Our follow-up work will move beyond institutional analysis to explore the behavioural levers and barriers in collective agri-environmental programs.

Keywords: Water resource use; common-pool resources; Ostrom's design principles; collective action; agri-environmental policy.

1. Introduction

Effective water resource management at the landscape scale is increasingly recognized as essential for addressing the hydrological realities and sustainability challenges facing European agriculture. As ownership is fragmented over European agricultural landscapes, a landscape level approach essentially entails an approach that cuts ownership boundaries. This demands collaborative approaches that engage farmers and other stakeholders in governance arrangements that reflect hydrological scales (McKenzie et al., 2013). At the same time, there is a need to better link payments and the delivery of ecosystem services to enhance the sustainability of agricultural systems (Wunder, et al. (2025). Such approaches could be developed as collaborative governance arrangements.

One of the most influential contributions to the governance of shared natural resources comes from Elinor Ostrom, whose design principles (DPs) were developed to explain the success of self-governed common-pool resource (CPR) systems (Ostrom, 1990). Ostrom's DPs (Cox et al., 2010; Ostrom, 1990) are widely used to assess institutions that manage CPR such as fisheries and water use (Ostrom and Gardner, 1993; Serafini et al., 2017) and air and water pollution problems (Epstein et al., 2014; Fleischman et al., 2014). Lacroix and Richards (2015) suggested that Ostrom's design principles could be applied to assess the long-term viability potential of a wide range of environmental policies, and illustrated this using the implementation of a carbon tax in Cox et al. (2010) as an example. In the case of water resources, the quality and availability of local water resources, whether they are threatened by scarcity or pollution, represent conventional common good challenges that require cooperation among involved stakeholders to manage the resources effectively. Hence, Ostrom's DPs could potentially serve as a diagnostic tool to assess how agri-environmental governance arrangements support or hinder sustainable collective action in agricultural water and nutrient management. Adherence to the DPs would not be a sufficient condition to achieve the required outcomes, but an alignment with the DPs could enhance the likelihood of success.

Water governance institutions have a long history, especially in managing scarce or excess water in agriculture. Local customs and social norms play a key role, shaping farmers' decisions and their willingness to participate in collaborative practices. This aligns with Burton and Paragahawewa (2011) view that results-based payments can strengthen the cultural roots of Agri-Environmental Scheme (AES) outcomes. Overall, such schemes may enhance social capital and deepen our understanding of how social norms or attitudes drive collective AES participation.

This study specifically applies Ostrom's DPs to evaluate the institutional robustness and challenges in water resource management across three European countries. It focuses on three cases situated in different regions of the continent, Denmark (Northern), Hungary (Eastern), and Spain (Southern), each with its own historical and institutional background in collective resource management. Two of the cases concern irrigation governance: one in Spain, where irrigation communities and groundwater user associations (CUMAS) have evolved to support sustainable water extraction; and one in Hungary, where newly established irrigation communities are responding to climate-induced water scarcity. The third case, from Denmark, focuses on nutrient management through targeted nitrogen regulation at the catchment scale. By examining these three diverse contexts, this study offers a comparative analysis of how Ostrom's principles are embodied, adapted, or absent across systems with varying institutional legacies, ecological challenges, and policy designs. In doing so, the study contributes to broader efforts to understand how principles of collective governance can inform the design and evaluation of agri-environmental policies and collaborative environmental management.

This Milestone provides a comparative analysis of three VISIONARY cases all addressing agri-environmental policy initiatives aiming to improve the sustainability of water resources. The common feature of the cases is that collective action has the potential to improve sustainability, but the collective feature is also potentially a barrier for farmers to join. The Milestone contribute to Task 3.4 as it provides the initial analysis of the schemes selected for experimentation of agri-environmental policy schemes. In this Milestone we identify a common theoretical framework for analysis of AECS where interactions between farmers and/or influence of other farmers actions on group members is an important part of the functioning and success of the scheme. This work will be complemented by further empirical analysis of the data collected in the three cases (Milestone 8). This will be based on a analyse the survey experiment, including a choice experiment in Denmark, workshops and a survey in Hungary and in-depth interviews in Spain. The water case studies will contribute important dimensions of the synthesis of our experimentation with AECS (Task 3.5) as the water cases specifically provide evidence about how collective schemes can be improved.

The remainder of this document is structured as follows: Section 2 provides a brief review of the literature and the policy context of the case studies; Section 3 outlines the methodology for the analysis of the case studies; Section 4 presents and overview of the existing policy evaluations and the results of our analysis; Section 5 discusses the findings; and Section 6 concludes the paper.

2. CPR concepts and the case study contexts

CPRs are resource systems which include waterbodies, irrigation system, fisheries, and forests, and their consumption is characterized by non-excludability (it is costly or impossible to exclude users from consuming a resource) and rivalry in consumption (one user's consumption reduces availability for others) (Ostrom, 1990; Ostrom, 2009). According to classical economic theory, the use of CPRs is expected to result in overexploitation and degradation, as individuals pursuing their own self-interest act independently without coordination, a phenomenon demonstrated by Hardin (1968)'s and described as "Tragedy of the Commons". The core dilemma is that the incentives at the individual level do not align with the collective good, leading to overexploitation, and in severe cases to resource collapse.

Economists have traditionally proposed two main solutions to CPR problem: i) assigning private property rights to transform the resources into a private good, theoretically enabling efficient management through market mechanisms (Coase, 1960), or ii) government enforcement mechanisms that aimed at correcting the negative externalities associated with CPRs use (Pigou, 1920). These solutions rely on formal institutional arrangements and assume that users behave based on individual rationality, incapable of collective action. However, these approaches often face problems such as lack of information, high transaction costs, enforcement challenges, and fail to account for local social norms and institutional complexity (Agrawal, 2001; Ostrom, 1990).

Ostrom (1990) challenged the universality of the "Tragedy of the Commons" by documenting numerous empirical cases where communities successfully managed CPRs through local institutions and social enforcement. She argued that under certain conditions, collective action and self-governance could lead to sustainable CPRs use. Ostrom identified eight DPs that serve as conditions for successful management of CPRs. The DPs describe the institutional features commonly found in successful, community-managed CPR systems. These principles, as later modified by Cox et al. (2010) include clearly defined boundaries; congruence between appropriation and provision rules and local conditions; collective-choice arrangements; monitoring; graduated sanctions; conflict resolution mechanisms; minimal recognition of rights to organize; and nested enterprises. Cox et al. (2010) also demonstrated that institutional success does not depend on the isolated fulfilment of each principle, but rather on sets of principles that interact contextually. This “cluster” approach suggests that the effective implementation of Design Principles (DPs) requires consideration of how they are combined across different environmental and social dimensions.

