Master Thesis

Agricultural Irrigation Development in Castilla y León (Spain): Driving Forces, Landscape Changes, and Sustainability Outcomes

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Abstract

Irrigation is crucial for agricultural production in many parts of the world. However, irrigated agriculture has been found to damage ecosystems and contribute to water scarcity. Concurrently, the need for irrigation is increasing due to rising demands for agricultural products and climate change-induced alterations in rainfall patterns. To preserve ecosystem services and human well-being while augmenting agricultural production, pathways towards a more sustainable water management are needed. Forming part of the international Sustainable Agricultural Intensification Pathways in Europe (SI-PATH) project, this thesis aimed to further understand agricultural irrigation development and its impact in the context of sustainability. Two study sites in Northern Spain with different irrigation system trajectories were researched, namely Santa María del Páramo (SMP) and Santa María de la Isla (SMI). A combination of document analysis, interviews, aerial photograph and satellite image analysis was applied. The mixed-methods approach served to examine the irrigation development since 1970, drivers of the irrigation system trajectories, landscape changes and their irrigation-relation, and sustainability outcomes of two irrigation systems used. The results showed that aerial pipes (AP) were partially introduced for on-farm sprinkler irrigation at both study sites from 1992 onwards, complementing flood irrigation. At the SMP study site, underground pipe networks (UPNs) tied to a land consolidation were established on the landscape level from 2005 onwards, completely replacing flood irrigation. Driving forces shared by both developments include water use efficiency, productivity, or work comfort and quality of life. The UPN was in the interest of a greater diversity of actors and further driven by national and regional agricultural policies, ambitions to foster rural development, and market growth and commercialization. A reduction in structural diversity through the removal of landscape elements and enlargements of parcels was prevalent with the UPN establishment. The UPN was furthermore associated with water use rebound effects. While its social sustainability outcomes were mainly rated positive, long-term economic farm viability and vulnerability of farmers to droughts were contested. Considering that the irrigation development researched fits into the trend in semi-arid regions and considering plans for future UPN establishments, a further negotiation of sustainability trade-offs recognized seems crucial. Suggestions towards more sustainability also include an alternative funding scheme for irrigation costs, the preservation of seminatural habitats in agricultural landscapes, and a shift from efficiency increases towards evaporation management.

Acknowledgement

This thesis allowed me to deepen my knowledge on agricultural irrigation and gain insight into the irrigation development in a region in Spain that was previously unknown to me. The embeddedness of my thesis into an international project deepened my understanding of irrigation in the context of agricultural development in Europe. I am convinced that the knowledge and experience I gained and the exchanges with all the people involved is valuable for my future professional and personal path.

I would like to sincerely thank my supervisors Franziska Mohr and Prof. Dr. Matthias Bürgi for guiding me through this thesis. I really appreciate the expertise, patience, and enriching insights they generously shared with me. Their support motivated me throughout the whole process, from the preparation phase to the field work, analysis, and writing of this thesis. I would also like to express my deep gratitude to my co-supervisor Dr. Felicia O. Akinyemi for sharing her remote sensing expertise with me and for answering my questions throughout all the phases of this thesis. A further major thanks goes to Virginia Ruiz-Aragón, without whom this thesis would not have been possible. Virginia already supported me prior to the field visit with her expertise on the local history and conditions, and she was indispensable for conducting and processing the interviews. Thank you for your patience, for your constant support, for all the laughter, and for sharing your network with me. In the same vein, I want to thank David, Feli, Lorenzo, Cami, and Santi for sharing their home, kindness, and knowledge with me. You made my stay an unforgettable experience. Another special thanks goes to all the interview partners. The interesting and detailed conversations not only form a crucial part of this thesis but were also personally enriching. Finally, I would like to thank everybody who proofread my thesis.

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List of Abbreviations

AIC	Agricultural intensity change
AP	Aerial pipes
CAP	Common agricultural policy
CHD	*Confederación Hidrográfica del Duero*
FENACORE	*Federación Nacional de Comunidades de Regantes de España*
FERDUERO	*Asociación de Comunidades de Regantes de la Cuenca del Duero*
FI	Flood irrigation
GEE	Google Earth Engine
GIS	Geographic Information System
ITACyL	*Instituto Tecnológico Agrario de Castilla y León*
MAPA	*Ministerio de Agricultura, Pesca y Alimentación*
MITECO	*Ministerio para la Transición Ecológica y el Reto Demográfico*
NDVI	Normalized Difference Vegetation Index
OHI	Oral history interviews
SEIASA	*Sociedad Mercantil Estatal de Infraestructuras Agrarias*
SEPI	*Sociedad Estatal de Participaciones Industriales*
SI	Sustainable intensification
SIPATH	Sustainable Agricultural Intensification Pathways in Europe
SMI	Santa María de la Isla
SMP	Santa María del Páramo
UPN	Underground pipe network
USGS	United States Geological Survey
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research

Spanish names and terms (except for place names) are written in italics to indicate their different grammatical configuration.

1 Introduction

1.1 Problem Statement

To grow food, we need water. Rainfed agriculture relies on water from rainfall, and irrigated agriculture depends on freshwater from rivers, lakes, and aquifers (FAO, 2020). In many parts of the world, irrigation plays a key role in agricultural production (Velasco-Muñoz et al., 2019). However, irrigation has been found to contribute to water scarcity (Scherer & Pfister, 2016). Agriculture worldwide accounts for 72% of water withdrawals (UN-Water, 2021), and irrigated agriculture is by far the largest user of freshwater (Velasco-Muñoz et al., 2019). Considering that 2.3 billion people currently live in countries with water stress (UN-Water, 2021), water scarcity is and continues to be of paramount concern (Scherer & Pfister, 2016). We are not on track to achieve the Sustainable Development Goal (SDG) 6, which is to ensure the availability and sustainable management of water and sanitation for all (UN-Water, 2021). Not only populations, but also ecosystems are negatively affected by water scarcity (Wada et al., 2014). Almost half of global water withdrawals are not compatible with sustaining ecosystem services (FAO, 2020), and irrigation has been found to contribute to ecosystem damage (Scherer & Pfister, 2016). Irrigated agriculture is hence crucial on the path to more sustainability (Antunes et al., 2017). Action for more sustainable water management is also urgently needed for agriculture itself, considering that more than 60% of irrigated cropland is highly water-stressed (FAO, 2020). Furthermore, rainfall patterns are already being altered by climate change (Velasco-Muñoz et al., 2019), which leads to water shortages in rainfed agriculture, puts livelihoods and food security at risk, and increases the need for irrigation (FAO, 2020).

The global demand for agricultural products is expected to further rise in the next decades (Tilman et al., 2011; Wirsenius et al., 2010). To meet this demand and maintain the competitiveness of agricultural sectors, there is a call to continuously intensify agricultural production processes (Bürgi et al., 2018). While agricultural intensification may help to meet the challenges of increasing food demand (Varghese, 2020), many agricultural practices adversely impact the environment (Newbold et al., 2015; Tilman et al., 2011). Agriculture has hence been identified to majorly drive environmental degradation in Europe (Pe'er et al., 2020). Furthermore, agriculture is considered to be one of the main factors contributing to the complex formation of European landscapes (Farina, 2000). Landscapes have undergone and continue to undergo changes that threaten their sustainability (Plieninger et al., 2016). Especially rapid landscape changes can negatively impact biodiversity and human well-being (Antrop, 2000; Tscharntke et al., 2005; Wu, 2013). The maintenance of the perceived cultural and recreational value of agricultural landscapes has also gained importance (Stoate et al., 2009). To sustain human well-being and a healthy environment while increasing agricultural production, alternative pathways with an enhanced degree of sustainability are needed (Helfenstein et al., 2020).

1.2 Research Context

To accommodate the necessities for future food security while sustaining the environment and improving the quality of life, the concept of sustainable agricultural intensification (SI) has been suggested (Pretty, 1997) and advocated by both scientists and policy makers (Helfenstein et al., 2020). Solutions that facilitate SI need to be understood and assessed across various geographical and temporal scales and contexts, because they are context-specific and multiple sustainability outcomes and trade-offs can emerge beyond the farm level (Bürgi et al., 2018). The operationalization of SI and addressing the associated challenges are the objectives of the Sustainable Agricultural Intensification Pathways in Europe (SIPATH) project by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) (Switzerland), Agroscope (Switzerland), and the Vrije Universiteit (VU) Amsterdam (The Netherlands). The interdisciplinary project started in 2018, and the main goals include (i) understanding the mechanisms of agricultural development in Europe over the past decades, (ii) assessing future mega-trends and their potential impacts on agriculture in Europe, and (iii) identifying potential pathways of sustainable agriculture intensification (Bürgi et al., 2018). Transformations and developments at farm and landscape levels are researched from a historical perspective because historical processes shaped the current state of agriculture (Jepsen et al. 2015). Studies on land use and landscape change in Europe (Kuemmerle et al., 2016; Plieninger et al., 2016) indicated strong regional differences in changes. The SIPATH project hence conducts case studies in landscapes of distinct characteristics across Europe. One of these study sites is in the municipality of Santa María del Páramo, which belongs to the autonomous community of Castilla y León in Northern Spain. Oral history interviews (OHI) with farmers were conducted at this site in 2021. They indicated major changes in agricultural irrigation since farmers interviewed started working in agriculture. Santa María del Páramo is the only study site within the SIPATH project that has developed a large-scale irrigation system. Further understanding this agricultural irrigation development is crucial, considering the contribution of agricultural practices to the formation of landscapes, and the relevance of irrigated agriculture in the context of sustainability.

1.3 Research Goals and Questions

This thesis aims to contribute to the research of land use change regarding a better understanding of agricultural irrigation development, resulting landscape changes, and associated sustainability outcomes. The main goals therefore include the reconstruction of the irrigation development and its drivers in Santa María del Páramo (Spain), as well as assessing its landscape impacts and ecological, social, and economic sustainability outcomes. To achieve the main goal, a second study site is incorporated for contextualization. The reconstruction of the irrigation developments and drivers at the study sites contributes to the SIPATH goal of understanding the mechanisms of agricultural development in Europe over the past decades (Bürgi et al., 2018). Assessing related landscape changes and sustainability outcomes may help to achieve the SIPATH goal of identifying potential pathways of sustainable agricultural intensification (ibid). The research questions to achieve the goals of this thesis are the following:

I. Which impact does the development of agricultural irrigation have on the landscape at two study sites in Spain?

   a) How was the agricultural irrigation developed at two study sites in Castilla y León (Spain) with different irrigation system trajectories?

   b) What are the drivers behind the irrigation system trajectories, and why did they differ between the sites?

   c) How did the landscape change during the same time span at the two study sites?

   d) How are the landscape changes related to the irrigation system trajectories?

