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Rural livelihoods displacement and mal-adaptation due to large-scale modern irrigation in Navarre, Spain

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ABSTRACT

The introduction and expansion of large-scale modern irrigation technology is often justified on the grounds of agricultural productivity and, more recently, climate change adaptation. However, the impacts of its accompanying process of agricultural intensification are seldom analysed from a social-ecological lens. Here we explore the effects of a large-scale modern irrigation (LSMI) project on farming livelihoods in Navarre, Spain. We identify farmers' main livelihood and land management strategies to show how they are affected by the adoption of LSMI technology. We show that the development of the LSMI project contributes to change farm management practices in ways that simplify cropping patterns while displacing some farmers towards drylands and forcing others to sell their arable lands. Furthermore, we suggest that the LSMI project adopters may become more sensitive to climate change in the long term. In light of these findings, we argue that LSMI projects, and irrigation policy more broadly, may be inadvertently eroding traditional and less intensive small-scale farming while contributing to land accumulation by large-scale and pro-intensification farmers. These processes may be sowing the seeds of future rural vulnerabilities under accelerating climate change.

1. Introduction

Land use intensification has been broadly understood as the process where a series of activities or technologies are undertaken or adopted with the intention of enhancing the productivity or profitability per unit area of rural land (Martin et al., 2018). In agriculture, modern irrigation technologies, which can encompass canals for water distribution, pumps, flow-regulating devices, hydraulic valves, irrigation programmers and on-field sprinklers, is increasingly regarded as a central pillar of land use intensification strategies, typically justified the grounds of productivity and climate change adaptation (Chartres and Noble, 2015; Abberton et al., 2016).

However, there is substantial debate over whether large-scale modern irrigation (LSMI) ought to be considered a strategic

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agricultural management approach in the face of climate change, particularly for rural smallholders (Wilhelmi and Wilhite, 2002; Berbel and Mateos, Cabello et al., 2015; Tarjuelo et al., 2015). In semi-arid regions such as the Mediterranean, the ecological and productivity effects of LSMI have been broadly debated (e.g. Urama, 2005; van Halsema and Vincent, 2012). Drawing on discursive paradigms such as sustainable intensification (Garnett and Godfray, 2012), ecological intensification (Bommarco et al., 2013), or climate-smart agriculture (Campbell et al., 2014; Harvey et al., 2014; Lipper et al., 2014), some scholars argue that LSMI can foster sustainable agricultural systems by using water and soil resources more efficiently. Others have more critically asserted that LSMI can be maladaptive, fitting into a wider hydro-social system that inequitably distribute social-ecological burdens of this technology (Fleischer et al., 2008; Mahdi et al., 2009; Swyngedouw, 2009). There is evidence that LSMI development can accelerate land concentration processes, marginalise small scale farming systems and increase chemical inputs use (Hussain and Hanjra, 2004; Mannke and Rath, 2011). It can also jeopardise sparing high ecological value land areas for biodiversity conservation (Vongvisouk et al., 2016).

Studies on the effects of land use intensification abound, particularly in the global South (Baccar et al., 2019; Kadipo Kaloi et al., 2021; Zimmerer, 2013). These generally focus on demonstrating the importance of irrigation to increase productivity and farmers' income and discuss which factors are determinant in the adoption of such technology (e.g. age, farm size, household size, credit access, farmers' experience distance to the canal and off-farm). Some of these analyses also mention that the current and future sustainability of intensive agricultural production system production systems is questionable due to their negative impacts on the environment and natural resources (Baccar et al., 2019; Kadipo Kaloi et al., 2021).

In western, European countries, however, research that investigates how land use intensification through LSMI affects traditional, small-scale rural livelihoods, especially in the context of accelerating climate change are lacking. To address this gap, we examine the impacts of LSMI on rural livelihoods in the region of Navarre, Spain, drawing on the Sustainable Rural Livelihoods' Framework (SRLF) (Scoones, 1998). We consider this case study representative of other Mediterranean and European semi-arid regions, not only in terms of the climate change challenges, such as prolonged droughts, but also in terms of persistent depopulation trends, competitiveness in global agricultural markets, and an increasing number of regulations often contested by farmers (EFE, 2024). In the article, we first analyse rural livelihoods in the study area and explore what combination of assets are associated with which livelihood strategies, paying specific attention to the role of LSMI in such strategies. We identify four main livelihood typologies which diverge in the crops grown, the land area worked, and other variables including age, economic endowment, education and whether or not the farming system incorporates LSMI.

2. Understanding the risk of maladaptation of modern irrigation farming systems

2.1. Sustainable rural livelihoods and the risk of maladaptation

The SRLF has contributed to our understanding of how farmers manage and acquire various assets, such as human, natural, social, physical, and financial resources, to sustain their livelihoods. This framework has been widely used to understand rural livelihood patterns in countries of the global South (Daur et al., 2016; Gerlitz et al., 2017; Russell-Smith et al., 2017), yet its application has been relatively limited in other contexts, such as in the global North, where access to different capital assets is generally less challenging (Villamagna and Giesecke, 2014).

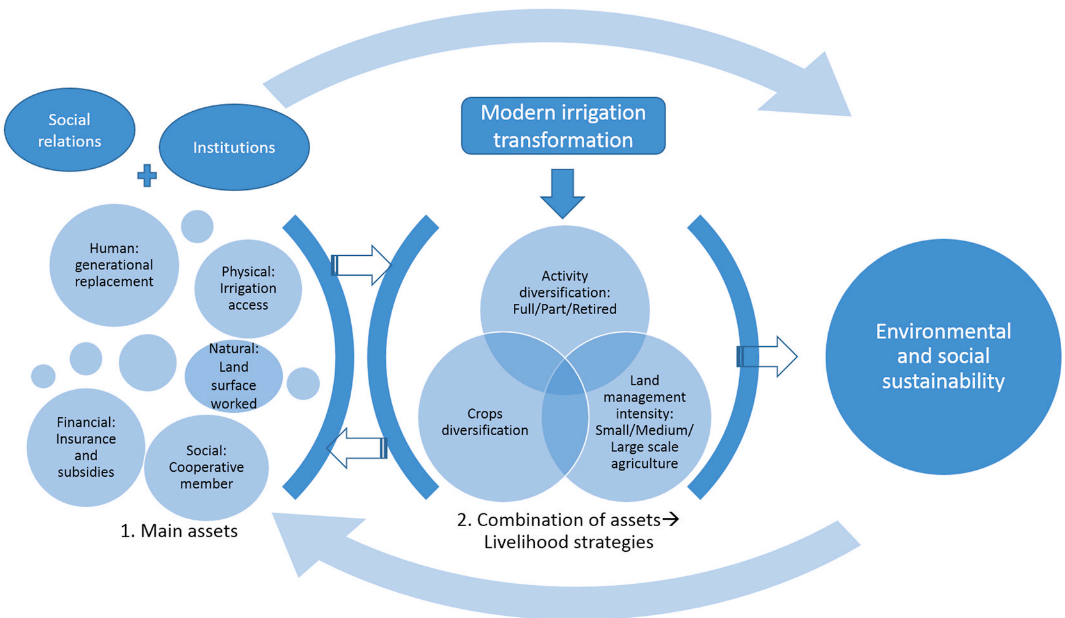

Fig. 1. The sustainable livelihoods framework applied to analyse the effect of irrigation development.