Ostrom’s work has laid the foundations for much research effort to nuance the concepts to understand modern day governance challenges in diverse contexts beyond socio-ecological systems. Notably, her work is the foundation for more recent work on polycentric governance systems. Unlike hierarchical models, polycentric governance acknowledges the importance of the participation of actors operating at different levels—local, regional, national, and international—who interact through shared rules and coordination mechanisms (Ostrom, 2010a). It represents an articulated network of authorities that can foster resilience and effectiveness in addressing global and local challenges (Ostrom, 2010a; Jordan et al., 2018; Baldwin et al., 2018). This institutional design can develop solutions tailored to its specific context, thereby reducing systemic risks (Jordan et al., 2018). Furthermore, it promotes participation and trust-building processes, as well as other key elements essential for a sustainable management of natural resources (Thiel et al., 2019; Carlisle & Gruby, 2019). Nevertheless, several authors caution that polycentricity does not inherently guarantee successful outcomes, as it may be hindered by policy fragmentation, incoherence, or high transaction costs (Heikkila et al., 2018). Consequently, robust institutional conditions are required to ensure its effective performance and development (Sovacool & Van de Graaf, 2018).

In this paper we focus on the classical application of Ostrom’s principles to the governance of socio-ecological systems. Water is a typical common-pool resource: it is rivalrous in consumption, difficult to exclude users from consuming it, and typically shared across multiple stakeholders and jurisdictions. The CPRs dilemma in water manifests in both quantity and quality dimensions. In terms of quantity, irrigation systems are often prone to over-extraction, in which classical economic models have long predicted the collapse of such systems unless access is priced or externally regulated (Hardin, 1968). However, Ostrom and Gardner (1993) showed that many irrigation associations have successfully managed water collectively by relying on social norms, rotational access rules, and mutual monitoring, particularly in developing countries.

Water quality degradation also presents a CPR problem, as the carrying capacity of the common sink is fixed. This implies that the mitigation actions are “rivalrous”, meaning that one actors mitigation action does limit the need for other actors to contribute. Industrial and agricultural actors often have weak incentives to reduce water pollution such as eutrophication, or salinization, unless they are subject to regulation or embedded in strong social enforcement mechanisms (Shortle and Horan, 2001). Ostrom’s DPs have also been applied to collaborative watershed management highlighting issues such as limited participation and weak coordination (Fleischman et al., 2014; Huitema et al., 2009; Imperial, 2005).

Groundwater systems are particularly vulnerable due to their invisible nature and the temporal disconnect between extraction and ecological consequences. Villamayor-Tomas et al. (2019) argue that while Ostrom's principles offer a robust framework, adaptive governance mechanisms are often necessary to address the dynamic and uncertain nature of aquifer systems. Case studies from India (Meinzen-Dick et al., 2016) and Spain (Garrido & Calatrava, 2020) further show that formal institutions alone are insufficient; successful groundwater management typically requires nested, polycentric arrangements that enable monitoring, local enforcement, and flexible rule-making. Recent studies emphasize that the effectiveness of Ostrom’s principles in water governance depends on their adaptation to multi-level and polycentric systems. Basurto and Ostrom (2009) and Pahl-Wostl et al. (2012) found that vertical coordination across multiple decision-making levels strengthens the legitimacy and capacity for action within polycentric water resource systems. Likewise, recent works show that nested governance structures can be particularly crucial in river basin management, ensuring coordination across scales and preventing free-riding behaviors (Lankford & Hepworth, 2010; Heikkila et al, 2018).

We now give an overview of the background for the cases. This helps to explain the nature of the CPR policy context including the environmental and governance challenges, which we seek to analyse in this research.

Groundwater users' communities in Spain

For most of the 20th century, groundwater was legally considered a private resource in Spain, unlike surface water, which was considered public and subject to a regime of concessions controlled by the state administration. This legal approach, which some authors have called "hydro-schizophrenia" (Llamas, 1975), served to stimulate the massive mobilisation of groundwater for agricultural use, but caused serious problems of overexploitation in many aquifers, in some cases perceived as a "drama of the commons" (Rica, 2016). The division between a public and a private regime lasted until the approval of the Water Law of 1986, which incorporated groundwater into public ownership, with the exception of rights prior to the approval of this Law. One of the aims of this legal change was to put a stop to the over-exploitation of groundwater resources, for which the Law and its regulatory development introduced new control and management mechanisms (Sanchis-Ibor et al., 2023). Currently, 220 groundwater bodies are in poor quantitative status (27% of the total) (Greenpeace, 2022) and models suggest that climate change trends could worsen this situation (Pulido et al., 2018).

The 1985 Water Law gave the River Basin Authorities (RBA) enforcement authority to control groundwater use and impose sanctions for illegal wells and excessive abstractions. According to this Law and the WFD of the EU, the RBAs can also declare that a body of groundwater is at risk of not reaching a good quantitative or chemical status. In this case, the following measures will be carried out: a) Within six months, the basin body will constitute a community of users (Comunidad de Usuarios de Masa de Aguas Subterránea, CUMAS) if there is not one or will entrust its functions on a temporary basis to an entity representing the concurrent interests. b) After consulting with the CUMAS, the Governing Board will approve within a maximum period of one year, from the date the declaration has taken place, an Action Program (also named Exploitation Plan) for the recovery of the good state of the body of water. Although these periods have been rarely fulfilled, the approval of this Action Program and the creation of the community of users have taken place in all the overexploited aquifers, with uneven impacts.

The CUMAS replicate the structure of the Communities of Irrigators, collective institutions for common pool resources management regulated since the 19th century by different laws. The Communities of Irrigators are collective organizations for water management that hold concessionary rights, coordinate the distribution of water among their members, and establish rules for their administration. The sovereign body of each community is the general assembly, composed of all its members, which elects a governing board to oversee daily management and a water jury to address conflicts. This is, in fact, one of the institutions used by Ostrom (1990) to set and define the 8 design principles for CPR management. CUMAS must adopt a nested structure, as a community of communities, integrating all kinds of users' associations. They adopt a comparable organizational structure. As in irrigation communities, their sovereign body is the general assembly, composed of one representative from each Community of Irrigators, as well as from other collective or individual users, the latter being grouped to ensure proportional representation. The assembly elects a governing board to oversee day-to-day management and a water jury responsible for resolving conflicts.

The Action Program aims to order the allocation regime to achieve a rational exploitation of resources, in order to achieve a good status of the groundwater bodies, and to protect and improve the associated ecosystems. The authorities can reduce all the concessions and private rights to meet the sustainable extractable volume, blocking all new groundwater abstraction concessions. It may establish the replacement of pre-existing individual intakes by community intakes and transforming the individual titles with their inherent rights, into a collective one. It also may provide the contribution of external resources to the groundwater body and can delimit protection areas where water usage and other activities are restricted to certain conditions controlled by the administrations (Water Law, 2001; RDPH, 1986).