II. Which environmental, social, and economic sustainability outcomes are associated with different agricultural irrigation systems?

   a) How do the environmental, social, and economic sustainability outcomes of aerial and underground piped irrigation systems differ?

   b) How are the sustainability outcomes reflected in different stakeholder perspectives?

1.4 Case Study Sites

Within the SIPATH project, a study perimeter of 25 km^2 belonging to the municipality of Santa María del Páramo had been selected (Figure 1). The municipality forms part of the El Páramo region, together with 20 other municipalities and 82 towns (García Martínez, 2020). The location of the second study perimeter was selected with the local project partner. The criteria for the selection included the occurrence of a different irrigation trajectory to the first study site but similar land use, topography, and climatic conditions. The suitable perimeter selected is in the area of Santa María de la Isla (Figure 1), one of five municipalities forming the Vega del Tuerto region (Ayuntamiento de Santa María de la Isla, n.d.). As Figure 1 shows, both study perimeters are located in the autonomous community of Castilla y León in Northern Spain (Ayuntamiento de Santa María de la Isla, n.d.; García Martínez, 2020), which is governed by the *Junta de Castilla y León*. The autonomous community comprises nine provinces united since 1983, of which León is the province the study sites belong to (Junta de Castilla y León, n.d.a). Both study perimeters also are part of the Duero River basin (Gómez-Limón & Riesgo, 2009). The Duero River basin extends over 98,073 km^2, of which 78,859 km^2 belong to Spain, and the rest of the area is part of Portugal (Pardo-Loaiza et al., 2021). The whole basin comprises 75 artificial reservoirs of large size with a capacity to store 7500 million m^3 of water (ibid).

To the east of the Santa María del Páramo (SMP) study perimeter, the Esla river passes, and to the west, the Órbigo river flows by (Figure 1). To the south, the fluvial terraces of the union of the Esla and Órbigo rivers begin (García Martínez, 2020). The Tuerto river passes through the Santa María de la Isla (SMI) study site. The SMP study site is situated at 813 meters of altitude (Ayuntamiento Santa María del Páramo, n.d.a), and the SMI study site lies at 789 meters of altitude (Ayuntamiento de Santa María de la Isla, n.d.). Both study sites exhibit a smooth topographic relief and similar climatic conditions. A Mediterranean-type climate with continental characteristics such as low rainfall and large differences in summer and winter temperatures is prevalent (Gómez-Limón & Riesgo, 2009). The average annual temperature in the province is 11.9 ºC, and the annual rainfall is around 460 mm (Junta de Castilla y León, n.d.b).

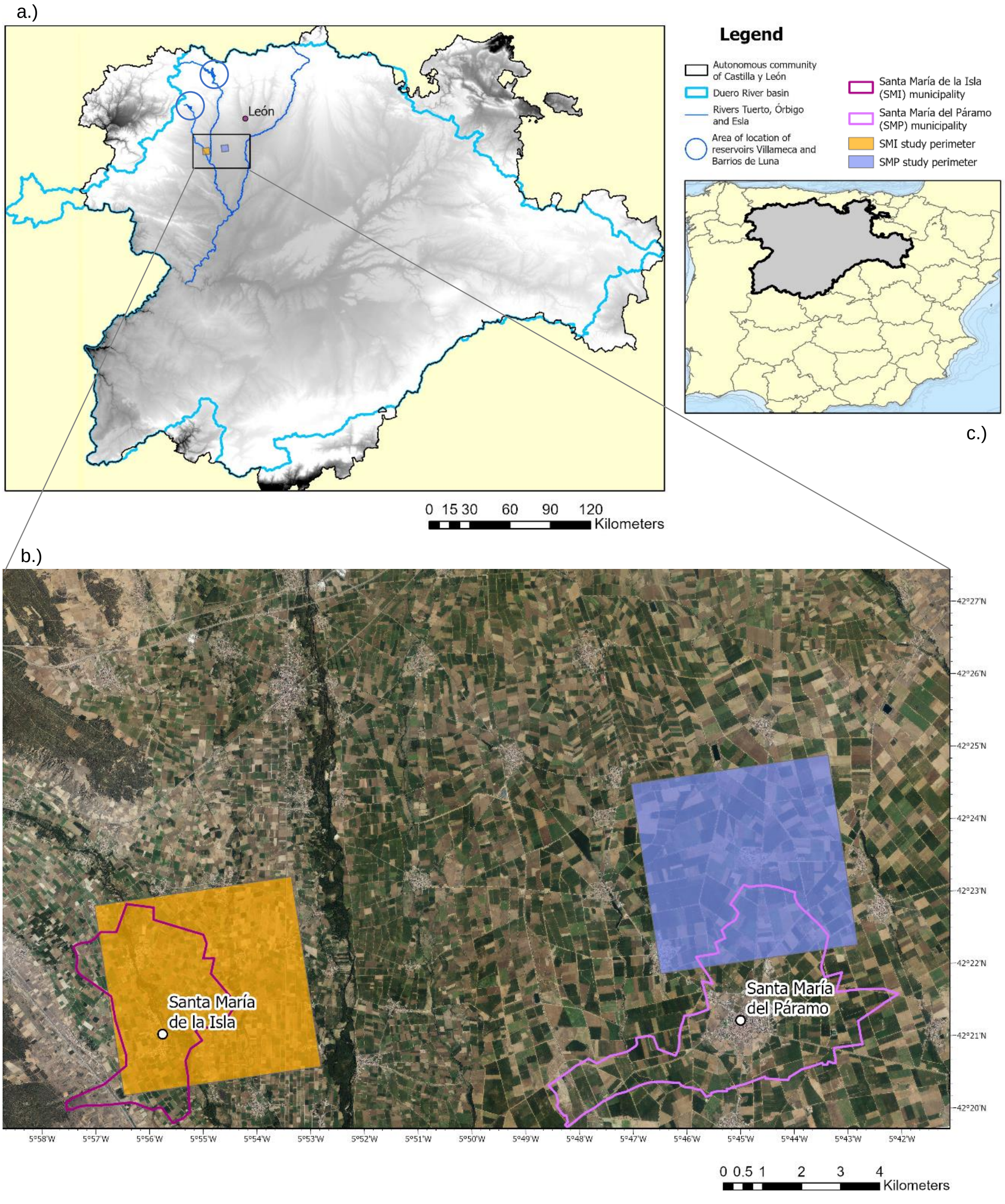

Figure 1: Location of the study sites Santa María de la Isla (SMI) and Santa María del Páramo (SMP). Map a.) shows the location of the study area in the Duero River basin and the autonomous community of Castilla y León, map b.) shows the location of the study perimeters and municipalities, map c.) shows the location of the autonomous community of Castilla y León in Spain (own figure, data sources: Orthophoto by Instituto Geográfico Nacional de España (IGN), administrative boundaries and hydrographic information by Confederación Hidrográfica del Duero (CHD)).

Irrigated agriculture is of great economic importance at both study sites (Ayuntamiento de Santa María de la Isla, n.d.; García Martínez, 2020). The history and extent of irrigated agriculture is elaborated on in chapter *2.3 Irrigated Agriculture in the Case Study Region*.

Demographic characteristics of the two study sites differ. In 2022, the municipality of Santa María de la Isla counted 462 inhabitants (INE, 2022a), and the municipality of Santa María del Páramo had 3065 inhabitants (INE, 2022b). Santa María del Páramo has a higher ratio of young inhabitants than Santa María de la Isla (Figure 2 and Figure 3).

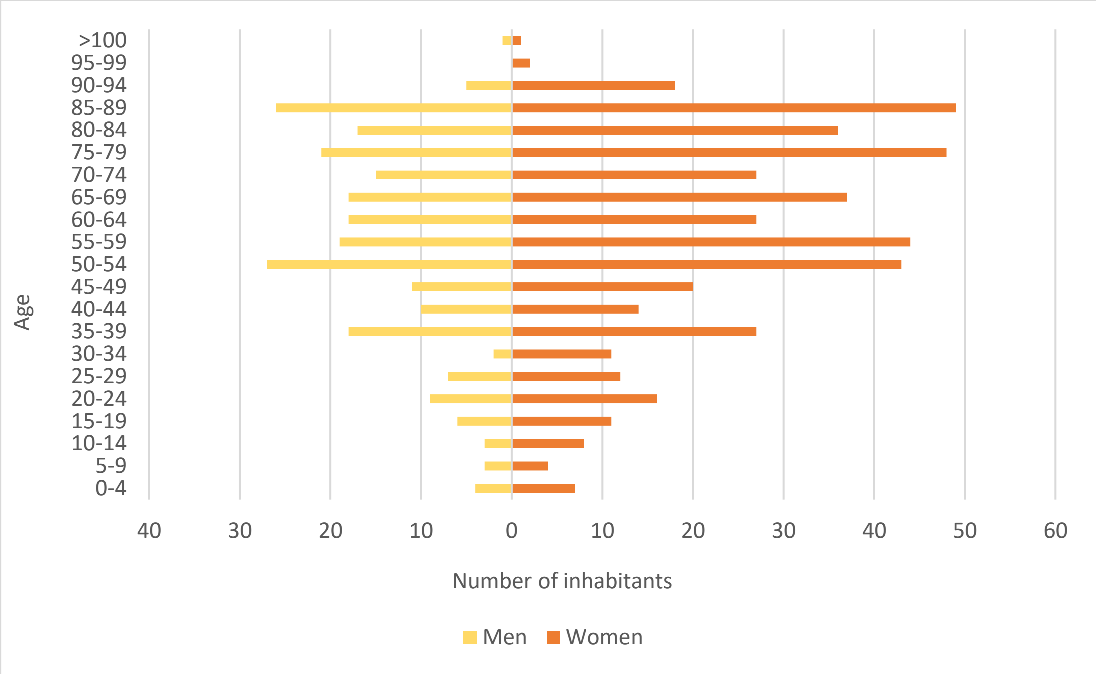

Figure 2: Age structure of population in Santa María de la Isla in 2022 (own figure, data source: INE 2022a).