The SRLF principally centres on individuals or groups of social actors and their relationships concerning their livelihood approaches. Those typically include different land management regimes (e.g. cropping systems), non-natural resource management activities (e.g. amount of time invested in alternative income sources or other livelihood activities) and the distribution of control over resources (e.g. the constrained access of small-scale farmers to irrigation water after the introduction of a new irrigation technology) (De Haan and Zoomers, 2005). The combination of these strategies affects farmers' livelihood outcomes (e.g. income level, income stability) and environmental sustainability (e.g. soils and water quality and biodiversity) (Allison and Ellis, 2001; Hahn et al., 2009; Scoones, 1998) (See Fig. 1).

Livelihood strategies can be categorized in multiple ways (Barrett et al., 2001; Chambers and Conway, 1992; De Haan and Zoomers, 2005; Rakodi, 1999). Among them, we find three broad clusters of strategies: land use intensification or extensification, livelihood diversification, and abandoning a given livelihood activity, e.g., farming (Paavola et al., 2009). Individuals may choose a combination of these strategies concurrently or sequentially (Scoones, 1998), which will inevitably involve combining, transforming, or substituting assets.

External factors, such as crop price fluctuations or agricultural policies (e.g. CAP), often constitute the basis of land use *intensification or extensification* strategies and, directly or indirectly, exercise an effect on agricultural biodiversity, land cover patterns, soil properties, and land-use or tenure regimes (Brown et al., 2020; García et al., 2020). For example, in many tropical and sub-tropical countries, cattle grazing subsidies have aided land use extensification, which in turn has induced large-scale deforestation and contributed to undermine the resilience of small-scale farming (Paavola, 2007; Zak et al., 2008). *Livelihood diversification*, in turn, is often aligned with risk aversion, which is key for smallholders who lack capital and aim to avoid economic losses, for example in the face of market or climate uncertainties.

However, not all livelihood strategies may be necessarily conducive to the ecological and/or socio-economic sustainability of rural households. It is important to understand if a given strategy has the potential to increase the vulnerability of the household, or of the broader social-ecological system that the strategy impacts upon. Such vulnerability assessment can shed light on maladaptive strategies, understood as actions that inadvertently raise the current or future vulnerability to climate change or other environmental and socio-economic stressors (Juhola et al., 2016). For instance, drawing on the previous example, land use extensification through cattle grazing subsidies can be a viable and economically efficient livelihood strategy in the short-term. But it can also contribute to increase the frequency of climate hazards through reduced forest cover and reduce soil fertility and the potential for ecological restoration in the medium-term, thus leading to enhanced vulnerability and reduced adaptive capacity for both rural people and ecosystems (Asare-Nuamah et al., 2021). Understanding livelihood strategies as potential maladaptive actions requires a systems perspective (see Rickards and Howden, 2012), and a reflexive approach which identifies interdependencies and relationships among actors, sectors and goals (Juhola et al., 2016).

2.2. The techno-institutional dimensions of farming systems

The growing liberalization of the primary sector, coupled with commodity price volatility and agricultural intensification policies, has led to a notable reshuffling of land ownership, agricultural labour, and land management practices since the late 20th century both in the global North and global South. As a result, small-scale farmers are facing an increase number of challenges with many already disappearing from rural agricultural landscapes. The transition towards intensified and large-scale farming can also be attributed to modern technologies, for instance those that facilitate the standardization and monitoring of farming operations (Deininger and Byerlee, 2012). The perceived greater efficiency of "modern" large farms, which adopt "scientific" agronomic methods, is often used as a justification to promote the concentration of rural resources and the development of large-scale agricultural operations. Likewise, mainstream rural development policies often emphasize the potential of large-scale farms to create employment opportunities and easier market access (Haggblade et al., 2010). However, large-scale agriculture has often been criticized for excluding local populations from their traditional agricultural land use practices (Binswanger et al., 1995; Baland and Robinson, 2008; Conning and Robinson, 2007; Nugent and Robinson, 2002), and more recently regarded as a new form of 'land grab' due to numerous examples of irregularities and corruption linked to modern rural property transfers (Zoomers, 2010).

The persistence of the family farm model in the global North can be attributed to three key factors (Allen and Lueck, 1998; Binswanger and Deininger, 1997; Deininger, 2003). First, family workers and the residual claimants of profits are more inclined to work diligently compared to wage workers, who may necessitate costly supervision. Second, family farms are frequently utilized to swiftly adapt management decisions according to specific sites, seasons, and market conditions. And finally, family farms are more adaptive in adjusting labour supply to accommodate the seasonality and annual variations of production. This adaptability is facilitated by the ease with which family labour can be reallocated to other on and off farm tasks, making of livelihood diversification a strategy of livelihood sustainability (Rosset, 2000). Several studies have highlighted the significance of maintaining crop diversity and a diversified farm portfolio as an adaptation strategy (Rahman and Hickey, 2020; Paavola et al., 2009; Albizua et al., 2019).

3. Case study and methods

3.1. The Itoiz-Canal de navarra project, Navarre, Spain

To study the role that LSMI plays in shaping farming livelihoods, and particularly traditional small-scale farming, we chose the case of the *Itoiz-Canal de Navarra* project in Navarre,[1] northern Spain. As mentioned earlier, this case study represents other Mediterranean semi-arid regions that have adopted LMSI, including several regions of southern Italy, Greece and Portugal. During the early 19th century, the study region faced challenges during the confiscation process when communal lands were converted into private property through public sales. However, despite this transition, it continues to stand out as one of the few regions in Spain that retain significant amounts of communal land (Aguas and Gastón, 2010). As a result, many farmers have been able to gain access to land. In some villages, private initiatives have acquired and returned lands, leading to various configurations of lands as commons.