Irrigation communities in Hungary

Hungary is often referred as a country of extremes regarding its hydrography. The entire country is located within the Danube River Basin, meaning that nearly all of its surface water resources flow in and out through the Danube. It also means that a large share of Hungary's surface water resources (cc. 90%) originates from watersheds beyond the country’s borders, and the majority of these water resources (cc 95 %) flows out of the country. In statistical terms, of the 117 km3 of water collected by the country's waterflows, 112 km3 comes from beyond its borders, while only 5 km3 is generated within the country through runoff. However, due to seasonal variations in runoff, uneven regional accessibility, and poor water retention capacities , only a fraction of this amount can be utilized (OVF, 2022) . It is also important to mention that land users showed minimal willingness to collaboratively manage the existing irrigation systems and water reservoirs in the early stages of the post-socialist era. Consequently, these capacities were gradually eroded or entirely lost. Moreover, large-scale land transformations such as river regulations and flood protection in the late 19th and early 20th centuries cut off main rivers from their natural floodplains, leading to significant reductions in water retention capacity and wetland habitats (OVF, 2022). In recent years, this legacy has become particularly burdensome: drought and aridification are now constraining agricultural production on former floodplains drained as part of river regulation projects. With climate change, Hungary's water management system is becoming increasingly vulnerable. Climate change affects the entire Danube River Basin, both surface water and groundwater bodies. Significant changes in precipitation patterns, increased flooding, droughts, heat waves, and increased evapotranspiration have been observed (ICPDR, 2021). Climate modelling for the Carpathian Basin projects further temperature increases, likely reaching 1°C in all seasons across almost the entire country by 2021–2050, and by the end of the century, it may exceed 4°C in the summer months compared to the 1961–1990 reference period. No major changes are expected in annual precipitation totals, but the seasonal distribution is likely to change significantly (decrease in summer, increase in autumn and winter precipitation). Heavy and intense precipitation events are expected to be more frequent in autumn, while the length of dry periods will increase most in summer (OVF, 2022). Consequently, prolonged and intensified droughts are anticipated caused by long periods of precipitation absence in various regions and at disparate intervals.

These circumstances make sustainable agricultural water management a strategic issue for Hungary (Süle et al., 2024). The reorganization of irrigated farming is a critical component of this, as a significant portion of agricultural subsidies are currently allocated to drought compensation rather than more efficient irrigation (Gaál, and Becsákné Tornay (2023). Therefore, Hungary has identified adoption of more efficient irrigation as a long-term policy priority (Magyarország Kormánya, 2014, 2023). This aims to enable Hungarian farmers to adapt in a more flexible manner to the challenges posed by climate change and further improve the efficiency of agricultural production. The policy objective is to promote the adoption of irrigated farming by establishing the necessary technological, legal, and financial conditions for this transition.

In Hungary, water management and water administration are regulated by laws, and coordinated and directed by the General Directorate of Water Management (OVF). OVF also coordinates the activities of the 12 regional water directorates. These sub-units have been organized for catchment areas and not for administrative regions and their operational areas have not changed for more than six decades. The regional directorates provide regular agricultural water services and coordinate the administration of agricultural water use.

Agricultural water use is restricted to water permit holders. Water permits are based on the declaration of water asset management consents, issued by the regional water directorate depending on available free water capacity, and the supporting opinions of other relevant authorities. Water permits specify water quotas for each agricultural water user depending on the area and crops to be irrigated.

Once the water permit is issued, agricultural water users must submit their water requirements for a given year to the regional water directorates at the beginning of each year, within the limits set in the permit. The regional directorates collect the demands from individual water permit holders, and calculate the water price for each agricultural water user for each irrigation system. As a final step, the General Directorate of Water Management also approves these calculations of water price at national level. Irrigation communities, as a newly introduced scheme, have an important role in reorganization of irrigation potential.

In 2019 a new legislation (hereafter denoted community scheme) established the category of irrigation communities. These communities may access specific forms of subsidies and other kinds of support, prepare environmental district plans for irrigation developments, and even operate local irrigation facilities (these facilities connect agricultural water service systems with the actual location of agricultural irrigation demand).

Another important objective expected from the community scheme is to encourage land users to collectively manage the maintenance and operation of the fragmented irrigation network. The extensive irrigation network developed during the socialist regime was designed for large-scale agriculture; however, the fragmentation of land ownership in the post-socialist era gradually hindered the functionality of the network.

The community scheme and the related implementing regulation govern the establishment and operation of irrigation activities of the members. The scheme is integral to the national irrigation strategy, which seeks to increase the area of irrigated land from 100,000 hectares to 400,000 hectares. In 2023, the name of the scheme was changed to Sustainable Irrigation Community to better comply with EU regulations.

To establish a sustainable water management community, farmers of different types can come together, though some types of farms need a minimum irrigation area in order to participate. Horticultural fruit and vegetable farms need to have at least 10 hectares of land intended to be irrigated to participate. Arable crops and industrial vegetable farms need to have at least 100 hectares of land intended to be irrigated to participate. A community can be established if at least two agricultural producers join . The two producers may be related by marriage or blood. This implies that the collective dimension of the scheme can be very limited, undermining the intended efficiency gains.

Recognition of communities is largely a top-down process, although applications are being started at the grassroots level. Applications for approval must be submitted to the Agricultural Water Management Department of the Ministry of Agriculture, which forwards the applications, together with a technical opinion, to the Minister of Agriculture. The communities are recognised by the

Minister. The legal form of community can be business association, cooperative or producer group. The scheme has its links to the Rural Development Plan and the CAP Strategic Plan through two calls: communities can apply for 100% support to cover operating and planning costs; and they can apply for subsidies to cover irrigation development investments, where they could receive an additional 20% on top of the 50% basic support intensity.

Targeted catchment level nitrogen regulation in Denmark

Since the late 1980s, Denmark has implemented a series of comprehensive water protection initiatives aimed at reducing nitrate pollution, particularly from agriculture. Beginning with the 1987 Action Plan on the Aquatic Environment, successive programs such as Action Plan II (1999 to 2003) and the Green Growth Agreement (2009) targeted reductions in nitrogen and phosphorus losses, gradually shifting focus from regulating root zone nitrogen (N) leaching to regulating N loads reaching marine waters. These efforts were aligned with European Union directives, including the Nitrates Directive and the Water Framework Directive (WFD), and led to the adoption of River Basin Management Plans for 2009 to 2015 and 2015 to 2021 (Danish Environmental Protection Agency, 2017). In 2015, the Food and Agriculture Package, agreed upon by the Danish government and supporting political parties, introduced a shift from general and uniform regulation to catchment level environmental regulation. This shift was implemented by removing the uniform 20% reduction in N application limits (Danish Environmental Protection Agency, 2017), which had been set below the economically optimal level since 1990s (Ministry of Environment and Food of Denmark, 2019). Instead, a geographically differentiated leaching limits and farm-specific nitrogen permits to balance environmental protection with increased agricultural productivity was established (Danish Environmental Protection Agency, 2017). A more targeted N regulation was introduced, which involved voluntary establishment of nitrogen catch crops allowing farmers to fertilize at the economic optimum, conditional on introducing catch crops in their crop management to control excess N leaching. In the current N regulation, the voluntary catch crop scheme offers flat-rate compensation for planting catch crops with the flexibility to choose alternative land-based measures like buffer zones, and land set-aside to achieve the required effect. Further, the current regulation combines voluntary and mandatory approaches, i.e. if the voluntary scheme does not result in sufficient measures being adopted (at catchment scale), then farmers are required to implement additional mandatory measures (without compensation). This implies that farmers in a catchment have a common scarce environmental sink and are influenced by the implementation of other farmers. This result in similar dilemmas as in conventional CPR policy implementation, as farmers do not have the incentive to take into account that their use of the common sink, infer costs on other farmers.