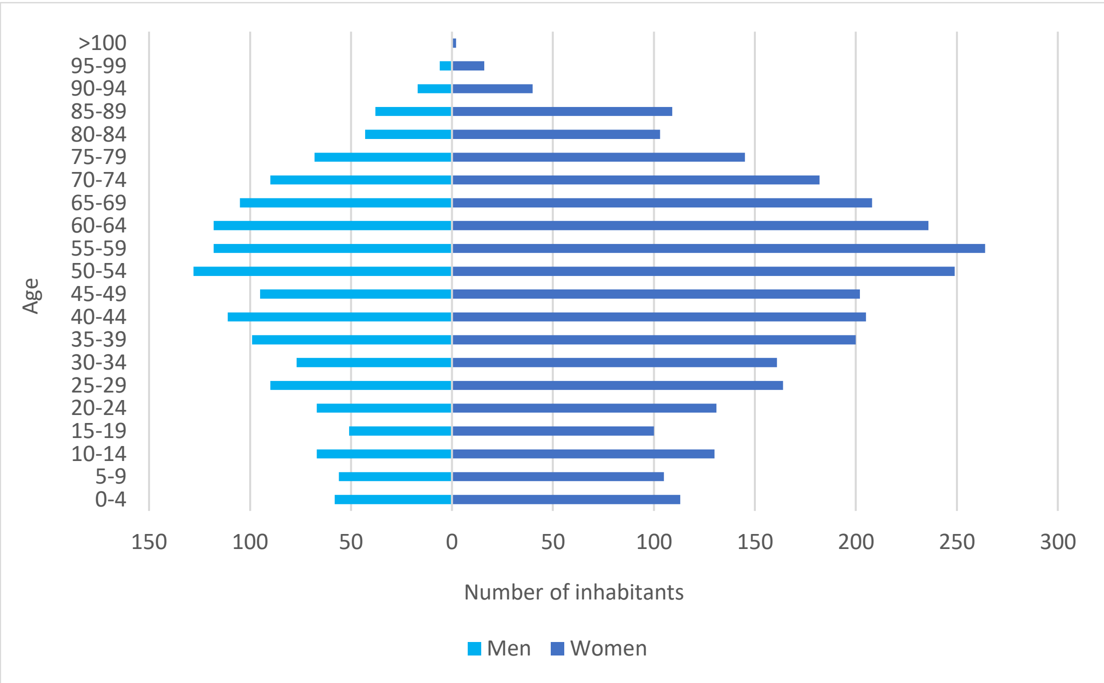

Figure 3: Age structure of population in Santa María del Páramo in 2022 (own figure, data source: INE 2022b).

2 State of the Art

This chapter presents an overview of literature relevant for the research goals and questions. To provide a basis, land use change in Europe is firstly addressed, including the study of driving forces of land use and landscape change. Secondly, the embeddedness of the topic of irrigation in research on agricultural intensification and sustainable agricultural intensification is elaborated on. Thirdly, literature on irrigation in the study site region is introduced. This allows to lastly present sustainability assessments of agricultural irrigation that have been carried out related to the case study region and research questions.

2.1 Land Use Change in Europe

Agricultural land use in Europe has undergone major shifts in the past 200 years that were researched by Jepsen et al. (2015). The so-called Intensification regime started before World War I in some European Countries, after 1918 in the others. In Northern Spain, the Intensification regime began around 1925 (Jepsen et al., 2015). During this land-management regime, new technologies and mineral fertilizers were introduced. Coinciding with industrialization and urbanization, market-oriented production started to emerge. These practices were then fully implemented during the following Industrialization regime, which homogeneously started in most European countries around 1950. From 1990 onwards, awareness of impacts of agricultural production on the environment increased, but intensive agriculture still dominates Europe (ibid). Levers et al. (2016) selected the period of 1990-2007 for researching agricultural intensity changes in Europe with a focus on yields and fertilizer application. Especially high yields and nitrogen application were found in Western and Central Europe (Levers et al., 2016). However, agricultural intensity is a complex phenomenon (ibid), and agricultural intensification is still considered an understudied land use change process (van Vliet et al., 2015). Land use change processes and the impacts of these changes are researched within land use science (Rindfuss et al., 2008), but van Vliet et al. (2016) found that the processes and impacts are mostly studied separately. The authors argue that land use science would benefit from further linking land use change processes and their impacts.

To understand how and why land use and landscapes change, the study of the so-called *driving forces* has evolved (Bürgi et al., 2005; Plieninger et al., 2016). Case studies examined changes and their drivers in local to regional contexts (Mottet et al., 2006; Bieling et al., 2013; Bürgi et al., 2017), and meta-studies have been conducted to identify patterns on a larger scale (Jepsen et al., 2015; van Vliet et al., 2015; Plieninger et al., 2016). A distinction into proximate and underlying drivers is often found within research on driving forces (Meyfroidt, 2016). Proximate drivers concern local human actions, underlying drivers refer to underpinning social and natural processes (Plieninger et al., 2016). Other authors prefer to avoid this distinction (Meyfroidt, 2016), so that the term of driving forces exclusively designates factors having contributed to changes (Bürgi et al., 2017). Bürgi et al. (2017) use the term *processes* for entities upon which driving forces act. Bürgi et al. (2022) further outline eight research avenues to advance the study of driving forces. The avenues include the conceptualization of the role of institutions as actors (avenue 1), for example through researching the interactions of institutions and other actors. Actors' decision making should be represented in the analysis of driving forces (avenue 2), to account for the relevance of actor decision making for land use change. Avenue 3 to 5 are concerned with how landscape changes are researched. The authors inter alia highlight the importance of analyzing landscape structures that are not represented in pixels, and the need to implement flexible system boundaries to include the effects of distant drivers. Furthermore, qualitative and quantitative information needs to be integrated for a comprehensive understanding of driving forces. Avenue 6 calls for a conceptualization of driving forces as causal chains as by Meyfroidt (2016), to uncover causalities of drivers. Land use regime shifts impede the anticipation of system changes, which leads to challenges that are addressed by avenue 7. The results of studies on driving forces should then be accessible, especially to people involved in planning and policy, to increase the application of knowledge generated (avenue 8). These eight research avenues may not only advance the study of driving forces, but also contribute to a path towards more sustainability (Bürgi et al., 2022).

2.2 Irrigation in the Context of (Sustainable) Agricultural Intensification

Many scientists, policy makers, and practitioners agree that agriculture needs to safeguard food security and simultaneously become more sustainable, but understandings of a sustainable intensification are manifold (Helfenstein et al., 2020), and concepts around sustainable intensification (SI) are often indistinct (Bürgi et al., 2018). This is why the SIPATH project aims at the operationalization of the broad concept, and at the identification of alternative pathways of SI. Related to the project, Varghese (2020) provides an overview of how three branches of literature contributing to the assessment of SI address intensification trajectories and sustainability trade-offs. The three branches are sustainability assessment of agriculture, agricultural intensification and land-use intensification, and sustainable intensification. Regarding the sub-dimensions of SI, Varghese (2020) differentiated agricultural production, management intensity, landscape structure, and their trade-offs with sustainability outcomes. Variations how the literature branches address the sub-dimensions of SI were found. Many frameworks lack an operationalization across multiple spatial scales (Varghese, 2020). A multi-scale conceptual framework to assess pathways towards SI was proposed by Helfenstein et al. (2020). The authors stress the consideration of multiple dimensions of sustainability in future research. An indicator framework that considers multiple sustainability dimensions has been developed by Diogo et al. (2022), for context specific sustainability assessments of agricultural intensity change in Europe.

In literature concerning agricultural intensity changes and sustainable intensification, the topic of irrigation can be found. Diogo et al. (2022) compiled a framework for sustainability assessment of agricultural intensity change, which comprises different mechanisms of agricultural intensity change. The authors identified the investment in irrigation infrastructure as a mechanism of agricultural intensity change operating in European agriculture, in the category of capital intensity. Adjusting the use of water was also categorized as such a mechanism, related to input-use intensity. Irrigation area and irrigation equipment can therefore be used as indicators of management intensity change, water efficiency is seen as an indicator for agricultural productivity change. Both management intensity change and agricultural productivity change are themes for assessing agricultural intensity change in Europe (Diogo et al., 2022). In a literature review on fields of action for sustainable intensification by Weltin et al. (2018), the topic of irrigation is prevalent under resource use efficiency as a field of action. Corresponding papers emphasize using fewer resources, such as irrigation water, or producing more outputs as pathways to enhanced agricultural productivity (Weltin et al., 2018). Water was the third most mentioned resource within the approaches to increase resource use efficiency. According to Weltin et al. (2018), topics like marginal water use and integrated crop water management (Jägermeyr et al., 2016) or rainwater harvesting (Dile et al., 2013) were the focus of methods to increase water use efficiency.

2.3 Irrigated Agriculture in the Case Study Region

In Spain, the economic relevance of irrigated areas has been frequently highlighted (Rodríguez, 2011). Spain's irrigation sector occupies 14% of the cultivated area, contributing to more than 50% of the final agricultural production (iAgua, 2019). In Castilla y León, irrigation transformations have become a main measure for economic improvements in the agricultural sector since the 1960s (Decimavilla Herrero, 1998).

García Martínez (2020) assessed the changes in the use of water resources in the Páramo region of Castilla y León, and the resulting economic and social transformations, from the mid-nineteenth century to 2020. The author identified water as the main element of transformation, contributing to the expansion of commercial agriculture. Major changes occurred from 1959 onwards, when the water from the *Barrios de Luna* reservoir allowed the use of irrigation water on a larger scale than the previous irrigation with wells (García Martínez, 2020). The traditional self-sufficient economic order was transformed into a productivist orientation (Franco Pellitero, 1986), in combination with the application of chemical fertilizers and the mechanization of agricultural practices, enabled through the new irrigation possibilities (García Martínez, 2020). These processes accelerated since 1992 with the application of the Common agricultural policy (CAP) and Spain's full inscription in European regulations (García Martínez, 2020; Alario Trigueros et al., 2016). According to García Martínez (2020), the Horizon 2008 National Irrigation Plan of the year 2002 initiated transformations towards on-demand pressure irrigation through a network of underground pipes that channel the water to farms. This transformation consolidated and continues to consolidate the commercial agriculture model (García Martínez, 2020). Regarding social changes in the context of irrigated agriculture after the arrival of the reservoir water, García Martínez (2020) described the transformation of some family farms to agricultural companies, a displacement of women in the background, an increasing individualistic mentality of farmers, and decreasing neighbourhood solidarity. Furthermore, the mechanization of agricultural practices decreased the need for human resources and caused a rural depopulation that continues into the present, according to the author.