The LSMI project involves a substantial irrigation channel that extracts water from the Itoiz dam. The channel's construction started in 2006 to develop 15 irrigation sectors that would provide water to 57,700 ha of non-irrigated cultivated lands. To date, there are 25 sectors and around 30,000 ha have been transformed. Since June 2023 two more sectors and some 2000 new hectares have been incorporated. By 2024 the enlargement of the 1st phase is expected to be completed, including 33 irrigation sectors covering approximately 37,000 ha. The second phase, is also expected to be tendered later in 2024 (Fig. 2).

Land in Navarre has been historically fragmented, primarily consisting of small subsistence agricultural plots. These plots were cultivated using intensive human labour, with limited mechanization and minimal reliance on artificial agrochemical inputs (Crecente et al., 2002). Over the past two decades, the former government of Navarre has actively pursued a transformational agenda to alter this historical landscape. Their efforts have centred on incentivizing investments in large, fixed capital infrastructure projects like the *Itoiz-Canal de Navarra*. Additionally, financial subsidies have been offered to encourage farmers' participation in irrigation schemes, as outlined in Navarre's Rural Development Program 2014–2020. Furthermore, the government's approach has involved promoting land concentration to facilitate the mechanization process and foster the growth of larger-scale agricultural enterprises. For instance, the Foral Law 18/1994 mandated that agricultural properties had to be larger than 5 ha to qualify for irrigation subsidies. This was aimed at bringing about significant changes in the agricultural landscape and at encouraging the modernization and expansion of agricultural practices (BON, 1994; Noticias de Navarra, 2017).

In fact, this process of land concentration (known locally as '*concentraciones de tierras*') was a prerequisite for transforming formerly rainfed agricultural lands into irrigated areas. As noted earlier, small plots of lands had to be brought together to encompass, at least, 5 ha and the resulting larger plots were classified in categories of quality and suitability for irrigation based on soil productivity and properties such as texture, stony loam, and organic matter. Therefore, if a landholder held 2 ha of high quality land, for example, he could gain access to the same area of equal quality, or to a larger area of lower quality, whether in the same or a different location. This process remained consistent for lands under traditional irrigation, yet the requirement of a minimal area of 5 ha presented a significant challenge, as 96% of these plots were less than 2 ha.

National and regional governments in Spain have promoted modern irrigation in the study area. Both governments have provided different subsidies and technical assistance at different scales (De Vries, A, and Garcia M., 2012). Government agencies have regarded modern irrigation as an opportunity for increasing yields, therefore household income, and providing jobs to future generations. For example, a few years ago Navarre's regional government advocated for the Itoiz-Canal de Navarra project on the grounds that it would '*ensure the satisfaction of a plurality of public needs, such as improving the quality of water supply to urban zones (including the city capital Pamplona); consolidating traditional irrigation; guaranteeing the transformation in modern irrigation; enabling the implementation of industrial land, controlling river floodplains and producing electrical energy*".[2]

3.2. Methods

To analyse the impact of LSMI on smallholder livelihoods in the study area, we utilized a mixed methods approach. Our methodology involved conducting 29 in-depth interviews from May to July 2013, using a snowball sampling technique. Interviews included targeted farmers (N = 13), policy-makers (N = 4), staff of the public company attached to the Navarre Government that projected the channel (N = 3), water management related NGOs (N = 2), members of consumer groups (N = 2), farmer unions (N = 2), water management company staff (N = 1), union workers (N = 1), and scientists (N = 1).[3] The interviews served two main purposes: first, to collect data for designing a household survey, and second, to gain insights into the historical development of the local agrarian system and its management practices. Our interview questions revolved around their experience in the agrarian sector, how they categorized farmers in the study area, and the prevalent agrarian practices (refer to the Appendix for details). Additionally, we included questions to analyse vulnerability and identify crucial rural institutions.

Between October 2013 and January 2014, a household survey to gather information on farmers' assets and livelihood strategies, as well as farmers' views on the adoption of LSMI, was also conducted in 22 villages impacted by the irrigation project (Appendix, section I and II). These villages are situated in the *Zona Media* and along the border of this region with the *Ribera Alta* of the Ebro River watershed (Fig. 2). A recent follow-up interview (May 2023) with the president of the irrigation community (Appendix, section IX and

[1] Navarre has a population of about 638,000 inhabitants, with a density of ca. 61 inhabitants per km^2 (30% lower than the Spanish average) (Expansión, 2017).

[2] https://www.navarra.es/home_es/especial/CanaldeNavarra/Itoiz+Canal+de+Navarra.htm accessed on 8th June 2017.

[3] See the Appendix for interview contents and a descriptive list of participants.