3. Methodology

We used an adapted Ostrom's design principles framework, which has been considered as a strong analytical tool to assess robustness of an institution (Cox et al., 2010) to evaluate and predict the performance of a water resource management in the three case studies. While all AECS examined involve a collective dimension rooted in common-pool resource problems, the degree to which this collective nature is institutionalized varies across the cases. The adapted design principles (Cox et al., 2010) used for this assessment are presented in Table 1. For each policy design in the three case studies, we systematically analyse how the DPS are reflected in practice by drawing on relevant policy documents and other resources.

Table 1. Modified Ostrom's design principles

Adapted Ostrom's principles	Description
1. *Well-defined boundaries*	• User boundaries: Clear boundaries between legitimate users and nonusers must be clearly defined • Resource boundaries: Clear boundaries are present that define a resource system and separate it from the larger biophysical environment
2. *Congruence between appropriation, provision rules and local conditions*	• Congruence with local conditions: Appropriation and provision rules are congruent with local social and environmental conditions. • Appropriation and provision: The benefits obtained by users from a common-pool resource (CPR), as determined by appropriation rules, are proportional to the amount of inputs required in the form of labour, material, or money, as determined by provision rules.
3. *Collective choice arrangements*	• Most individuals affected by the operational rules can participate in modifying the operational rules. Management plans (e.g., community meetings) are available.
4. *Monitoring*	• Monitoring users: Monitors who are accountable to the users monitor the appropriation and provision levels of the users. • Monitoring the resource: Monitors who are accountable to the users monitor the condition of the resource.
5. *Graduated Sanction*	• Appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and the context of the offense) by other appropriators, by officials accountable to the appropriators, or by both.
6. *Conflict resolution mechanisms*	• Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials.
7. *Minimum recognition of rights*	• The rights of appropriators to devise their own institutions are not challenged by external governmental authorities.
8. *Nested enterprise*	• Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

Specifically, we draw from three main sources; i) a review of documentation related to the legal and institutional frameworks of the three cases; ii) previous analyses of the ecological and social impacts of the policy initiative in the specific cases; and iii) targeted interviews with stakeholders involved in water management where documentation to analyse the design principles was not available.

The next section describes the three case studies we use to test the DPs in more detail. Then follows a review of previous analysis of the collective arrangements implemented in the three cases.

4. Results

4.1 Description of the existing policy evaluations of the cases

Spanish case

The creation of CUMAS has progressed in Spain since the approval of the Water Law of 1986, although the number of entities created is insufficient and not all of them appear to have achieved the management and sustainable use objectives for which they were created. Since, 2020, the creation of top-down CUMAS - officially promoted - has not been very effective, due to the lack of effective legal tools and, above all, due to the distrust of users. However, significantly, when the CUMAS were created by the users themselves, from the bottom up, they have achieved considerable success (Custodio, 2023). This was concluded based on a quantitative evaluation of the degree of good groundwater management and governance based on a set of criteria, including knowledge, administration and socioeconomic aspects. This allowed the relative comparison of 8 real cases representing different Spanish situations and characteristics, at different scales and in different areas. He obtained the information from expert consultation, semi-structured interviews and document reviews. As a result, the State Administration and experts (López-Gunn and Martínez-Cortina, 2006; Rica et al., 2012; Rica, 2016) have agreed that the creation of CUMAS should be intensified and some aspects of their development improved. In fact, since 2020 several RBAs are actively promoting the creation of these CUMAS by stimulating bottom-up processes, following the recommendations of the green paper on water governance recently published by the Ministry (MITECO, 2022). This document calls for strengthening the management capacity, staffing, technical and administrative resources and training of user communities, encouraging the sharing of resources among smaller ones. It calls for greater transparency and accountability and their participation in broader mechanisms of co-responsibility in water and river management. It also recommends reforming the Water Law to allow user communities to support water quality management (MITECO, 2022). In short, there is a high degree of consensus in the country on the need to promote the creation and development of the CUMAS and there is a call for greater support for the institutional development of the CUMAS to guarantee the effective fulfilment of their public functions.

Hungarian irrigation community case study

In the Hungarian case, the efficacy of the community scheme is assessed solely on the actual and potential expansion of irrigated land. Another policy objective is to enhance irrigation efficiency via technological advancements by implementing additional water-saving technologies. Nonetheless, the monitoring capabilities and reporting regulations are inadequate to present an accurate depiction of the actual progress. Consequently, it is infeasible to precisely quantify the volume of water conserved by these novel technologies.. This is being further strengthened by irrigation water users' lack of intent and demand for accurate water withdrawal measurements, as well as the practice of tracking water use by irrigation equipment and crop type. This presents a challenge during inspections when attempting to demonstrate improvements in water use efficiency. Consequently, it is harder to achieve a shift in mindset toward more sustainable farming practices. In community settings, this is even more difficult, as the total water usage must be broken down to the level of individual users.

The community scheme imposes no requirements concerning the complexity of irrigation projects, indicating that they are not required to adapt to water catchment areas. Consequently, communities are frequently formed through pre-existing collaborations and partnerships. The scheme is advantageous for the communities with already functioning irrigation systems, as they can easily access resources (through CAP funds) to further develop their current systems. In contrast, communities starting from scratch are stuck in a rut from the moment they are formed, as in many cases large-scale public infrastructure development would be needed to start developing their irrigation projects. However, these public infrastructure developments have been suspended by the Hungarian government for an indefinite period.

Furthermore, the lack of a holistic approach is also decisive in how the community scheme is embedded in the Hungarian water management system. Although the water management system has progressively adopted a holistic and integrated approach, particularly influenced by the EU Water Framework Directive; certain areas still require improvement. Deficiencies exist in the application of integrated water management principles in both the planning and implementation phases. The monitoring systems for climate, hydrology, water quality, and land use are also not integrated, hindering comprehensive assessments and evidence-based responses. Therefore, field-based decisions often rely on experience rather than data-based knowledge. Notwithstanding governmental assistance, collaboration among farmers remains limited, as they exhibit a greater propensity to invest in individual solutions rather than collective initiatives (Gaál and Becsákné Tornay, 2023; Süle et al., 2024; Saád, 2021).