As described in chapter *1.4 Case Study Sites*, Santa María del Páramo belongs to the Páramo region. Hence the elaborations above may generally account for the SMP study site. However, García Martínez (2020) highlighted Santa María del Páramo as more urbanized compared to its highly ruralized surroundings, with a demographic evolution characterized by less emigration. The author mentioned that besides changes in agricultural irrigation, a greater economic diversity of the town contributed to its distinct demographic evolution. The other study site in Santa María de la Isla is part of the Vega del Tuerto region. No scientific literature could be found on its local- to region-specific history of irrigated agriculture. However, Rubio Pérez (1997) mentioned the dependence of agriculture on river irrigation water since the middle age in plains around rivers in Castilla y León. With the river Tuerto passing through Santa María de la Isla, this historical dependence may account for the SMI study site. Furthermore, like SMP, the study site belongs to the Duero River basin, where agriculture was characterized by weak links to urban and foreign markets, small family farms, and self-sufficiency prior to transitions towards commercial agriculture, as elaborated by Pérez Romero (2009). Low value-added irrigated crops dependent on subsidies have become dominant in the Duero River basin since the application of the CAP (Riesgo & Gómez-Limón, 2005), and irrigated cereal crop production began to characterize agriculture in the basin (Gómez-Limón & Riesgo, 2009). From a scenic perspective, increases in similar irrigated cultivations tend to homogenize the landscape in the Duero River basin (Rodríguez, 2011). An increasing landscape homogenization, increasing commercialization of irrigated crop production, and the historic relevance of irrigation for agriculture may hence be shared by both study sites, while more details on irrigation development could be found for the SMP study site.

2.4 Sustainability Assessments of Agricultural Irrigation

Agricultural irrigation has been increasingly researched from the perspective of sustainability (Velasco-Muñoz et al., 2019). Velasco-Muñoz et al. (2019) analysed global research carried out on sustainable irrigation in agriculture in the period of 1999 to 2018. The authors identified four main research lines within research on sustainable irrigation. The research lines include (i) climatic change, environmental impact, and natural resource conservation, (ii) unconventional water resources, (iii) irrigation technology and innovation, and (iv) water use efficiency. Spain was amongst the most relevant countries for research on sustainable irrigation (Velasco-Muñoz et al., 2019). Relevant topics in Spain identified by the authors include energy resource management, water productivity, efficiency, or environmental protection. Velasco-Muñoz et al. (2019) found an overall dominance of the environmental dimension in research on sustainable irrigation in agriculture. The authors highlighted the necessity to further integrate social and economic dimensions, but also noted the importance of more knowledge regarding environmental impacts of irrigation practices on the local to the regional level.

A multi-dimensional approach to assess the sustainability of irrigated agricultural systems was developed by Antunes et al. (2017). Their framework covers the four dimensions environmental integrity, economic resilience and profitability, social well-being, and good governance. The authors applied their approach to ten irrigated agricultural systems, of which two are located in Spain. The locations of the framework application do not tangent the Duero River basin. The first site, in the east of Spain, is dominated by large farms and intensive surface use, with cereal, vineyard, and alfalfa as main crops. Similar economic characteristics to the study sites of this thesis therefore seem to be prevalent. However, groundwater is the main water source, and groundwater exploitation has been identified as central sustainability issue. In the dimension of social well-being, unequal water distributions have been highlighted by Antunes et al. (2017). This accounts as well for the second site, which is in the south of Spain, and is characterized by small farms with almond trees, olive trees, citrus, and medlar as main crops, irrigated with surface water, groundwater, and reused water (Antunes et al., 2017). Water scarcity has been identified as main sustainability challenge for this site. Due to differing characteristics of the agricultural systems investigated by Antunes et al. (2017) to characteristics of the study sites of this thesis, equivalent sustainability outcomes cannot be assumed.

Gómez-Limón and Sanchez-Fernandez (2010) developed a methodology to evaluate farm sustainability using composite indicators that cover the environmental, social, and economic dimensions. The authors applied their methodology to two agricultural systems in Castilla y León: Rainfed agriculture in the countryside and irrigated systems in the Duero River basin. The indicators showed little difference between the two agricultural systems. The authors concluded that farm sustainability in any agricultural system is largely determined by elements such as the size of farms, the age of farmers, or agro-environmental payments (Gómez-Limón & Sanchez-Fernandez, 2010). The location of one irrigated system researched by the authors hence tangents the study site region of this thesis, but it must be noted that the focus of the assessment lied on farm sustainability rather than on the sustainability of irrigation. The assessment provides an insight into the sustainability of irrigated farms assembled in one category in comparison to rainfed farms, but not on the sustainability outcomes of different irrigation systems, which is the research interest of this thesis.

The sustainability assessments elaborated on above are focused on the current state of the systems researched. Temporal scales are seldom discussed in sustainable agriculture (Varghese, 2020), as sustainability assessments in agricultural landscapes usually cover one year (Eichler Inwood et al., 2018). Helfenstein et al. (2020) argue that to account for outcomes at different points in time, multiple sustainability dimensions across various temporal scales should be considered.

To the best of my knowledge, no multi-dimension sustainability assessment of irrigation systems had hence been carried out for the study site region of this thesis. However, environmental, social, and economic transformations related to irrigation in the Duero River basin can be encountered in literature. On the one hand, irrigation in the Duero River basin has been found to enable more diversification of crops, harvest security, and thus allow farms to survive that may otherwise be too small to survive (Rodríguez, 2011). On the other hand, the shift towards monoculture that occurred in relation to the development of irrigation was mentioned to have contributed to the decrease in the number of farms, to have created more economic dependency of the Páramo region (García Martínez, 2020), to have left farmers with little bargaining power in the market (González de Molina, 2001), and to have increased contamination by pesticides (García Martínez, 2020). The public opinion in Castilla y León generally considers irrigated agriculture as positive, because irrigated agriculture is perceived as contributing to social welfare (Gómez-Limón & Ramos, 2007). Nonetheless, a survey by Gómez-Limón and Gómez Ramos (2007) found that the regional society opposes the transformation of new areas into irrigation. Demands for budget to be used more efficiently in other public policies and wishes for a stricter regulatory policy that minimizes environmental impacts in the region were expressed (Gómez-Limón & Ramos, 2007).

3 Conceptual Framework

The present chapter elaborates on conceptualizations that are part of this thesis. While most concepts have been mentioned embedded in literature in the previous chapter, this chapter focuses on their adoption and adaptions related to the research goals and questions. The understanding of landscapes, including agricultural landscapes, is firstly presented. Subsequently, the conceptualization of driving forces of land use and landscape change, and how actors are included into the conceptualization, is presented. The incorporation of a conceptual framework on agricultural intensity and sustainable intensification is then described. Lastly, the understanding of sustainability underlaying this thesis is elaborated on and is related to agriculture and outcomes of irrigation systems.

3.1 Landscapes

A landscape perspective is necessary to understand the effects of agricultural land use change (Tscharntke et al., 2005). Human activities contribute greatly to landscape changes (Farina, 2000), and the landscape scale has been found suitable to assess outcomes of agricultural practices, including non-market outcomes (Helfenstein et al., 2020; Kleijn et al., 2020). Considering that irrigation-related landscape changes are researched within this thesis, an elaboration on how landscapes are conceptualized forms an essential basis.

In this thesis, landscapes are understood as complex and dynamic (Antrop, 2000), consisting and resulting of interactions of natural and/or human factors (ELC, 2000). Taking a landscape approach, bio-physical and socio-economic processes are co-considered at various spatial scales, which allows to surpass sectoral approaches and to better account for complex land use challenges (Bürgi et al., 2017; Helfenstein et al., 2020). The interconnection between livelihoods and ecosystems is hence recognized (Torralba et al., 2023), and the perception of stakeholders can be incorporated into the study of landscape changes (Bürgi et al., 2017).

For the understanding of agricultural landscapes, the conceptualization is based on Diogo et al. (2022) (Figure 4), because the authors focus on agricultural landscapes and consider multiple scales. The conceptualization of multiple scales allows to capture diverse perceptions of stakeholders (Diogo et al., 2022) and to prevent the loss of relevant information (Varghese, 2020). Agricultural landscapes therein consist of farms, communities, and agro-ecosystems. Farms are viewed as decision-making units that comprise agricultural fields. Farm managers make decisions inter alia at the scale of agricultural fields, by altering management intensity and landscape structure. Communities consist of interconnected actors of various roles. Agro-ecosystems comprise plants, animals, and microorganisms. The natural and anthropogenic components of agricultural landscapes are interrelated and partially overlapping, embedded in the regional scale, including distant regions, and the earth system. Regions are the administrative entities, at which oftentimes relevant political decisions are made, and the earth system forms part of the conceptualization to account for outcomes at the global scale. The different scales are not fixed, but they are coherent entities with rather open boundaries (ibid).

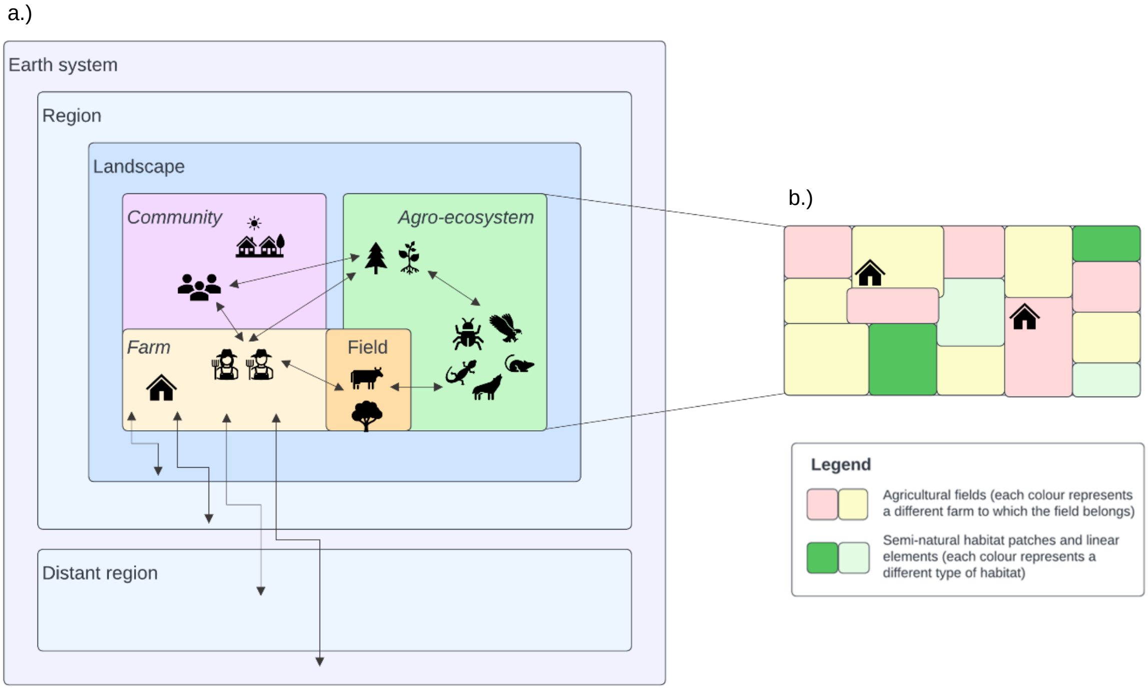

Figure 4: Conceptualization of agricultural landscapes (own figure, largely based on Diogo et al. (2022)). Part a.) shows interactions between anthropogenic and natural components operating across spatial scales, represented with arrows. Part b.) illustrates the landscape structure of an agro-ecosystem comprising agricultural fields of different farms, which are intertwined with semi-natural habitat patches and linear elements, such as hedgerows or tree lines.