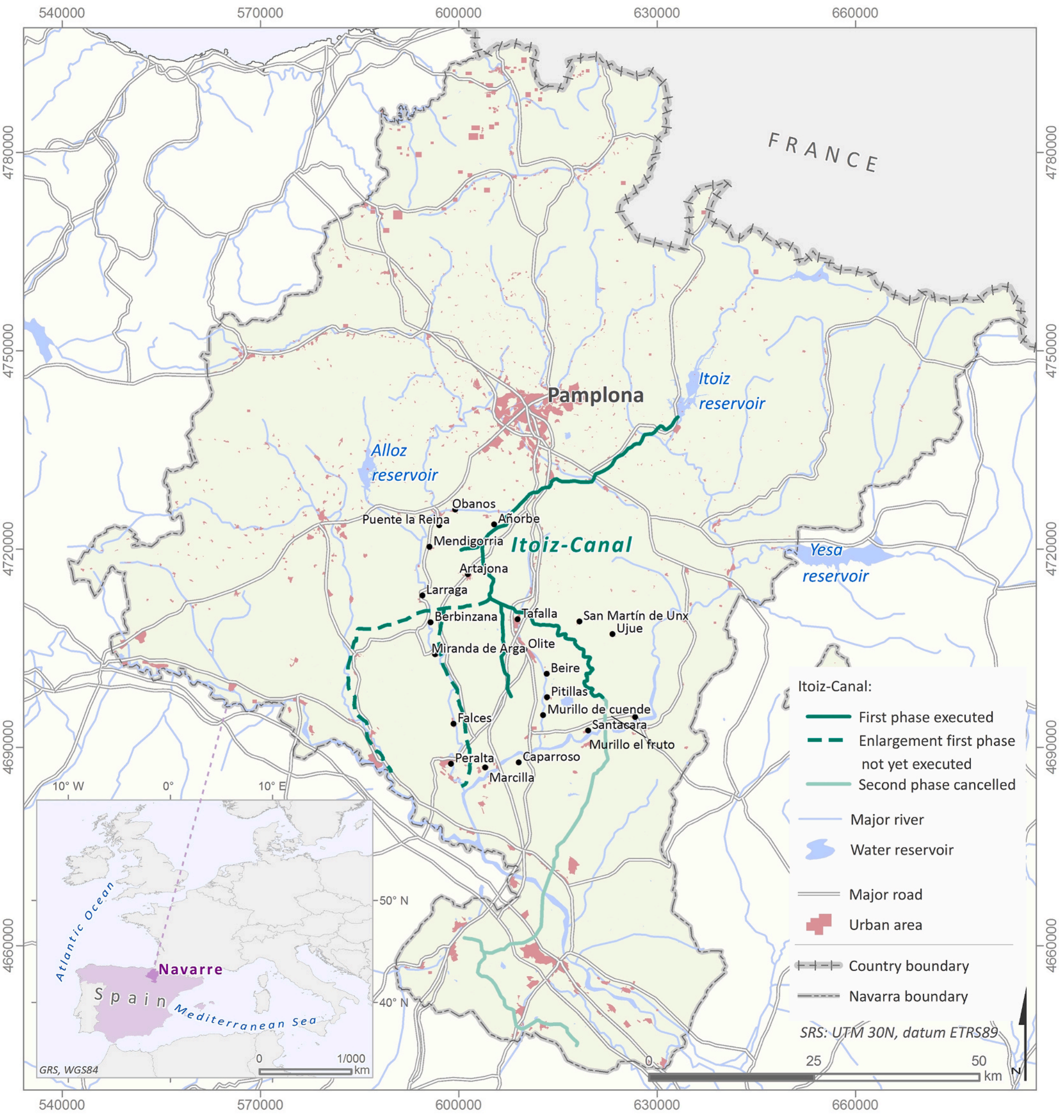

Fig. 2. Location of Navarre province and Phase 1 of the Itoiz-Canal de Navarra irrigation project.

X) confirmed that the main changes induced by the project on farms' structure and livelihood management practices took place when the transformation occurred, which means that the data obtained remains relevant and can shed valuable insights on how technological intensification in agricultural systems might affect livelihood sustainability and climate vulnerability.

A total of 381 household surveys were conducted (Appendix, section III), and participants were chosen using probability sampling methods.[4] Following manual data cleaning, we performed a multiple correspondence analysis (MCA) on land management variables such as land surface, modern irrigation usage, and type of fertiliser. Additionally, we conducted a hierarchical cluster analysis (HCA) on the factors derived from MCA to identify distinct farmer groupings. The mode is the value that appears most often in a set of data; in this case Cla/Mod refers to the part of the total population that is in the cluster. Mod/Cla refers to the most recurring value in the cluster. The v-test (last column in Table 2) indicates the size differences between class and mode: the larger the number, the higher the representation of that variable is in the given cluster (in comparison to other clusters). Livelihood profiles were determined using land management proxy variables, with a particular emphasis on the adoption of modern irrigation and its associated land management practices. Subsequently, these characteristics were compared to farmers' socio-demographic variables, including their access to assets (Table 1).

[4] The underlying principle of probability sampling is that every case – every member of the study population – has a known probability of being included in the sample, and therefore statistically valid inferences can be made from the sample to the overall population (Newing et al., 2011, p. 67). Based on sample size calculation and to achieve a 95% confidence interval, household sampling required a minimum of 360 surveys, randomly selected, to statistically represent the 2555 farmers in the case study area (Newing et al., 2011).

Table 1
Capital assets and livelihood options of farmers in the case study in Navarre.

Capitals		Proxy variable
Human capital	Work experience	Number of years in farming activities
	Total number of members in the household	Number of people living in the same household
	Generational replacement	Whether sons or daughters will keep farming in the future
	Number of member working in the farm	Number of people belonging to and working in the farm
	Number of members economically dependent	Number of people in the household who depend on the head in economic terms
	Number of member who had emigrated	Number of people who used to live in the household but moved to another country/city
Financial capital	Subsidies	Financial support by the regional government
	Common Agricultural Policy	European subsidies given per land area unit
	Modernization	Navarre government subsidy to modernize the farms
	Irrigation	Navarre government subsidy to install modern irrigation
	CUMA	Cooperative to share agrarian machinery
	Cooperative (other)	Organisation to store crops, sell them, get advice and buy agrarian inputs at a better price
	Insurance	Coverage under a contract in which one party agrees to compensate another for a loss
	Integral	Insurance that covers a variety of events such as climatic stressors, animals attack etc.
	Hail	Insurance that covers hail damages
	Others	Other kind of insurances
	Financial aid from family/friends	Borrowed income from family or friends
Physical capital	Irrigation access	Whether farmers can irrigate (traditional, modern or any other way)
	Modern irrigation installation	Whether farmers have adopted modern irrigation on their lands
	Machinery	Whether farmers own or rent machinery
	Internet	Whether farmers access and use the Internet with agrarian aims
Social capital	Cooperatives	Whether farmers participate in agrarian cooperatives
	Agrarian workers' union	Whether farmers participate in agrarian syndicates
	Support from Navarre's Institute of Technology and Agricultural and Food Infrastructure (INTIA)	Whether farmers use INTIA's advice services
Natural capital	Land	Land ownership
	Owned	Payment made to the owner of land for the right to use it
	Rented	
Rural livelihood strategies		
Farmer profile		Whether farmers are employed full or part-time in farming or/and whether they have other income sources in the household
Work for agro-industry		Whether farmers access this kind of agro-contract
Fertilization type		Type of fertilizer used: organic, mineral
Irrigation system		Whether they irrigate crops or not
Type of crop		Hectares of each crop

In addition to collecting quantitative data, we conducted focus group discussions (see Appendix section V, VI, VII and VIII) to gather qualitative insights, complementing the quantitative results. The process of triangulation allowed us to combine and integrate both, qualitative and quantitative findings, and provide a more comprehensive understanding of the connections between theory and empirical observations. In June 2015, an exploratory focus group involving five people (see Appendix V and VI) was organized in the village of Miranda de Arga to examine the irrigation management system resulting from the modern irrigation project. The participants included two members from the traditional irrigation community (who eventually became members of the modern irrigation community), a local environmental activist, a landowner who declined to participate in the irrigation project, and a technician from the agricultural extension agency INTIA that guided the village's involvement in the irrigation project.[5] In December 2016, we conducted two additional focus groups (see Appendix VII and VIII) involving 17 farmers, representing the diverse livelihood profiles found in the case study area. One focus group took place in the village of Artajona, located in *Zona Media*, while the other was held in Miranda de Arga, a village in *Ribera Alta.* To ensure a balanced representation of each livelihood group, we employed a cluster sampling approach. Farmers were contacted and invited to participate voluntarily in the focus groups.

To maintain neutrality and create a comfortable environment, we selected neutral locations to host the focus groups – the agrarian cooperative for one group and the municipal library for the other group, each located in their respective villages. These focus groups served the purpose of validating the quantitative analysis and obtaining further insights into farmers' perspectives on modern irrigation technology and their views on the future of farming in the region.