Danish coastal catchment regulation case

In Denmark's targeted nitrogen regulation, the Danish Ministry of Food and Agriculture evaluates the scheme's performance after the application period and again following implementation. Each year, the Ministry estimates the necessary nitrate reduction by calculating the area of additional catch crops required in each water catchment, expressed in hectares and as a percentage of the arable crop area, based on nitrate reduction targets for 108 coastal catchments and adjusted for local soil nitrate retention. During the application stage, farmers voluntarily submit applications to participate. In the selection phase, the regulator assesses whether the number and quality of applications are sufficient to meet environmental objectives, selecting participants based on nitrogen retention potential and land area (see Table 1A in the Appendix). Table 1A shows that the participation rate in the voluntary nitrogen reduction effort is very high, based on information from voluntary applications (Ministry of Environment of Denmark, 2024). If needed, the agency may impose mandatory participation on non-applicants. During implementation, participants receive subsidies based on flat-rate compensation, with their final payments subject to random inspections covering 1% of participants. Non-compliance may result in reduced subsidies or a lowered fertilizer allowance for the next planning period (Table 2A in the Appendix). However, there is a lack of clear reporting on the outcomes of implementation and monitoring. This concern is further supported by the Danish National Audit Office's recent criticism of the Ministry of Food and Agriculture's control of agricultural nitrogen discharge, which was described as too weak (Rigsrevision, 2024). The criticism particularly highlights the Ministry of Environment's poor follow-up on voluntary nitrogen reduction targets. According to the state auditors, the inadequate monitoring risks allowing excessive nitrogen to go undetected and creates uncertainty about whether the voluntary measures are effectively improving water quality and reducing nitrogen pollution. However, a preliminary finding from a recent ex-post evaluation of the targeted nitrogen regulation suggests that the scheme may significantly reduce nitrogen leaching on targeted farms (Abay et al., 2025).

4.2 Evaluation of the cases using Ostrom's DPs

In this section, we conduct a thorough evaluation of the specific cases using Ostrom's DPs. The presence of each design principle in the case studies is summarized using three categories: present, partially present, or absent.

Design principle 1A: user boundaries: clear boundaries between legitimate users and nonusers must be clearly defined. This design principle states that clearly defining social boundaries, distinguishing between users and non-users of CPRs, enhances the likelihood of successful management and sustainability.

This design principle (1A) is present in all the three cases. In Spain, user boundaries are clearly defined through national legislation. All users of an overexploited aquifer are legally required to join the relevant groundwater user association (CUMAS) and comply with its management rules and exploitation plan. This obligation applies to both individuals and groups, such as irrigation communities. Each CUMA formalizes user participation through regulations that determine decision-making rights based on the users' characteristics and numbers. Hungary's sustainable water management communities also meet this design principle. These entities are formalized as cooperatives or business entities comprising at least 75% agricultural land users within a defined irrigation district. Membership requires legal proof of land usage, and the community must submit a member list and a declaration of legal land use. This ensures that only legitimate users can participate, establishing a clear user boundary. In the Danish case, the Targeted Nitrogen Regulation defines user boundaries by applying the scheme solely to active farmers within 108 designated coastal catchments. Other stakeholders, such as municipalities and industries, are excluded as they are governed under separate regulations. Farmers operating in multiple catchments must comply with the specific requirements in each catchment. These features confirm the presence of clear social boundaries in the Danish scheme.

Design principle 1B: Resource boundaries: clear boundaries are present that define a resource system and separate it from the larger biophysical environment. This principle emphasizes that well-defined biophysical boundaries (such as physical limits separating resource systems) and governance-defined spatial boundaries (such as socially constructed geographic regions) are both crucial to the CPR management success.

The physical boundaries of common-pool water resources are clearly defined in all three cases, supporting Design Principle 1B. In Spain, the physical and social boundaries of groundwater resources are aligned and legally defined, with each CUMAS required to be established within a specific Groundwater Body designated by the Ministry of Ecological Transition. This framework emerged from the EU WFD, which replaced the earlier concept of Hydrogeological Units with more precise groundwater bodies based on hydrogeological characterization. These bodies include even low-permeability aquifers of local significance, supporting both water supply and ecosystem functions. While the "body of water" is used as a management unit, the aquifer remains the foundational, physically delineated entity for governance, in line with Principle 1B. In Hungary, sustainable water management communities operate within officially designated irrigation districts, which are determined by ministerial decision. These districts consist of explicitly listed land parcels used by lawful members of the community for irrigation, and the lists are publicly available. This formal recognition ensures that the boundaries of both users and the physical resource are clear and transparent, fulfilling the criteria of Principle 1B. Denmark's targeted nitrogen regulation relies on hydrological models to define precise spatial and biophysical boundaries for its 108 coastal catchments. These models establish the connection between agricultural nitrogen emissions and downstream environmental impacts, distinguishing between surface and groundwater pathways. The catchments, based on this national model guide the nitrogen reduction requirements for farmers. Although uncertainties remain, especially at high spatial resolution, the approach allows for targeted regulation based on scientifically defined biophysical boundaries. Despite potential issues due to model limitations, the system still meets the requirements of Principle 1B.

Design principle 2: This design principle is also divided into two principles.

Design principle 2A. Congruence with local conditions: appropriation and provision rules are congruent with local social and environmental conditions. This principle emphasizes the importance of aligning rules with the specific characteristics of both the resources and the resource users. It ensures that governance measures are appropriately tailored to the scale and magnitude of impacts on the CPR system.

DP 2A is present with different rigour in the three cases. Spain's groundwater management system requires each CUMAS to develop an Exploitation Plan tailored to the specific conditions of the designated Groundwater Body. This plan must aim for sustainability by reducing extraction, improving efficiency, and potentially including artificial aquifer recharge measures. It must also define clear objectives, implement abstraction controls, and establish a monitoring system. Importantly, extraction quotas are mandatory and vary based on the annual recharge dynamics. These plans are revised periodically through negotiation between CUMAS representatives and the Ministry. Thus, there is a strong alignment between the rules of appropriation and the prevailing social and environmental conditions, fulfilling Principle 2A.

In Hungary, allocation of water resources is determined by water permits that each agricultural water user must hold in order to be eligible to practice irrigated farming. Communities may have several members with such water rights; in such cases, these quotas are added together. Communities must also hold a so-called environmental district plan for official authorization of their irrigation development investments and irrigated farming activities. These plans consider environmental, nature conservation, and soil protection regulations and conditions. The environmental district plan is valid for an indefinite period, but must be regularly reviewed and updated if the environmental, nature conservation, or soil protection conditions change. This document qualifies as an official authoritative opinion, is valid for an indefinite period, but must be reviewed every five years. Furthermore, the sustainable water management community must strive to implement the best agricultural practices that can be applied in the irrigation district to support sustainable water management, although no official definition of such practices currently exists. These provisions suggest that Principle 2A is present, albeit with some practical limitations.