3.2 Driving Forces of Land Use and Landscape Change

As explained in chapter *2.1 Land Use Change in Europe*, the concept of driving forces has evolved to research land use and landscape changes. Driving forces are thereby regarded as the forces that cause the observed changes (Bürgi et al., 2005). The forces can be either intensifying or impeding (ibid). The term *processes* is adopted for entities upon which driving forces act (Bürgi et al., 2017), which accounts for irrigation development and landscape change in the case of this thesis. Five main categories of driving forces are differentiated: (1) Political and institutional, (2) economic, (3) cultural and personal, (4) technological, and (5) natural and spatial drivers. This categorization is based on Bürgi et al. (2005) and Plieninger et al. (2016), with an expansion of the cultural driving forces by a personal component, to emphasize actors' decision making, a research avenue to advance the study of driving forces suggested by Bürgi et al. (2022). Accordingly, a conceptual model that links land changes with driving forces and actors forms the foundation to emphasize on actors' decision making. Based on Hersperger et al. (2010), driving forces and actors are viewed as closely interacting, which leads to change (Figure 5). A detailed analysis of the interactions, which this model allows for (Hersperger et al., 2010), surpasses the scope of this thesis. However, acknowledging the interactions of actors and driving forces enables the integration of data on actors' behavior and serves to address the role of actors (Hersperger et al., 2010). Institutions are also viewed as actors within this thesis, as suggested by Bürgi et al. (2022).

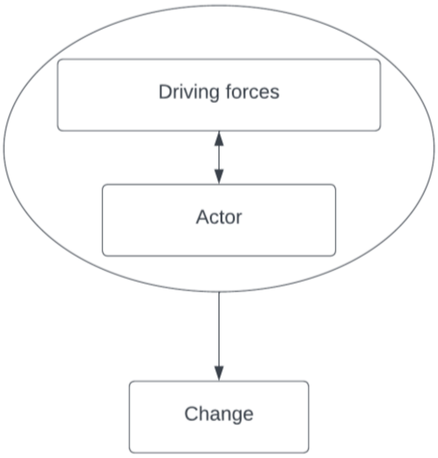

Figure 5: Conceptual model linking land change with driving forces and actors adopted from Hersperger et al. (2010). Arrows indicate the main directions of influence. Driving forces and actors are closely interacting, and their interaction results in change.

3.3 Agricultural Intensity Change (AIC) and Sustainable Intensification (SI)

A further helpful conceptual framework that is incorporated in this thesis is one by Diogo et al. (2022). The framework considers multiple dimensions of agricultural intensity and sustainability, operating across spatial and temporal scales. According to the framework, agricultural intensity change is defined as the process of changing management intensity and/or landscape structure, to enhance agricultural productivity. Changes in agricultural intensity may affect interrelated, context-specific socio-ecological processes, which may in turn lead to an enhanced or hindered ability of agricultural landscapes to deliver ecosystem services. The combined changes in socio-ecological processes and provision of ecosystem services result in environmental, social, and economic sustainability outcomes (Diogo et al., 2022). Sustainable intensification is then understood as a development where agricultural production and sustainability are increased, a pathway coming with trade-offs that should be made transparent (Helfenstein et al., 2020). As described in chapter *2.2 Irrigation in the Context of (Sustainable) Agricultural Intensification*, the increase in irrigated area and investment in irrigation equipment are seen as indicators of management intensity change, and increased water efficiency is seen as an indicator for agricultural productivity change within this framework (Diogo et al., 2022). Irrigation system changes may therefore have multiple sustainability outcomes.

3.4 Agricultural Sustainability

The understanding of sustainability in this thesis is based on the initial conceptualization of the Brundtland report (Brundtland, 1987), which considers the environmental, economic, and social dimension as equally valuable dimensions of sustainability. Since the Brundtland report, the concept of sustainability has become increasingly prominent in the context of agriculture (Latruffe et al., 2016). However, not only the definitions of sustainable agriculture have multiplied (Pretty, 2008), but also the themes and indicators within the three pillars have become manifold (Latruffe et al., 2016). In the following, the conceptualization of sustainability adopted and adapted is firstly elaborated in relation to agriculture in general before it is related to agricultural irrigation in the next chapter. Overall, sustainability is regarded as context dependent (Pretty, 2008; Antunes et al., 2017; Diogo et al., 2022).

Agricultural systems of high sustainability are often characterized as those with the aim of making use of environmental goods and services without damaging them (Pretty, 2008). Especially the environmental dimension has experienced an "explosion" of indicators (Riley, 2001). The environmental indicators found in literature have been grouped into ten themes by Lebacq et al. (2012). These cover nutrients, pesticides, non-renewable resources, land management, emissions of greenhouse gases and acidifying substances, biodiversity, and physical, chemical, and biological soil quality (Lebacq et al., 2012). While the understanding of the environmental dimension as a dimension covering a wide range of themes forms the background of the thesis, it is obvious that a selection of themes, adapted to the local research context and the scope of the thesis, is needed. The selection is elaborated on in chapter *4.1 Mixed-methods Research Design*. Furthermore, Latruffe et al. (2016) pointed out that many environmental indicators rely on a valid cause-and-effect relationship, which leads to the impression of linearity. Despite the usefulness of this reliance for measurement purposes, the awareness of a greater complexity behind the indicators is important (Latruffe et al., 2016).

For the social agricultural sustainability dimension, Latruffe et al. (2016) recognize two main categories: The farm community level and the society level. On the farm community level, social sustainability mainly relates to the well-being of farmers, their families, and employees working on the farm (Latruffe et al., 2016). The society level relates to the demands of society, which in turn depend on prevailing values and concerns (Lebacq et al., 2012). The distinction of the farm community and society level is integrated into the understanding of social sustainability within this thesis. However, the focus lies on the farm community level because determining the demands of society surpasses the scope of this thesis. As in the environmental dimension, indicators adjusted to the local context and research questions are selected. A remark by Latruffe et al. (2016) worthwhile mentioning is the mainly qualitative nature of social indicators. Therefore, they may contain a greater subjective component than environmental and economic indicators, and social sustainability indicators are regarded as more difficult to operationalize (Janker & Mann, 2020; Latruffe et al., 2016).

Related to the suggestion that a farming community should be provided with prosperity by agriculture (Van Cauwenbergh et al., 2007), economic agricultural sustainability is often perceived as economic viability (Latruffe et al., 2016), meaning that the long-term survival of a farming system in a changing economic context should be guaranteed. This understanding is adopted for this thesis. Indicators are again adapted to the research context, but may cover a smaller number of themes than environmental and social sustainability indicators, which is usual in the agricultural sustainability context (Latruffe et al., 2016). To measure economic viability, profitability, liquidity, stability, and productivity are predominantly considered (Latruffe et al., 2016). While some authors see farm autonomy or dependence as part of the social sustainability dimension, others attribute it to the economic dimension (ibid). Due to the interrelatedness with farm revenue and costs (Latruffe et al., 2016), autonomy and dependence are perceived as part of the economic dimension within this thesis.

3.5 Sustainability Outcomes of Irrigation Systems

Sustainability in the context of irrigation is often viewed as practices increasing crop yield and reducing water losses (Mancosu et al., 2015; Velasco-Muñoz et al., 2019). When agricultural irrigation is analysed from a three-dimensional perspective of sustainability, dominant sustainability objectives are the physical and biological continuity of the agricultural system, economic efficiency of resource uses, and social participation in decision-making processes (Velasco-Muñoz et al., 2019). These objectives are incorporated into the selection of sustainability indicators, but they are expanded by the understanding of the agricultural sustainability dimensions elaborated above. This means that for each sustainability dimension, the wide range of themes is recognized, and the indicators are selected to cover the different sustainability themes that are relevant for the research context. The selection of the indicators is elaborated on in more detail in chapter *4.2 Selection of Categories and Indicators*. Furthermore, a temporal dimension is incorporated, because rather than the state of irrigation, the research goal of this thesis is to analyse the sustainability outcomes associated with irrigation systems. Sustainability outcomes are hence viewed as results related to irrigation systems, which are perceived to positively or negatively impact the indicators selected within the three sustainability dimensions.

4 Methodology

To answer the research questions, a mixed-methods research design was applied, which is presented at the beginning of this chapter. The categories and indicators selected to gather data for are secondly presented. Each method of data collection and analysis is then elaborated on separately, namely in chapters *4.3 Document Analysis*, *4.4 Interviews*, *4.5 Aerial Photograph Analysis*, and *4.6 Satellite Image Analysis*.

4.1 Mixed-methods Research Design

For a comprehensive understanding of land use and landscape change, quantitative and qualitative data need to be integrated (Bürgi et al., 2022). A holistic sustainability assessment also calls for an integration of quantitative and qualitative data, as the frameworks by Antunes et al. (2017), Helfenstein et al. (2020), and Diogo et al. (2022) illustrate. A mixed-methods approach was therefore chosen to answer the research questions. Table 1 provides an overview of methods applied to gather and analyse data for the associated research questions. To research the irrigation development and the drivers of irrigation trajectories, documents were consulted, and interviews were conducted. Landscape changes and their relation to irrigation trajectories were spatially analysed with aerial photographs and satellite images, and interview data was used to complement the results. Sustainability outcomes were researched with a combination of document analysis and interviews. The spatial analysis was limited to the two study perimeters of 25 km^2, which can be viewed in chapter *1.4 Case Study Sites*. To prevent the loss of relevant information (Varghese, 2020), larger spatial levels were considered in the document analysis and interviews where possible.

Table 1: Methods to gather and analyse data for the associated research questions.

Method	**Associated research questions**
Document analysis	– Irrigation development and drivers of irrigation trajectories (RQ Ia & Ib) – Sustainability outcomes of irrigation systems (RQ IIa)
Interviews	– Irrigation development and drivers of irrigation trajectories (RQ Ia & Ib) – Landscape changes and relation to irrigation trajectories (RQ Ic & Id) – Sustainability outcomes of irrigation systems and perspectives of stakeholders (RQ IIa & IIb)
Aerial photograph analysis	– Landscape changes (RQ Ic)
Satellite image analysis	– Landscape changes (RQ Ic)

4.2 Selection of Categories and Indicators

Irrigation Development

An initial selection of irrigation development categories to consider was put together prior to field work based on the document analysis elaborated on in the following chapter *4.3 Document Analysis*. The categories were inductively adapted after field work based on the interviews conducted. The categories finally included irrigation water sources, irrigation system trajectories, relation to land consolidation and administrative procedure, and irrigation practices. Furthermore, actors involved in the irrigation development were researched, to account for the role of actors in land use change, as suggested by Bürgi et al. (2022).