During fieldwork, secondary information was also gathered from key policy documents and media sources related to the

[5] INTIA is a company of Navarre's regional government that has projected the *Itoiz-Canal de Navarra* project and guided its implementation on the ground. It also provides technical services and market-advice to farmers throughout the region.

Table 2
Characterisation of the clusters regarding farmers' land use management (N = 364).

Key variables to characterise clusters of farmers	Cla/Mod	Mod/Cla	v-test
Small scale diversified farmers (N = 125)			
No irrigated maize conventionally fertilised	64.80	92.80	12.72
No irrigated (other) cereal conventionally fertilised	75.00	76.80	12.11
No irrigated maize (0 Ha)	64.50	87.20	11.66
No rainfed cereal (0 Ha	74.51	60.80	9.94
Low surface (0–5 Ha) of irrigated 'other' crops	69.51	45.60	7.42
No irrigated cereal (0 Ha)	47.23	88.80	7.33
Conventionally fertilised irrigated 'other' crops	64.20	39.69	5.86
Medium scale organic farmers (N = 22)			
Organic fertilised rainfed cereal	100.00	68.18	9.56
Organic fertilised rainfed vineyard	100.00	40.91	7.05
Low surface (0–5 Ha) of rainfed vineyard	23.53	36.36	3.57
Organic fertilised irrigated maize	50.00	18.18	3.42
Organic fertilised irrigated 'other' crops	23.08	27.27	2.98
Low surface (>5 Ha) of rainfed vineyard	23.81	22.73	2.74
Large-scale intensive farmers (N = 86)			
Mixed fertilised rainfed cereal	83.05	56.98	10.81
Mixed fertilised irrigated maize	67.95	61.63	9.71
Quite extend area (75 Ha) of rainfed cereal	60.61	46.51	7.23
Quite extend area (>50Ha) of irrigated maize	63.33	22.09	4.81
Medium scale intensive farmers (N = 131)			
Conventionally fertilised irrigated maize	81.82	61.83	11.11
Conventionally fertilised rainfed cereal	64.20	79.39	10.21
Conventionally fertilised irrigated cereal	85.71	50.38	10.18
No rainfed 'others' (0 Ha)	42.47	96.95	6.04
Medium area of irrigated maize (10–50 Ha)	55.10	41.22	4.52
Small area of irrigated maize (5–10 Ha)	69.23	20.61	4.42
Small area of rainfed cereal (10–50 Ha)	54.02	35.88	3.93

Note: "Cla/Mod" refers to the ratio of the contribution of the class variable to the model's inertia. The "Class Variable (Cla)" refers to the variable that defines the different clusters or groups of farmers. Each farmer is assigned to a particular cluster based on their characteristics or attributes. This class variable essentially represents the grouping of farmers into distinct categories. Model's Inertia (Mod): Inertia, in the context of MCA, refers to the amount of variation in the data explained by the dimensions or factors derived from the MCA. The model's inertia represents the total variability in the data that is captured by the MCA dimensions. If the Cla/Mod ratio is high, it suggests that the clusters effectively capture distinct patterns or structures in the data. Conversely, if the Cla/Mod ratio is low, it implies that the class variable (the clusters) contributes relatively little to the overall variability explained by the MCA dimensions. This could indicate that the clusters are not well-defined or that other factors contribute more to the variability in the data.

construction of the irrigation channel and the subsequent implementation of modern irrigation technology in the study area. These data covered periods before, during, and after the fieldwork. For instance, valuable insights were obtained from the licensed private enterprise responsible for constructing the small channels and piping infrastructure (AguaCanal). This information helped to shed additional light on the irrigation project's financing status, the progression of water tariffs, and the participation of private companies in the development of irrigation infrastructure. Additionally, we analysed information provided by INTIA to better understand the perspective of Navarre's government regarding the irrigation project's development and the main crops being promoted alongside it. Furthermore, we collected data from claims presented in Navarre's Parliament by affected councils and political parties regarding the project's impact and implications.

The lead author also conducted participant observation as part of the research. This involved engaging in informal conversations with selected farmers and observing and documenting their daily activities over five months in 2013–2014 across the surveyed villages. Farmers were accompanied in their daily agricultural tasks for about a week, visiting three organic farms and two intensive farms. During these visits, the author observed farmers' interactions with technical extension agents from the cooperative and salespersons of seeds and fertilisers. Furthermore, the lead author closely interacted with members of various agrarian cooperatives, such as those in the villages of Artajona and Peralta. Several meetings were also attended which were organized by different organizations to discuss the implications of modern irrigation on farming. These meetings included one organized by the Una Nueva Cultura del Agua (now known as UrBizi), a non-government organization (NGO), in the village of Beire in May 2012, and another organized by the agrarian union EHNE in the village of Larraga in December 2013. The qualitative information gathered through participant observation provided valuable insights into how farmers managed their land and their perceptions of modern irrigation and its effects on their livelihoods.

Finally, in April–May 2023, we analysed all references to the project made by the main local newspaper (Noticias de Navarra) over the previous 5 years, and we also conducted two additional semi-structured interviews with a small farmer and with the president of the irrigating community. Our aim was to investigate if the irrigation zone had expanded or decreased, the number of farmers who have joined or left the project since the fieldwork took place, the crops grown nowadays, and to discuss again with these interviewees the main benefits and problems that irrigation has brought about to local communities (see Appendix, section IX and X).

4. Disentangling agrarian livelihoods and land use intensification in Navarre

4.1. Four main livelihood strategies

Based on our analysis of survey data, we identified four primary livelihood strategies closely linked to agricultural management practices. These strategies vary in terms of the main cultivated crops (e.g., maize, vineyard, other cereal, and "other" crop), cultivated land area, type of adopted fertilisers (organic, inorganic, or mixed), and the adoption of modern irrigation.

The livelihood types were categorized as: *small-scale diversified farming* livelihoods, comprising 34% of farmers; *medium-scale organic-farming* livelihoods, accounting for 6%*; large-scale intensive farming* livelihoods, representing 24%; and *medium-scale intensive farming* livelihoods, constituting 36% (see Table 2).

We conducted Hierarchical Cluster Analysis (HCA) to classify different profiles (Fig. 3 and Table 2). We selected variables with a p-value <0.05, ensuring that each cluster was represented by significantly different characteristics across the livelihood profiles.

For instance, the first row in Table 2 indicates that the absence of irrigated maize (conventionally fertilised) is a key variable that defines a cluster of farmers associated with the *small-scale diversified* livelihood profile. The value of Cla/Mod suggests that approximately 65% of farmers growing irrigated maize in the entire sample belong to the cluster of *small-scale diversified* farmers. Additionally, data revealed that 93% of farmers within this cluster do not cultivate irrigated maize.