Denmark's targeted nitrogen regulation sets reduction goals based on the ecological status of coastal catchments, which differ across space and time. Farmer effort requirements are proportionate to land area and are adjusted as required to meet water quality (nitrogen reduction) targets. The system combines voluntary compensated participation with mandatory uncompensated enforcement if goals are not met. While the design aligns environmental targets with local nitrogen conditions, it gives limited attention to social conditions, which may result in uneven economic impacts across farms. As such, the rules for appropriation are environmentally congruent but only partially consider social conditions, making Principle 2A only partly present in the Danish case.

Design principle 2B. Appropriation and provision: the benefits obtained by users from a CPR, as determined by appropriation rules, are proportional to the amount of inputs required in the form of labour, material, or money, as determined by provision rules. This principle relates to the distribution of costs and benefits within a group of resource users in environmental governance. This is commonly known as the proportionality principle, as it emphasizes fairness and equity by ensuring that the benefits individuals receive are aligned with their contributions.

Design Principle 2B, proportionality between benefits and costs, is fully present in the Spanish and Hungarian cases but only partially present in the Danish case. In Spain, proportionality is maintained by adjusting groundwater use rights through the Exploitation Plan, ensuring that all users receive quotas aligned with their irrigable land area, regardless of whether their rights originated from private or public systems. In Hungary, members of water management communities pay water service fees proportionate to their actual use, maintaining fairness, though determining the optimal fee level remains a key operational challenge. In Denmark, proportionality is evident in the voluntary component of the targeted nitrogen regulation, where farmers are compensated per hectare based on the measure adopted, covering the opportunity cost. However, the uniform compensation does not reflect the varied environmental impact of individual actions, and mandatory compliance measures, if triggered, offer no compensation, leading to a misalignment between effort and reward. This, coupled with unequal economic burdens across farm types, makes the application of Principle 2B only partially present in this case.

Design principle 3. Collective-choice arrangements: most individuals affected by the operational rules can participate in modifying the operational rules. This principle stipulates the active involvement of resource users in the modification of operational rules, either directly or through legitimate representation.

Design Principle 3, which focuses on user participation in governance, is fully present in Spain and Hungary through direct or legal-entity-based structures, but only partially present in Denmark where farmer influence is mostly indirect. In Spain, CUMAS are governed directly by their users, who elect representatives in general assemblies that serve as the sovereign decision-making body. Management rules require majority approval, ensuring strong user participation and representation. In Hungary, water management communities function as formal legal entities like cooperatives or limited liability companies. Their governance is regulated by relevant laws covering establishment, management bodies, and officials, so user participation is ensured through these legal structures. In Denmark, farmers have limited direct involvement in shaping the scheme's operational rules, which are often set top-down. However, they influence policy indirectly via lobby groups, agricultural organizations, and elected officials. Therefore, user participation is only partially present.

Design principle 4. Monitoring:

4A: Monitoring users: monitors who are accountable to the users monitor the appropriation and provision levels of the users. This principle emphasizes that user behaviour, in terms of both appropriation and provision, should be monitored by either the users themselves, an overseeing organization, volunteers or a paid employee, such as a guard, who is accountable to the users.

Monitoring systems exist in all three countries, but only in Spain and Hungary cases are the monitors directly accountable to the users, aligning clearly with Design Principle 4A. In Spain, user-based monitoring is central to the functioning of CUMAS. These organizations are designed for self-management, with users overseeing groundwater use and reporting to the basin authority. Monitoring is nested: irrigation communities monitor their members, and CUMAS report to the RBA. While the RBA also conducts independent inspections, the core monitoring is done by actors accountable to users. The adoption of remote sensing, smart meters, and mobile apps reflects a growing trend toward tech-enabled, user-driven oversight. In Hungary, communities conduct self-monitoring, mainly through water meters and ad hoc on-site inspections. While not all areas have access to advanced technology, the monitoring is conducted by individuals accountable to the user group. This confirms the presence of Principle 4A, as the structure empowers user-led oversight of water appropriation. In Denmark, monitoring is administered by a government agency, not by the users or their representatives. It includes application monitoring (reviewing and comparing submitted applications with nitrogen reduction plans) and implementation monitoring (verifying compliance via random inspections and most recently the inspection is supplemented by satellite imagery (Earth Observation at DHI, 2025)). While it may be effective in assessing environmental compliance, the monitors are not accountable to the users, meaning this case does not fully meet the criteria of Principle 4A. Furthermore, as previously noted, concerns remain regarding the insufficient clarity surrounding the outcomes of the implementation monitoring process.

4B: Monitoring the resource: monitors who are accountable to the users monitor the condition of the resource. This principle underscores the importance of monitoring environmental conditions, specifically the physical resource status, to adjust the rules accordingly and manage resources sustainably.

Environmental monitoring is present in all three cases, but only in Spain and Hungary is it conducted by those accountable to the users, fulfilling Design Principle 4B; Denmark does not meet this criterion due to institutional separation between users and monitors. In Spain, the CUMAS actively monitor the condition of the aquifer by tracking well levels and sharing this information with their members, ensuring users are informed about resource status. Although the RBA also conducts independent monitoring, potential discrepancies between the two do not undermine the fact that user-accountable monitoring exists, satisfying Principle 4B. In Hungary, regular monitoring of water resources is integrated into the national river basin management planning in accordance with the European Union's Water Framework Directive. The river basin management plan must be reviewed every six years. Beside that, communities must maintain and submit environmental data, including soil tests, crop types, and water usage, for regular review and adjustment of plans. Because this monitoring is tied to community operations and accountability, the principle is clearly present. In Denmark, monitoring of the physical resource (coastal and groundwater bodies) is performed by the Ministry of Environment, independent of the farmers or agricultural monitors. This separation means that those monitoring the resource are not accountable to users, and thus, the case does not fully meet the conditions of Principle 4B.

Design principle 5. Graduated sanctions: appropriators who violate operational rules are likely to be given graduated sanctions (depending on the seriousness and the context of the offense) by other appropriators, by officials accountable to the appropriators, or by both.

Graduated sanctions are formally present in all three cases, but their actual enforcement varies. Spain applies proportionate and user-approved penalties effectively, Hungary has legal provisions with weak practical enforcement, and Denmark enforces strict sanctions through state institutions but lacks user involvement. In Spain, graduated sanctions are clearly defined and implemented by the users themselves through the CUMAS and irrigation communities. Infractions are categorized by severity, with penalties ranging from minor (€300) to very serious (€10,000), including possible suspension of abstraction rights. These sanctions are established and approved collectively by users, fulfilling Design Principle 5 strongly and in practice. In Hungary, while communities have legal authority to sanction their members through business or cooperative statutes, enforcement is generally weak due to lenient quotas and minimal oversight. Although the principle is embedded in law, it is not effectively applied in practice, making its presence more formal than functional. In Denmark, graduated sanctions are enforced by the state rather than by users or their accountable representatives. Non-compliance can lead to strict financial penalties and reductions in nitrogen quotas, using a structured framework that considers severity and scale (see Table 2A). However, farmers are not involved in designing or applying these sanctions, and implementation gaps remain, indicating the principle is present but detached from user accountability.