Landscape Change

As previously mentioned, a landscape assessment had already been carried out for the SMP study site within the SIPATH project (Helfenstein et al., 2023). Using the same indicators allowed to incorporate the results of the SMP study site. Besides changes in land use, this landscape assessment included indicators of landscape structure (ibid) due to the importance of structural landscape elements for non-market outcomes (Helfenstein et al., 2020). The landscape structure indicators cover the number of field trees, the length of hedgerows and tree lines, and field size (Helfenstein et al., 2023).

Since landscape changes in the context of agricultural irrigation are researched, an additional indicator that goes beyond the visual interpretation of land use and landscape structure was included into the landscape assessment. The Normalized Difference Vegetation Index (NDVI) was chosen as an additional indicator because it is sensitive to photosynthetic vegetation (Soudani et al., 2008) and allows to capture vegetation dynamics in agricultural land use systems (Bellón et al., 2017). The NDVI can also be incorporated into assessments of irrigation performance (Poudel et al., 2021) and has been used to detect droughts (Sruthi & Aslam, 2015) or estimate crop yield (Poudel et al., 2021). Furthermore, the NDVI exhibits a simple calculation and is widely applied in vegetation studies (Sruthi & Aslam, 2015). NDVI computations result in values from -1 to +1 (Pettorelli et al., 2005). Negative values correspond to water bodies, and values close to 1 indicate vigorous vegetation (Huang et al., 2021).

Sustainability Outcomes

An indicator-based framework is useful for sustainability assessments (Varghese, 2020). The SIRIUS framework for assessing the sustainability of irrigated agricultural systems by Antunes et al. (2017) was used as a starting point, since this framework consists of a multidimensional indicator set that was put together in a participatory manner, specified on the topic of irrigation. Considering that sustainability is highly context-dependent (Pretty, 2008; Diogo et al., 2022; Antunes et al., 2017), the indicator set was adapted to the study sites and research context, under consideration of the conceptual frame elaborated in chapters *3.4 Agricultural Sustainability* and *3.5 Sustainability Outcomes of Irrigation*

Systems. Some indicators, such as the annual groundwater recharge, were eliminated because they were not measurable within the scope of this thesis. Some indicators were not included because they did not serve the research goal, as for example the share of population with domestic water supply. Some indicators were simplified to facilitate the data collection. Other indicators were added to the indicator set, based on exchanges with the local partner and on the interviews previously conducted within the SIPATH project. The context-specific framework for integrated sustainability assessment of agricultural intensity change by Diogo et al. (2022) was also consulted to adapt the indicator set. A temporal dimension was added to the indicators considering the importance of historical development for the current state of agriculture (Jepsen et al., 2015) and the inclusion of multiple temporal scales into sustainability assessments (Helfenstein et al., 2020). During and after data collection, the indicators were further adapted inductively. The resulting indicator set can be found in the annex *A: Sustainability Indicator Set*. To adjust the work effort to the scope of the thesis, the sustainability indicators were not applied to all irrigation systems but to two main irrigation systems.

Sustainability is per se an anthropocentric concept, determined by values and norms (Janker & Mann, 2020), and different stakeholders have different visions of sustainability (Helfenstein et al., 2020). Since the active engagement of stakeholders for the definition of sustainability indicators before data collection lied outside the scope of this thesis, stakeholder perspectives on sustainability outcomes were incorporated in the data collection and analysis, as described in chapter *4.4 Interviews*.

4.3 Document Analysis

The method of document analysis allows to decipher already existing material and is therefore relevant for research with a historic dimension (Mayring, 2016). The procedure of the document analysis and the criteria for the document selection were based on Mayring (2016) and Flick (2016). Already existing material was used in two distinct steps of this thesis. Firstly, online sources were consulted prior to the field visit to get a general idea of the irrigation development, select suitable interview partners, and prepare interview questions. Regional online newspapers and a master thesis on the history of regional water resources were identified as suitable sources for this first step (see Table 2). Information on irrigation system trajectories, actors, and useful contextual information were extracted from the documents and assembled in a chronosystemic timeline. This representation tool has proven to account for the complexity and multi-dimensionality of processes at work in landscapes (Bergeret et al., 2015; Spiegelberger et al., 2018). Chronosystemic timelines allow to simultaneously consider bio-physical and socio-economic dynamics, and to better understand the procedural dynamics over time (Spiegelberger et al., 2018). The resulting timeline accordingly served to obtain an overview of the assembled information prior to field work, to refine the interview methodology, and additionally served as an orientation during field work. It can be viewed in the annex *B: Document Analysis Based Chronosystemic Timeline*.

Already existing material was secondly consulted to complement the interview data collected regarding the irrigation development and sustainability outcomes. The selection of the material was based on the interviews conducted. The material includes booklets and data provided by interview partners, and online sources interview partners referred to. Table 2 displays the documents consulted and abbreviations used to reference them in the results chapter.

Table 2: Abbreviations, authors, document title, and type of documents consulted prior and after field work. The website URLs can be found in chapter 8.2 Web Sources.

Abbreviation	Document author and document title	Document type
Documents consulted prior to field work		
Diario de León (v.d.)	41 articles of Diario de León with relation to irrigation trajectories, from 2005 to 2022.	Online newspaper articles
García Martínez (2020)	García Martínez, J. G. (2020): El Páramo Leonés y los recursos hídricos: Transformaciones en época contemporánea.	Master thesis
Documents consulted after field work		
Agricultura y Ganadería (n.d.)	Agricultura y Ganadería (n.d.): Agricultura y Ganadería de Castilla y León.	Website
Ayuntamiento SMP (n.d.b)	Ayuntamiento Santa María del Páramo (n.d.b): Comunidad de Regantes.	Website
CHD (2009)	Confederación Hidrográfica del Duero (2009): Embalse de Villameca.	Website
CHD (2019a)	Confederación Hidrográfica del Duero (2019a): Historia y funciones.	Website
CHD (2019b)	Confederación Hidrográfica del Duero (2019b): Características generales de la cuenca del Duero.	Website
CHD (2019c)	Confederación Hidrográfica del Duero (2019c): Embalse de Barrios de Luna.	Website
CHD (2019d)	Confederación Hidrográfica del Duero (2019d): Embalse de Villameca.	Website
CRBT (2021)	Comunidad de Regantes del Bajo Tuerto (León) (2021): Análisis del sector agroindustrial de la zona Baja del Tuerto (León): La agricultura y la industria agroalimentaria pendiente de la modernización del regadío.	Booklet
CRCAV (2019)	Comunidad de Regantes del Canal Alto de Villares (León) (2019): Estudio socio-económico y agroindustrial de la CR. Canal Alto de Villares (León): La modernización del regadío, clave para la supervivencia de esta zona.	Booklet
FENACORE (2023a)	Federación Nacional de Comunidades de Regantes de España (2023a): Quiénes somos.	Website
FENACORE (2023b)	Federación Nacional de Comunidades de Regantes de España (2023b): Entitadas federas.	Website
FERDUERO (2019a)	Asociación de Comunidades de Regantes de la Cuenca del Duero (2019a): Quienes somos.	Website
FERDUERO (2019b)	Asociación de Comunidades de Regantes de la Cuenca del Duero (2019b): CCRR miembros.	Website

Grupo Tragsa (n.d.)	Grupo Tragsa (n.d.): Quiénes somos.	Website
ITACyL (n.d.)	ITACyL (n.d.): Quiénes somos.	Website
Junta de Castilla y León (n.d.c)	Junta de Castilla y León (n.d.c): Solicitud de iniciación del procedimiento general de concentración parcelaria.	Website
MAPA (2020)	Ministerio de Agricultura, Pesca y Alimentación (2020): Funciones y estructura.	Website
MAPA (n.d.)	Ministerio de Agricultura, Pesca y Alimentación (n.d.): Sociedad Estatal de Infra-estructuras Agrarias (SEIASA).	Website
MACL (2021)	Medio ambiente de Castilla y León (2021): Periodos de sequía.	Website
SCBL (2023)	Sindicato Central del Embalse de los Barrios de Luna (2023): Creación.	Website
SEIASA (2013)	Sociedad Estatal de Infraestructuras Agrarias (2013): ¿Qué es SEIASA?	Website
SEPI (n.d.)	Sociedad Estatal de Participaciones Industriales (n.d.): Quiénes Somos.	Website

4.4 Interviews

4.4.1 Interview Partners

The initial literature research indicated that the written documents available could not exclusively answer the research questions. Interviews were hence conducted with people directly involved in the processes of interest to gather data for all research questions. Different groups of stakeholders were interviewed depending on the information needed. Based on the definition of experts by Gläser & Laudel (2009), the stakeholders interviewed were seen as sources for in-depth knowledge for the content of interest. The according selection of interview partners is elaborated on below and abbreviations to refer to interview partners are displayed in Table 3.

Table 3: Description of interviewee abbreviations.

Interviewee abbreviations	**Description**
SMP01, SMP02, SMP03, SMP04, SMP05	Farmers of the Santa María del Páramo (SMP) study site
SMI01, SMI02, SMI03, SMI04, SMI05	Farmers of the Santa María de la Isla (SMI) study site
IC01, IC02, IC03	Members and employees of local irrigation communities
IU01	Person in a leading position at a central board of irrigation communities
RG01	Person in a leading position at the regional agricultural department
EE01, EE02, EE03	Environmental experts

Farmers

For the reconstruction of the irrigation development and drivers of irrigation trajectories (RQ Ia & Ib), information on landscape changes and their relation to irrigation trajectories (RQ Ic & Id), and on sustainability outcomes (RQ IIa & b), farmers were firstly interviewed, because they are the most direct users of irrigation systems, and because contacts had already been established within the SIPATH project in the previous year. To account for the historic dimension of the research questions, farmers of older age were preferred as interview partners. The farmer interviews can be classified as oral history interviews (OHI). This type of interview serves to research historical processes from the perspective of contemporary witnesses (Truesdell, 2002). Besides the older age of farmers interviewed, a further criterion for the interviewee selection was that the farmers had parcels belonging to one of the irrigation communities at the study sites. To enable a study site comparison, an equal number of interviews at each study site was aimed for. Wierling (2003) suggests ten OHI to grasp local land use patterns. Since ten interviews at each study site would have gone beyond the time resources of this thesis, five farmer interviews were conducted at each study site, leading to a total number of ten OHI. The choice to reduce the number of farmers interviewed also allowed to interview further stakeholders. Farmers were contacted by the local partner, and further farmers to interview were found through snowball sampling, that is through asking farmers interviewed for further contacts (Flick, 2009). Three farmers of the sample had already been interviewed within the SIPATH project in the previous year. To gather detailed information, the interviews were conducted with the heads of the farms. In nine cases, this led to male interview partners and in one case, a farmer couple was interviewed.