The *small-scale diversified* farming livelihood profile was mainly concentrated in the northern part of Zona Media and Ribera Alta of Navarra, and they had not adopted modern irrigation technology. These farmers typically cultivate small plots (up to 1 ha) of vegetables and woody crops, such as olive and almond trees. This group stands out from others based on their socio-demographic characteristics and livelihood assets. The farmers in this profile are generally older, with 60% of them being 65 years or older. They consist of both part-time and retired farmers who continue to work their land, and they generally lack technical agrarian studies. The profile also exhibits a higher proportion of women-headed households, and their income is predominantly derived from farming activities and retirement subsidies. Interestingly, only 20% of these farmers have agrarian insurance, and 33% receive agricultural subsidies from the EU's Common Agricultural Policy (CAP). They seldom seek technical agricultural advice, and none of them grow crops for sale in national or international markets.

The *medium-scale organic* livelihood profile is closely linked to the cultivation of cereals and vineyards. These crops are primarily grown in rainfed systems with organic fertilisation, and the farm plots are relatively smaller, spanning less than 10 ha. Although some of these farmers employ irrigation, their watering practices involve drip irrigation with moderate water consumption levels compared to those engaged in more intensive farming livelihoods. The farmers belonging to this profile are generally younger, with approximately 70% falling within the age range of 35–55 years. They exhibit a higher level of formal education, with 22% having pursued an agrarian degree at the university level. Moreover, *medium-scale organic* farmers have access to financial assets, including farming credits and savings. Insurance-related expenses are relatively low for this group, but they have significant access to subsidies, with 77% receiving irrigation subsidies and 55% benefiting from modernization subsidies. Additionally, they show a keen interest in obtaining financial loans for farming purposes. Interestingly, medium-scale organic farmers do not actively participate in agrarian cooperatives

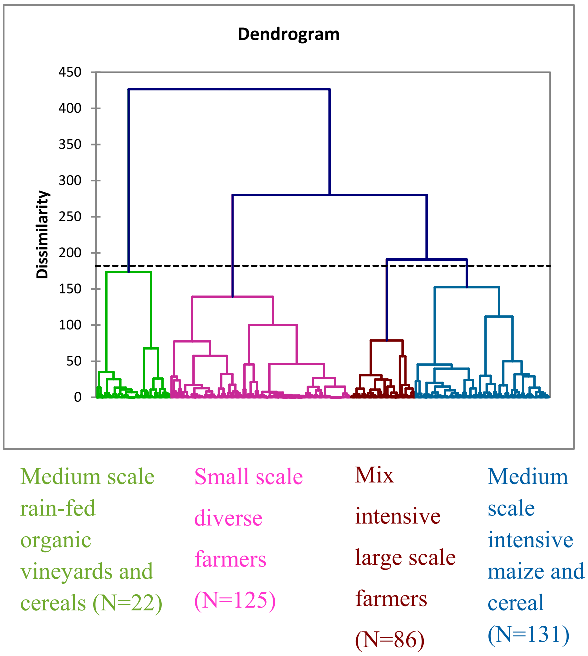

Fig. 3. Hierarchical cluster analysis of the main factors derived from the MCA.

or farmers' unions as much as their counterparts engaged in intensive farming (approximately 45% do not participate or do so sporadically). Furthermore, they do not heavily rely on technical advice from INTIA for their farming practices. Furthermore, we observed that 100% of farmers engaged in growing organically-fertilised rainfed cereals and vineyards belong to the *medium-scale organic* farmers' group. These findings shed light on the distinct characteristics and practices of various livelihood profiles within the study area.

The *medium-scale intensive* livelihood profile is characterized by farmers who have adopted modern irrigation and have shifted their focus towards maize crops, cultivating predominantly on plots ranging from 5 to 50 ha using conventional fertilisation methods (constituting 83% of the profile's members). This group includes relatively young farmers who are actively involved in full-time farming and actively participate in cooperatives and farmers' unions (comprising over 60% of the profile). Moreover, they have good access to farming subsidies. For instance, around 95% of these *medium-scale intensive* farmers have accessed agricultural subsidies from the EU-CAP, and 74% have received the regional government's irrigation subsidy. They also enjoy a high level of access to bank credits and agrarian insurance (60% in both cases). These farmers rely on INTIA's technical advice for land management practices related to land fertilisation, use of seeds, and irrigation patterns. The production of this group is predominantly market-oriented, with 20% of them being engaged in contract farming with agribusiness, which is the highest share across all livelihood profiles. This specific livelihood profile highlights a strong emphasis on modern agricultural practices and market-driven approaches within the study area.

The *large-scale intensive* livelihood profile comprises farmers who depend on cultivating extensive agricultural areas, with plots exceeding 50 ha, focusing on rainfed cereals or irrigated maize. They use both, conventional and organic fertilisers for their crops. This profile shares similarities with the medium-scale intensive farmers' group but includes a proportion of older and retired farmers. This farming profile is predominantly found in the southern area of *Ribera Alta*, likely influenced by its closer geographical proximity to the region's capital, which facilitates greater market engagement. Despite having a lower level of formal education, these farmers actively participate in cooperatives (60%) and farmers' unions (40%). Furthermore, these farmers rely on INTIA's technical advice for their land management practices. Their access to financial assets, such as credit and agrarian insurance, is slightly lower than that of medium-scale intensive farmers, with 42% having access to bank credit and around 95% benefiting from CAP subsidies. This specific livelihood profile demonstrates a substantial reliance on agriculture as a means of livelihood, particularly for farmers cultivating larger areas of land.

Among all farmers of the last two groups, most farmers expressed that the adoption of modern irrigation entailed benefits but also risks such as a higher use of fertilisers and pesticides than in rainfed systems. This perception is held by 69% and 65% of the survey participants, respectively.

> *"If in this village we had a barley average production of 3500 kg/Ha, now with irrigation we have 7000 kg/Ha, we have practically doubled … Also, if it doesn't rain in a while, you feel relax thanks to irrigation. Drought was a problem before, if you have a bad harvest a year, you still had to pay for the herbicides etc. Irrigation gives you the job and it gives you the risk too. I refer to the investment that comes with it. You spend a lot more because you need to use much more fertiliser, herbicides are much more expensive. It's changed radically, if you used to spend 30 euros in one hectare, now you can spend 90"* (I.4, Middle age full-time farmer of the Northern area with irrigated and rainfed crops).