Design principle 6. Conflict-resolution mechanisms: appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and *officials. This principle emphasizes that the availability of low-cost conflict resolution mechanisms is vital, as they enable appropriators and officials to address conflicts caused by ambiguities in the rules without needing to renegotiate or dispute the existing regulations.*

Conflict-resolution mechanisms are well-developed and user-centred in Spain, legally defined but externally governed in Hungary, and formally present but centralized and institutional in Denmark. In Spain, conflict resolution is handled internally through a nested system involving Irrigation Juries at both the CUMAS and community levels. These juries, composed of elected members, aim first for mediation and issue rulings only when necessary. This system is fast, cost-free, and rarely escalates to formal courts, strongly aligning with Design Principle 6. In Hungary, conflict-resolution processes are defined by broader legal frameworks governing cooperatives and producer groups. Communities act according to their statutes, and external conflicts (e.g., irrigation easement disputes) are addressed with statutory rules and compensation requirements. However, these mechanisms are not uniquely designed for the water management system, making the principle only partially present. In Denmark, conflict resolution is primarily institutionalized. Farmers who disagree with sanctions or decisions under the nitrogen regulation scheme may appeal to the Environment and Food Board of Appeal or seek legal redress through the courts. While mechanisms are available, they are formal and often costly, and users are not directly involved in managing them, indicating only limited alignment with the spirit of this design principle.

Design principle 7. Minimal recognition of rights to organize: the rights of appropriators to devise their own institutions are not challenged by external governmental institutions. This principle stipulates that it is essential for resource users to have the ability to create their own rules without interference from higher authorities, particularly given the prevalence of top-down environmental governance that has often undermined local resource rights.

Recognition of users' rights to organize is strongly present in Spain through mandated and supported self-management institutions, partially present in Hungary due to legal permissions but limited scope and absent in Denmark where top-down regulation dominates. In Spain, the right to self-organize is not only recognized but actively mandated by the state in the case of overexploited aquifers. Users are required to form CUMAS and manage the aquifer collectively, with strong institutional backing. This fulfils and exceeds the requirements of Design Principle 7. In Hungary, water user communities have full legal authority to organize and manage irrigation investments according to environmental plans. However, the framework does not promote broader, collaborative forms of water governance (e.g., retention or floodplain management), making user organization permissible but not holistically supported, indicating partial presence of the principle. In Denmark, despite a general tradition of agricultural self-organization, the targeted nitrogen regulation is a strictly top-down policy. It does not facilitate or recognize farmers' rights to devise their own nitrogen management rules or market-based coordination mechanisms, resulting in the absence of Design Principle 7 in this case.

Design principle 8: Nested enterprises: appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises. This principle emphasizes that due to the nature of environmental problems, local governance systems must be nested within higher-level governance structures.

Nested governance structures are clearly present in Spain and Hungary, though challenged in Hungary by institutional fragmentation, while Denmark shows partial presence through its integration into multi-level governance but lacks clearly nested user-level institutions. In Spain, the governance structure of CUMAS reflects classic nested enterprises. CUMAS themselves are composed of smaller irrigation communities, replicating Ostrom's nested layers model. At a higher level, their coordination with the River Basin Authorities (RBAs), which include user assemblies, suggests a form of co-management that still fits within a nested governance framework. This principle is clearly present. In Hungary, irrigation communities are legally embedded in a national water governance hierarchy, suggesting structural nesting. However, the effectiveness of this nesting is undermined by fragmentation and overlapping mandates among state agencies. Despite these challenges, the hierarchical design aligns with the principle, so it is considered present. In Denmark, the targeted nitrogen regulation exists within a broader EU and national governance framework (e.g., CAP funding, EU Water Framework Directive), and implementation involves multiple actors like catchment consultants. However, the lack of strong user-level organizations or clear functional nesting among local, regional, and EU actors limits the depth of this principle's application. Therefore, the principle is only partially present.

Table 2. Presence of Ostrom's design principles in the three case studies

	Presence of design principle		
Design principle	Spanish case	Hungarian case	Danish case
1A. user boundaries	Present	Present	Present
1B. Resource boundaries	Present	Present	Present
2A. Congruence with local conditions	Present	Partially present	Partially present
2B. Appropriation and provision	Present	Present	Partially present
3. Collective choice arrangements	Present	Present	Present
4A. Monitoring users	Present	Present	Partially present
4B. Monitoring the resource	Present	Present	Partially present
5. Graduated Sanction	Present	Present	Present
6. Conflict resolution mechanism	Present	Partially present	Partially present
7. Minimum recognition of rights	Present	Partially present	Absent
8. Nested enterprise	Present	Present	Partially present

5. Discussion

Ostrom's DPs have been widely used as diagnostic tools to analyse the performance of CPRs institutions in different settings (Cox et al., 2010; Fleischman et al., 2014). The application of Elinor Ostrom's DPs across the Spanish, Hungarian, and Danish water resource management systems related to agriculture reveals both the relevance of these principles and the varying degrees to which they are realized in practice.

Our analysis reveals that the Spanish case most comprehensively fulfills Ostrom's DPs. It demonstrates a high level of institutional maturity, with clearly defined user and resource boundaries, strong congruence between rules and local socio-environmental conditions, and robust user participation in decision-making. The system is further supported by user-accountable monitoring, well-functioning graduated sanctions and conflict resolution mechanisms, and institutional recognition of users' rights to organize. Crucially, governance activities are organized in nested layers, from irrigation communities to CUMAS and RBAs, making the Spanish case a strong example of decentralized, collective CPR management embedded in a multilevel governance structure. Institutional support for polycentric, nested governance, where multiple authorities interact to make and enforce rules, is essential for long-term commons resilience (Andersson and Ostrom, 2008; Ostrom, 2010b). The alignment with Ostrom's DP is unsurprising, as Spain's groundwater management system was among the cases that originally informed Ostrom's framework (Ostrom, 1990).

This adaptation of the Spanish model to Ostrom's DPs largely explains the public support for the implementation of this model in aquifers and the positive assessment that, in general terms, administrations (MITECO, 2022) and experts (Custodio, 2023) make of the CUMAS. But obviously, this does not mean that all CUMAS meet their sustainable management objectives or that they achieve them with the same speed or intensity. Other factors also influence the evolution of these institutions, and many of them have also been considered by the theory of common pool resources. These other factors, such as the existence of overly large and/or heterogeneous user groups; their lack of autonomy; the lack of understanding of the nature of the aquifer; and the lack of transparency in resource management are some of the main limitations to successful collective action in collective groundwater management that have been identified by some authors (Molle and Closas, 2019).