Irrigation Community

The initial document analysis indicated irrigation communities as relevant actors involved in irrigation developments. With the help of the local partner, one irrigation community member in a leading position in Santa María de la Isla (IC01) and one irrigation community member in a leading position in Santa María del Páramo (IC03) could be contacted and interviewed to gather information on irrigation trajectories and their drivers (RQ Ia & Ib) and on sustainability outcomes (RQ IIa & b). Landscape changes were not addressed in detail in the interviews, because the interviewees had limited time resources. However, the local partner and the author could accompany two employees of the SMP irrigation community (IC02) on their field inspection round. During this inspection round, additional questions about the irrigation trajectories could be asked, and irrigation infrastructure could be taken photos of. This field visit enhanced the author's understanding of irrigation infrastructure addressed in interviews.

Irrigation Union

Based on the interview questions asked, an irrigation community member suggested an interview with a central board of irrigation communities and provided the according contact. The person contacted and subsequently interviewed (IU01) held a leading position in both a governmental and a non-governmental irrigation union and provided information on irrigation trajectories and their drivers (RQ Ia & Ib). The secretary of both unions was also present and added remarks during the interview.

Regional Government

An irrigation community member furthermore provided the contact of an employee of the regional agricultural department (RG01), which could be interviewed on the governmental perspective on irrigation trajectories and their drivers (RQ Ia & Ib).

Environmental Experts

As Diogo et al. (2022) pointed out, most farm-level indicators on socio-economic sustainability outcomes can be assessed using farm surveys or interviews. Accordingly, farmers and irrigation community members provided detailed information on economic and social sustainability outcomes of irrigation systems. To gather further information on environmental sustainability outcomes and to obtain a more differentiated view, environmental experts were interviewed as suggested by Kienast & Helfenstein (2016). The search for interview partners with expert knowledge on environmental outcomes at the study sites was challenging. The project partner could contact members of two environmental organizations, of which one organization is active nationwide, and one organization is regionally active. The third environmental expert interviewed was an organic farmer active in environmental education in the area of the study sites.

4.4.2 Interview Procedure and Guidelines

Interview Location

The interviews took place face-to-face either on the farm of the interviewee, at the office of irrigation communities or unions, at the regional government, or at home of the local project partner, depending on the preference of the interviewee. Three interviews were conducted via phone, due to large distances or personal circumstances of the interviewee.

Interview Structure

At the beginning of each interview, the interviewees were informed about the context of the thesis and the topics addressed in the following questions. The interviewees were asked for permission to record the interviews. All interviews were conducted with a guideline, to obtain the desired information while maintaining a greater openness than in standardized questionnaires (Flick, 2007). The first questions of the farmer interviews were of open character, as Stephan (2004) suggests for the start of an OHI. This allowed the interviewees to narrate about their life in agriculture and the role of irrigation. Semi-structured questions on farmer biographies and farm characteristics followed, to collect contextual background information on the farmers interviewed. These questions were based on the SIPATH questionnaire conducted in the previous year. The three farmers who were interviewed for the second time were not asked the same questions again. Besides the opening questions to the farmers, all interview questions were of semi-structured form. This structure keeps interviews to the topic, simultaneously allows interviewees to express their knowledge and views on their own terms, and additional questions for more in-depth information can be asked (Wilson, 2014). The content of the semi-structured guidelines was adapted to the expertise of different stakeholder groups as elaborated in the previous subchapter *4.4.1 Interview Partners*. The first farmer interview served as a pre-test. The wording of the questions was refined with the help of the local partner, and the questions were further adapted during field work. The guidelines can be found in the annex *C: Interview Guidelines*.

All interviews were conducted in Spanish, with the presence of both the local project partner and the author. The native-speaking project partner had the lead of the interviews. This impeded that the author's limited fluency in Spanish led to linguistic shortcomings during the interview, which could have negatively impacted the quality of the interview data (Marschan-Piekkari & Reis, 2004) or the interviewee's comfort (Drew, 2014). The presence of the author during the interview was relevant nonetheless for the author's understanding of the local research context (Filep, 2009). The author asked additional questions for clarification, mostly at the end of the interview. The interviews were recorded with two phones. At the end of the interview, all interview partners signed a declaration of consent for the scientific and anonymized use of the content recorded. The interviewees could keep a copy of the consent form.

Interview Duration

The duration of interviews was between 30 minutes and three hours. A few interview partners did not provide answers related to interview questions and were therefore asked the same question more than once. Some interview partners were also asked for clarifications in hindsight via phone.

4.4.3 Interview Processing and Qualitative Content Analysis

The interviews were transcribed with the software MAXQDA, under consideration of transcript guidelines compiled within the SIPTAH project. Thought pauses were noted in brackets and answers with no relation to the topic were summarized descriptively. The interviews were subsequently translated to English. With both the transcription and the translation, the local project partner was consulted for clarifications. Personal information of interview partners was anonymized to protect the interviewees' privacy.

The analysis of the translated interviews was carried out in the software MAXQDA. To extract relevant information and decipher personal perceptions out of guided interviews, the qualitative content analysis is helpful (Mayring, 2016). The method according to Mayring (2016) served as an orientation for the interview analysis. Categories, codes, and subcodes were first deductively created under consideration of the research questions, the concept of driving forces presented in chapter *3.2 Driving*

Forces of Land Use and Landscape Change, and the sustainability indicator set, and were then inductively adapted based on the interview material. The segmentation of the transcripts into the very codes and subcodes served to compile the results in written, tabular, and graphic form.

4.5 Aerial Photograph Analysis

4.5.1 Data Collection

Aerial photographs had been used as data for the landscape assessment within the SIPATH project because the spatial resolution of satellite images is often too coarse for determining structural characteristics at the agricultural landscape scale (Helfenstein et al., 2020). The two time points selected were the years 2002 and 2017. For the analysis of the second study site within this thesis, aerial photographs from the same flights were downloaded from the website of the *Instituto Geográfico Nacional de España (IGN)*. The orthophoto of the year 2002 stems from a flight between June and August and has a spatial resolution of 0.5 meters. The flight in 2017 was in July and the resulting orthophoto has a spatial resolution of 0.25 meters. To aid the landscape mapping, a land use map of the year 2020 with the resolution 1:25’000 was downloaded, also from the *Instituto Geográfico Nacional de España (IGN).* This was the same map which had aided the SMP study perimeter analysis.

4.5.2 Landscape Mapping with ArcGis Pro

The software ArcGIS Pro (Version 2.9.5) was used to carry out the landscape mapping. The same methodology as in the SIPATH project was applied (Helfenstein et al., 2023), to ensure the comparability of results. According to the SIPATH methodology, land use and landscape elements were classified through visual interpretation. A mask of non-agricultural land was firstly created, and parcels were mapped, using feature lines. Land use was then marked with feature points, based on the European Nature Information System (EUNIS) habitat classification (EEA, 2019), as in the SIPATH project (Helfenstein et al., 2023; annex *D: SIPATH Land Use Classification*). The land use map underlaid facilitated the visual interpretation, especially with small waterways that were difficult to detect. The analysis already carried out for the SMP study site was also consulted repeatedly throughout the analysis, to ensure a classification based on the same visual criteria. Feature lines and feature points were followingly transformed to land use polygons. Landscape elements such as tree lines, hedgerows, and field trees were also mapped with feature lines and feature points, based on the SIPATH criteria (Helfenstein et al., 2023; annex *D: SIPATH Land Use Classification*). Statistics were calculated and maps for visual representation of the results were created with ArcGIS Pro. Further quantitative evaluations were carried out with Microsoft Excel and R.

4.6 Satellite Image Analysis

4.6.1 Data Collection

Landsat satellite images of 30-meter spatial resolution provided by the United States Geological Survey (USGS) via the Earth Engine Data Catalog (Earth Engine Data Catalog, n.d.a; USGS, n.d.) were used for the NDVI calculation. To cover the periods of interest, the two image collections *Landsat 5 TM Collection 2 Tier 1 calibrated top-of-atmosphere (TOA) reflectance* (Earth Engine Data Catalog, n.d.b; USGS, n.d.) and *Landsat 8 Collection 2 Tier 1 calibrated top-of-atmosphere (TOA) reflectance* (Earth Engine Data Catalog, n.d.c; USGS, n.d.) were selected. Tier 1 data was preferred over Tier 2 data, because the former had been inter-calibrated across the Landsat sensors (Yale University, 2023). The computation of top-of-atmosphere (TOA) reflectance had been carried out by USGS according to Chander et al. (2009).

4.6.2 Remote Sensing with Google Earth Engine

To calculate the NDVI, the cloud computing program Google Earth Engine (GEE) by Google was selected, because it facilitates processing large amounts of data over extended periods of time (Amani et al., 2020). The NDVI was calculated for both study perimeters with codes based on the methodology of Geospatial Ecology and Remote Sensing (GEARS, n.d.). The normalized difference method was applied, using the Near-InfraRed (NIR) and Red bands, which correspond to bands 4 and 3 for Landsat 5 (USGS, 2016), respectively bands 5 and 4 for Landsat 8 (NASA, 2021). The formula (1) used for computation is displayed below.

$$(NIR - Red) / (NIR + Red) \qquad (1)$$

Dates of interest were then filtered, and the study perimeters were clipped out of the image collections. Clouds were filtered with the median reducer according to GEARS (n.d.). The resulting codes can be found in the annex *E: Remote Sensing Codes*. NDVI values were subsequently exported to Excel to create charts and calculate statistics. The monthly NDVI mean over each study site was calculated for two 7-year periods. These time periods were selected according to the research questions, to analyse the relation of irrigation changes and NDVI values. The mean was used because satellite image availability varied between study sites and between months, and because no outliers were detected during the periods selected. A t-test was conducted to determine the significance of differences in means.

5 Results

Actors involved in the irrigation development at the two study sites are presented at the beginning of this chapter, followed by results on the irrigation development and the driving forces of the irrigation system trajectories. Afterwards, landscape changes and their relation to the irrigation system trajectories are displayed. Environmental, economic, and social sustainability outcomes are lastly presented, including results on the reflection of sustainability outcomes in stakeholder perspectives.

5.1 Actors

This chapter focuses on actors involved in the irrigation development at the two study sites, to facilitate the understanding of the subsequent results on the development. A typology of key actors is followed by information on farm-level and institutional actors. The interviews conducted served as main data source. The overview of interviewee abbreviations can be consulted in chapter *4.4.1 Interview Partners*. Where necessary, interview data was complemented by documents, which are referred to accordingly. The document abbreviation key can be consulted in chapter *4.3 Document Analysis*.