4.2. Institutional change and land concentration driven by large-scale irrigation

Here we set to identify the drivers influencing land concentration and agricultural intensification. We explain how these processes have taken place in the *Itoiz-Canal de Navarra* project. We also examined the ongoing short-term consequences of such developments as they impact land use change through changes in land tenure and crop selection. Livelihood sustainability is proxied by the extent of crop diversification and land tenure profiles, as these are the key determinants of the long-term feasibility of rural livelihoods. We used land transactions, such as the rental and purchase of arable lands, as key indicators. This allows us to gauge the extent to which livelihoods are sustainable amidst the changes brought about by the project.

The Navarre government and associated official organizations, including INTIA and local agrarian cooperatives, share with the Spanish state the presumption that Navarre had previously underutilized its water resources for agriculture. Therefore, modern irrigation has the potential to unlock this hydrological potential and contribute to boost regional rural development (de Vries and Garcia, 2012; Parlamento de Navarra/Nafarroako Parlamentua - Noticias Presidencia, 2015). This perspective further solidified the belief in the region that the *Itoiz-Canal de Navarra* project was of paramount importance reflected by many of the related legal developments. For instance, the Spanish Real Decree 22/1997 justified the construction of the *Itoiz* dam by highlighting the benefits it would carry for local farmers and the country more generally. Subsequently, Navarre's Foral Law 7/1999, Navarre's Irrigation Plan, and Foral Law 1/2002, focusing on agrarian infrastructures, were introduced to create favourable conditions for the modern irrigation project, enabling it to receive additional regional funding. Furthermore, communal land decrees and laws, including Foral Law June 1986 (repealed by Foral Law 6/1990), were also amended to facilitate modern irrigation. For instance, Foral Orders 186/2011 and 185/2015 explained that local councils transforming communal lands could obtain a higher subsidy for implementing modern irrigation only if they prioritized full-time farmers over others while distributing communal lands among neighbouring farmers. These legal developments and amendments were aimed to support and promote the modern irrigation project within the region.

Over time, and as in many other European regions (see van Vliet et al., 2015), the interplay of technological and institutional factors has led to land concentration and an increase in the intensity of land management practices in Navarre. Notably, maize cultivation has become widespread in the study area, in substitution of traditional rotations of vegetable and fruit tree plantations, such as chickpeas, pears, peaches, cherry trees, garlic, dried beans, and thistles. This shift towards maize cultivation has also elevated the probability of irrigation-adopters engaging in contract-farming arrangements for national and international markets. Additionally, a regional scheme for biofuel production has emerged as part of these evolving agricultural practices in the study area, which has also entailed a notable transformation in land use and farming practices, driven by a combination of technological advancements and institutional incentives. (Diario de Noticias de Navarra, 2017).

Concerns related to property concentration and changes in cropping patterns were raised by participants in our three focus groups. For example, a participant claimed:

> "*Modern irrigation financing has meant to concentrate land in fewer hands. The financial investment this project requires has obliged many people, who cannot afford or are not interested in such a project, to sell their lands to others*" (FG-3, Miranda de Arga neighbour).

Another interviewee also raised other concerns over the high investment farmers must make over a 30-year period, and the large uncertainties associated to the costs of maintaining infrastructure and the impact of climate change on water availability:

> *"In Navarre, the problem is that a 100-kilometre channel has been planned in one way and has come out of another and a large part of the financial effort has to be made by a single generation of the current farmers since we must pay it in 30 years and not executed directly by the hydrographic confederations where they are paid over a lifetime …. Besides, there are several "other" problems such as including unsuitable lands for irrigation, the concessional system of the works and their influence on the exploitation of the built infrastructure, the amount of water in the reservoir and its relationship with climate change"* (I-1, Irrigation community president and farmer)

Furthermore, interviewees were pessimistic about the future of small-scale farming. They believed that land concentration will proceed apace: "T*he large farmer of today will be the small one tomorrow*", noted one of the medium-scale intensive farmers interviewed (FG2-6).

As reported by focus group participants, observed during fieldwork, and supported by reviewed documents, modern irrigation has resulted in an uneven access to communal farming lands among the villages affected by the irrigation channel. Local (village) councils have begun allocating communal land to full-time, young farmers, who tend to be the primary adopters of modern irrigation technology. This has led to a rise in the rental prices of communal farming lands and the extension of rental periods, thereby limiting the access of older and retired farmers to such lands. These developments have brought about significant changes in land use and access to resources within the affected communities (Boletín Oficial de Navarra, 2015).

The qualitative insights we gathered are consistent with the findings from our survey data. Notably, *medium* and *large-intensive* farmers have been able to amass more land by purchasing or renting additional plots, while *small-scale diversified* farmers have sold their land. Our data indicate that 34% of the surveyed farmers acquired new land, with approximately 26% purchasing between two and 5 ha, and an additional 22% opting to rent new land within the modern irrigated system zone. Furthermore, in the small village of Miranda de Arga, where modern irrigation replaced traditional methods, farmers reported that there was a 28% of landowners less within just one year (2015–2016). This suggests a shift towards fewer farmers possessing larger property entitlements. These trends illustrate the ongoing land concentration and transformation of land ownership patterns within the study area, aligned with the adoption of modern irrigation practices.

Focus group discussions revealed that land concentration was resulting in the abandonment of traditional crops, which also suffered from increasing competition in the global market and thus lower prices (Gobierno de Navarra, 2015).[6] One participant noted that "*such trend of betting for quantity and not quality is happening worldwide …, not only in agriculture but everywhere*" (FG-1, INTIA technician), while another resentfully asked "*why has the government of Navarre not* supported *industries that search for the quality of their products instead of choosing the strategy of competing through quantity*?" (FG-3, Miranda de Arga farmer).

Participants agreed that favouring quantity over quality, and less diverse over more diverse cropping patterns was contributing to the homogenisation of farming livelihoods. They believed that *small-scale diversified* farmers were likely to disappear in the coming decades and they expected *medium-scale intensive* farmers to diminish in the future, leaving *large-scale intensive* farming as the dominant livelihood in the region, perhaps co-existing with a small share of small-scale farmers focused on organic-grown crops as a niche market. In the words of a focus group participant:

> *"Today, small-farming agriculture is difficult; we rather have a technically driven, market-oriented agriculture. I have heard that in the village of Caparroso some people are buying land to grow forage, erasing hundreds of traditional farms. We do not know where they are coming from, who they are. People are desperate" (*FG2-2*, medium-scale intensive farmer)*.