Our results show that the Hungarian case's alignment with the most of the of the DPs (6 of the 8 DPs). Legal frameworks provide a solid foundation for user boundaries and proportional cost-benefit arrangements (DPs 1 & 2B), and formal organizational rights are recognized (DP 7). However, challenges remain in terms of implementation. While collective-choice arrangements and monitoring are formally structured (DPs 3, 4A, 4B), weak enforcement and fragmentation between responsible institutions reduce the system's effectiveness. Nested governance exists in theory (DP 8), but coordination across levels is often unclear or inefficient, undermining adaptive management potential. This discrepancy between formal structure and practical function is a documented limitation in commons governance literature, particularly in post-socialist contexts, where institutional legacies affect local governance capacity (Cleaver and De Koning, 2015). Overall, the Hungarian case illustrates that institutional design alone i.e. fulfilling the DPs, is not enough, effective water governance requires functional implementation, context-specific planning, and active engagement with local user needs and behaviors.

The Hungarian case shows that the fulfillment of the Ostrom's DOs alone is insufficient to ensure successful collective resource management. Rather, effectiveness also depends on factors such as pre-existing social capital, networks of trust, and the presence of legitimate local leaders (Baland & Platteau, 1996; Wade, 1988, Shalsi et al., 2019). Social capital is context-specific, dynamic, and historically embedded (López-Gunn, 2006), and therefore, previous successful experiences function as social proof that cooperation yields benefits. They can generate a virtuous cycle: greater trust leads to increased collective action, which in turn reinforces further successes. In the absence of these successful past experiences, or as in the Hungarian case, in the presence of resentment and distrust of collective action, derived in this case from the negative effects of agrarian collectivism imposed during the socialist era, the development of collective action institutions for the management of natural resources becomes an enormous challenge that hinders the development of the abovementioned virtuous cycle.

Compared to the Spanish and Hungarian cases, the Danish targeted nitrogen regulation case, deviate substantially from Ostrom's DPs. While the policy is grounded in science-based environmental targeting and supported by sophisticated modelling to define resource boundaries, it lacks sufficient user-level autonomy and collective organizational mechanisms. The key DPs, particularly those emphasizing user participation, self-monitoring, conflict resolution, and rights to self-organize (DPs 3-7), are only partially fulfilled or absent. This is primarily due to the top-down nature of the scheme, in which operational rules are determined by central authorities and enforced through state institutions without direct involvement of resource users. Although the policy operates within a nested governance framework through EU and national structures (DP 8), the lack of a formal role of the bottom-up institutions (Graversgaard, 2018) has in the past limited its capacity for adaptive, locally embedded management. The disconnect between regulation and local agency is particularly problematic in managing non-point pollution sources. Perhaps reflecting these shortcomings, the scheme's effectiveness has recently come under scrutiny by state auditor (Rigsrevision, 2024).

Our findings highlight the critical need to integrate design principles into the evaluation and reform of agri-environmental and climate governance frameworks in Europe. The contrast between Spain's user-embedded governance and Denmark's state-centric model suggests that empowering users to participate in monitoring, enforcement, and rulemaking can lead to more legitimate and context-sensitive solutions. Furthermore, the Hungarian case highlights the importance of not just embedding rights in law but ensuring they are supported through clear mandates, stable coordination structures, and institutional capacity. Overall, the variation in how DPs manifest in Spain, Hungary, and Denmark points to the importance of institutional context, policy design, and ecological challenges in shaping outcomes. While no model is without limitations, Ostrom's DPs could offer a valuable normative and analytical benchmark for designing agri-environmental arrangements that are adaptive, participatory, and resilient.

However, an analysis of the performance of these institutions in the three countries should not be limited to examining design principles (DPs). Other elements highlighted by common-pool resource theory can broaden this assessment. As noted, factors such as the nature of the user group, the characteristics of the resource system, and the level of social capital can also be decisive (Agrawal, 2001; Shalsi et al., 2019). Moreover, while the bottom-up configuration of collective management institutions is essential, the influence of state institutions—and a certain degree of top-down intervention or control—should not be underestimated.

First, because the credibility of potential state intervention, reinforced by the state's legitimacy to impose restrictions, can significantly shape group behavior (Molle & Closas, 2019). Second, because achieving a balance between sanctions and incentives—"sticks and carrots"—is crucial, as restrictions are likely to be accepted only when offset by adequate benefits (Shortle and Horan, 2001), a condition that often requires substantial public resources (Closas et al., 2017). In sum, the most effective governance of common-pool resources tends to emerge when perceived benefits outweigh costs under the credible threat of state intervention, when these processes take place where bottom-up and top-down strategies flow within a well-balanced polycentric system.

We also observe that the DPs are largely silent on the motivations and behavioral factors influencing farmers willingness to engage in and contribute to sustainable resource management. We see a particularly promising line of research to unpack the push and pull factors associated with collective governance water resource policies. The three cases offer distinct historical paths of development for the agricultural sector which gives a different context for the acceptance of collective policy tools.

It is important also to note some limitations of this study. First, the three cases have been defined based on a general dataset regarding their legal and institutional characteristics. Naturally, each country may present a wide range of local variations, with differing degrees of success depending on various contextual factors. While some of these particularities have been considered in the analysis, they have not been addressed in a systematic or exhaustive manner. Second, the study is based on only three case studies which, although all focused-on water governance, exhibit considerable heterogeneity, making direct comparison challenging. This implies that while the application of the

DPs is highly useful for assessing institutional robustness and sustainability, the small number of cases requires caution when drawing broader conclusions that might affect the general theory of collective resource governance. Third, it should be acknowledged that the DPs, as previously discussed, define key characteristics that help in understanding collective management institutions for common-pool resources. However, they are not the only analytical tools available. The robustness and sustainability of such cases also depend on other factors and indicators that have been progressively developed through subsequent research following Ostrom's seminal work.

6. Conclusion

This study has shown how collective water governance arrangements in Spain, Hungary, and Denmark vary in their alignment with institutional conditions that support sustainable common-pool resource management. Spain's case, with strong user self-organization embedded in supportive legal and nested governance structures, most closely matches the enabling conditions for effective collective action. Hungary's case demonstrates partial institutional alignment but lacks operational effectiveness, while Denmark's case, though environmentally targeted, falls short in user involvement and legitimacy. While Ostrom's design principles offer a valuable lens to assess institutional fit and capacity for collective action, they provide limited insight into the individual-level motivations, constraints, and social dynamics that shape farmer participation. Institutional design is necessary but not sufficient implementation depends, among others, on economic and behavioural factors. Our follow-up work will move beyond institutional analysis to explore the behavioural levers and barriers in collective agri-environmental programs.

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Appendix 1

Table 1A Participation in the nitrogen reduction efforts as assessed after the application stage

Year	Effort requirement (ha)	Voluntary application(ha)	Additional requirements
2017	137,560	144,220	3,253
2018	114,300	105,000	3,000
2019	138,200	139,350	275
2020	373,000	370,000	12,493
2021	373,600	359,200	17,200
2022	373,500	350,150	22,200
2023	373,000	352,800	12,320

Table 2A: Sanctions in the Danish targeted regulation (Ministry of Food and Agriculture, 2023)

Stage	Violation rate range	Penalty (%)
1	0 – 10 %	10
2	10 – 20 %	24
3	20 – 50 %	65
4	Over 50 %	100