5. Displaced and maladaptive farming livelihoods

Disentangling the main features of farming livelihoods is paramount to understand the social-ecological heterogeneity of agrarian systems, and to explore how these livelihoods are affected by changing institutional contexts and emerging agrarian technologies. Our case study reveals that both the regional and national governments have developed policies for promoting livelihood intensification strategies (Leichenko and O'Brien, 2013; O'Brien and Leichenko, 2000). Consequently, the livelihood diversification strategy – which is commonly the autonomous response of climate-vulnerable communities – gets compromised, even when might be the most

[6] Consult at <http://www.denominacionesnavarra.com/index.php/en/>.

appropriate adaptation strategy for smallholder livelihood sustainability under future climate change scenarios (Rahman et al., 2018, 2021).

Drawing upon the SLA framework, we have identified four livelihood profiles among farmers affected by the *Itoiz-Canal de Navarra* irrigation project. These four profiles have also allowed us to identify the key features of the present social-ecological agrarian system and to highlight those most likely to persist or change in the future and in the context of LSMI.

We have also found that the *Itoiz-Canal de Navarra* project is transforming the scale and practices of agricultural management in the study area, spurred by indirect processes of land concentration and intensification of land-use practices through increased use of herbicides and fertilisers. This is consistent with other studies related to modern irrigation in Spain. For example, demonstrate that the adoption of modern irrigation in semi-arid watersheds of Spain a higher dependency on oil, water and fertilisers. Regional and national governments in Spain have relied on modern irrigation technology to increase crop productivity and promote 'sustainable' agriculture but in so doing catalysed the increasing concentration of land property, and the development of larger-scale farming systems. Irrigation technology has thus contributed to the substitution of a traditional knowledge-based community-driven irrigation system with a more expert-driven one (Albizua and Zaga-Mendez, 2020; Rahman et al., 2021).

These institutional and technological drivers combined have contributed to the gentrification of *small-scale diversified* farmers, who become inclined to sell their lands or are pushed to align with an agricultural model that relies on built infrastructure, heavier machinery, and higher use of agrochemicals. Consequently, local farmers are becoming less diverse in the produce grown and the management strategies employed and an increasing number have to invest heavily and assume greater financial risks. The increased use of fossil fuel inputs, the progressive loss of more diverse farming strategies and related management knowledge, the concentration of property and higher levels of indebtedness may reinforce the vulnerability of agrarian social-ecological systems and jeopardise their ability to cope in a more variable and potentially water scarce climate (Garnett and Godfray, 2012). In our study, all except *small-scale diversified* farmers have adopted a land accumulation strategy that involves higher financial dependency on irrigation infrastructure and the bundle of related artificial inputs, geared to further land use intensification.

Modern irrigation adopters can benefit from the rules embedded in irrigation institutions to a larger extent than small-scale and less market-oriented, or socially networked farmers (see e.g. (Mahdi et al., 2009). However, these adopters, being also likely to face increased climate variability and extreme heat waves, become more sensitive due to their larger extension of water dependent crops and heavy dependence on external inputs (Albizua et al., 2019). For instance, Fleischer et al. (2008) warned that irrigation systems would not alleviate climate change impacts but instead increase water dependency levels and farmers' drought-related perceptions. Likewise, Terrado et al. (2016) warned that the most threatened regions under future scenarios of global change were among those suffering from water scarcity and with larger land areas devoted to irrigation. Moreover, water consumption and carbon emissions of agricultural production often increase in irrigated systems and new challenges arise such as waterlogging, intensive water consumption crops and soil erosion, leading to maladaptation in the long term (Albizua et al., 2019). Unsurprisingly, farmers claim that they are suffering from lowering net benefits and the unprecedented escalation of raw materials and energy costs (Garde, 2022).

Finally, we concur with Crecente et al. (2002), who showed that in the case of small-scale Galician farmers (in northwest Spain) farmers were unable to benefit from irrigation and land consolidation processes, while social and economic benefits were derived by larger and more market-integrated farmers. Likewise, Deininger and Byerlee (2012) noted that the enlargement of farms and the increased dependence on markets has also been a key tenet of modern irrigation in many regions throughout Latin America and Eastern Europe, Southeast Asia, and more recently sub-Saharan Africa. The findings also offer insights into why modern irrigation might not be conducive to climate change or socio-economic adaptation in the long term. We acknowledge, nonetheless, that this transition towards greater intensification on large-scale farms is also probably both a cause and consequence of rural depopulation, which has also driven land abandonment and led to the increase in the frequency and intensity of wildfires in Navarre over the last decade (García, 2022).

6. Conclusion

Global consumption, production, and trade of agricultural commodities continue to increase rapidly, and technological innovation along the commodity chain, from seed engineering to irrigation and new processing and packaging technologies, underpin the dominant capitalist agricultural model worldwide (Hall, 2015). In this paper, we have analysed the farming livelihoods of a region affected by a large-scale modern irrigation project to show that an uneven combination of capitals associated with access to modern irrigation technology shapes land management intensities and determines different types of rural livelihoods. We have argued that LSMI has brought about changes in land tenure and cropping patterns which have been conducive, on the one hand, to the progressive marginalisation of small-scale traditional farmers and, on the other hand, to the reduction in the diversity of crops grown. We have also shown that public policies and organizations play a critical role in fostering these processes through regulatory and financial incentives for land concentration and irrigation adoption.

Obviously, we acknowledge that modern irrigation technology should not be regarded as the only driver of the processes documented in this article, since depopulation and other market-related conditions may also influence rural livelihoods' configurations and strategies in the study region. However, we have provided solid evidence that LSMI is a key contributor of land abandonment by small-scale farmers and, in such a role, irrigation technology reifies agricultural productivity at the expense of other agrarian values. This aligns with a cornucopian view of agricultural systems where growth continues to overshadow the social-ecological sustainability of agrarian systems, and which forecloses the opportunity of imagining agricultural landscapes controlled by small and productive farmers, and not in the hands of agribusiness. Unfortunately, there are other examples of policy- and technology-driven agricultural development initiatives, including the EU's biofuels policy and certification schemes (Helliwell and Tomei, 2017) or the case of photovoltaic systems in Spanish agrarian systems (Carreno-Ortega et al., 2017), which are also (albeit maybe unwillingly inducing profound land use changes and social-ecological dilemmas. The impacts of LSMI on farming livelihoods, rural property, and agricultural biodiversity are some of the consequences of the increasing market competition and neo-liberalization of the world's agricultural systems. This research demonstrates the importance of supporting small-scale and highly diversified farming, husbandry and forestry activities to promote more resilient and less vulnerable rural territories in the face of accelerating climate change.

CRediT authorship contribution statement

Amaia Albizua: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **H.M. Tuihedur Rahman:** Writing – review & editing, Supervision, Conceptualization. **Esteve Corbera:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Unai Pascual:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare no competing interests. This is, there are no financial and personal relationships with other people or organizations that could inappropriately influence (bias) this work.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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