5.1.1 Typology of Key Actors

Key actors involved in the irrigation development were categorised into institutional actors, economic actors, and individuals (Table 4). Institutional actors include both governmental and non-governmental entities. Actors categorised as economic exhibit a participation in economic endeavours. Companies of the national government were categorised as institutional and economic actors because they exhibit features of both types.

Table 4: Typology of key actors. Types of actors who interviews were conducted with are presented in italics. Institutional actors are coloured according to estimated governmental influence, based on the colour scheme presented in Figure 6. Red indicates direct governmental influence, pink indicates indirect governmental influence, and yellow indicates independence of governmental influence.

Institutional actors	**Economic actors**	**Individuals**
Ministries of the national government	Banks	*Farm-level actors*
Hydrographic confederation	Agro-industrial companies	Non-agricultural landowners
Agricultural department and institute of the regional government	Engineering companies	Non-agricultural land users
Central boards of irrigation communities	Irrigation companies	
Local irrigation communities	Cooperatives	
Non-governmental irrigation unions		
Environmental organizations		
Companies of the national government	Companies of the national government	

5.1.2 Institutional Actors

Considering the number of institutional actors involved in the irrigation development and the complexity of linkages between institutional actors, a graphic overview was created (Figure 6), and to further facilitate the understanding of linkages between institutional actors, a data-based estimation of governmental influence on institutional actors was included in the graphic overview. Elaborations on institutional actors follow below Figure 6.

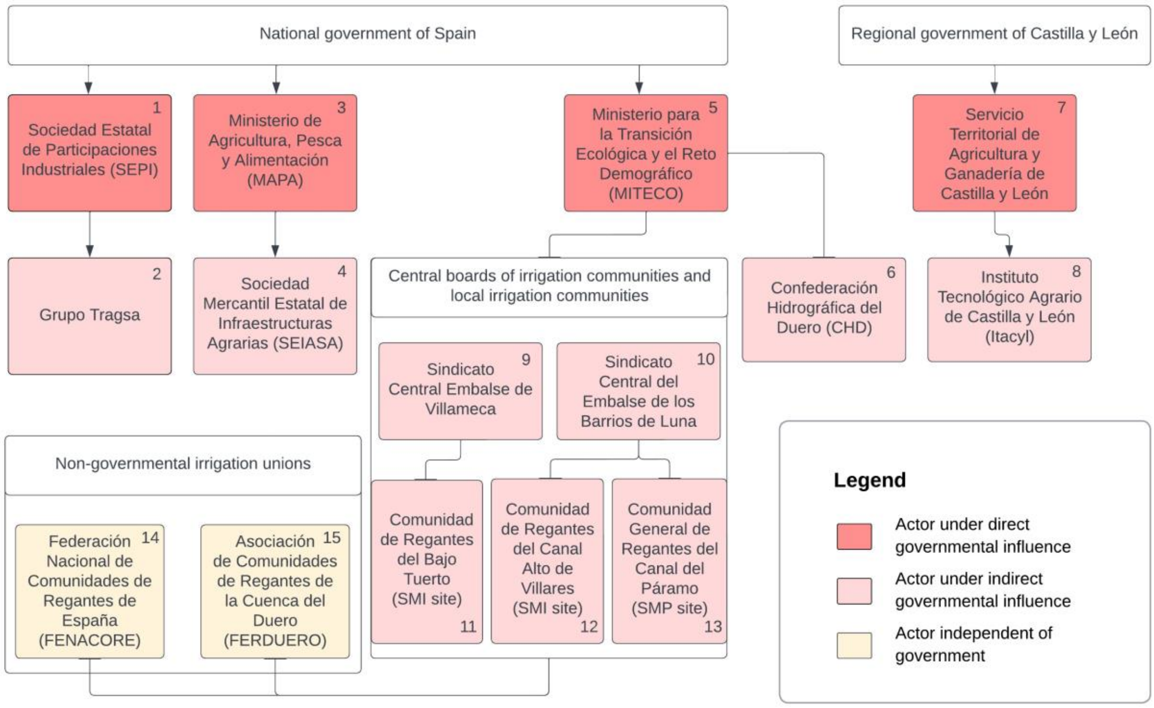

Figure 6: Overview of institutional actors with data-based estimation of governmental influence. Arrows represent the establishment of an entity by an actor, lines indicate affiliations of actors. Actors are numbered to follow the elaborations in the text below, where the numbers appear as footnotes (own figure).

National Governmental Entities

On the national level, the *Ministerio de Agricultura, Pesca y Alimentación (MAPA)*[3] is the department within the general state administration responsible for agriculture, fisheries, and food. It proposes and executes the government's policies in these matters (MAPA, 2020). As an instrumental company of the *MAPA*, the *Sociedad Mercantil Estatal de Infraestructuras Agrarias (SEIASA)*[4] was established in 1999 (MAPA, n.d.). The purpose of *SEIASA* is the promotion and contracting of investments in irrigation development and consolidation works (SEIASA, 2013). A further state company involved in the execution of irrigation projects is the *Grupo Tragsa*[2] (Grupo Tragsa, n.d.). The *Tragsa* group forms part of the *Sociedad Estatal de Participaciones Industriales (SEPI)*[1]. The *SEPI* public law entity was designed by the government for the public business sector, to increase corporate shareholdings profitability (SEPI, n.d.).

The *Confederación Hidrográfica del Duero (CHD)*[6] manages the water of the Spanish part of the Duero River basin, under the *Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO)*[5] (CHD, 2019a). The administrative territorial of the *CHD* covers 78,859 km^2 (CHD, 2019b), including both study perimeters. The confederation prepares the basin hydrological plan, its monitoring and revision, and is responsible for the administration and control of the public water domain (CHD, 2019a). This includes the release of water from reservoirs to irrigation communities.

Regional Governmental Entities

The *Servicio Territorial de Agricultura y Ganadería*[7] is the department of the regional government of Castilla y León concerned with agriculture, livestock, and rural development (Agricultura y Ganadería, n.d.). Attached to the ministry of agriculture and livestock of the regional government of Castilla y León, the *Instituto Tecnológico Agrario de Castilla y León (ITACyL)*[8] was created, to promote the development of Castilla y León's agri-food industry and agricultural innovation, including agricultural irrigation (ITACyL, n.d.).

Local Irrigation Communities

Irrigation communities are corporations under public law, created by ministerial orders. As stated by interview partners, the purpose of a community of irrigators is the management of a water resource and the distribution to its members. A farmer automatically becomes a member of a community through irrigating his or her land. The leadership positions in an irrigation community are mostly occupied by active or former farmers.

The *Comunidad General de Regantes del Canal del Páramo*[13], of which the SMP-farmers are part of, encompasses roughly 5'000 farmers. The farms located in 29 villages entail a total of 17,000 irrigated hectares of farmland (Ayuntamiento SMP, n.d.b). The community was founded in 1953, with the arrival of the water by the *Barrios de Luna* reservoir (ibid).

The irrigated area that belongs to the municipality of Santa María de la Isla is divided into four communities. The communities on the left bank of the *Tuerto* river, supplied by the *Villameca* reservoir, are the *Comunidad de Regantes de Santa María de la Isla*, *Comunidad de Regantes de Presa de la Manga*, and *Comunidad de Regantes de San Felix de la Vega*, *Villarnera y Santibáñez de la Isla* (CRCAV, 2019). In 2021, these communities fusioned with another community and two groups of communities into the *Comunidad de Regantes del Bajo Tuerto*[11], with a total of 1'867 irrigated hectares (ibid). On the right bank of the *Tuerto* river, the irrigated area of the municipality of Santa María de la Isla (431 hectares) is part of the *Comunidad de Regantes del Canal Alto de Villares*[12], and is supplied by the *Barrios de Luna* reservoir. The community was founded in 1974 and encompasses four further municipalities, with a total of 2'254 hectares (CRCAV, 2019).

Central Boards of Irrigation Communities

The *Sindicato Central del Embalse de los Barrios de Luna*[10] is a central board of reservoir water users. Its creation was inaugurated in 1946, in compliance with the Water Law of 1879 (SCBL, 2023). It includes all irrigation communities supplied by the *Barrios de Luna* reservoir. The central board is concerned with the distribution of water among its users and associated administrative tasks. It is dependent on the *Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO)*[5]. With the *Sindicato Central Embalse de Villameca*[9], an equivalent board exists for the management of the *Villameca* reservoir water.

Non-governmental Irrigation Unions

The *Asociación de Comunidades de Regantes de la Cuenca del Duero (FERDUERO)*[15] is an association of 134 irrigation communities of the Duero River basin, with a total of 232,685 irrigated hectares (FERDUERO, 2019a). The association was created in 2007 to defend the interests of irrigators. It is independent of state bodies (ibid). Both the *Sindicato Central del Embalse de los Barrios de Luna*[10] and the *Sindicato Central del Embalse de Villameca*[9] are members of *FERDUERO*[15] (FERDUERO, 2019b).

On the national level, the *Federación Nacional de Comunidades de Regantes de España (FENACORE)*[14] brings together irrigation entities, both communities and central boards, dedicated to the administration of water for irrigation. It is a non-profit and politically independent association, created in 1955 (FENACORE, 2023a). *FENACORE*'s fundamental objective is to defend the interests and rights of water users in Spanish irrigation (ibid). The association represents 700,000 irrigators with a total of almost two million hectares of irrigated farmland. Both the *Sindicato Central del Embalse de los Barrios de Luna*[10] and the *Sindicato Central del Embalse de Villameca*[9] are members of the national association (FENACORE, 2023b).

5.1.3 Farm-level Actors

An overview of relevant information on farmers interviewed is provided in Table 5 and complemented below.

*Table 5: Overview of biographies and farm changes of farmers interviewed. When farmers provided a range of numbers regarding farm size or property, the average was chosen for the display in the table. *Before refers to the time point when a farmer took over own lands, after refers to the time point of the interview or retirement.*

		Farmers interviewed in Santa María de la Isla (SMI)					Farmers interviewed in Santa María del Páramo (SMP)				
		SMI 01	SMI 02	SMI 03	SMI 04	SMI 05	SMP 01	SMP 02	SMP 03	SMP 04	SMP 05
Farmer biographies							(couple)				
Age		55	46	52	56	50	70, 64	71	64	59	61
Own farm at age		28	36	26	19	32	25, 19	26	22	25	20
Non-agricultural activity		None	Little	None	Little	None	None	Little	None	None	None
Farm changes											
Farm size [ha]	Before*	6.5	30	17.5	9	16.5	17.5	10	36	10	1.5
	After*	42	50	50	30	57.5	37	13	83	24	83
	Difference	35.5	20	32.5	21	41	19.5	3	47	14	81.5
Property [%]	Before*	20	1.5	0	0	33	60	0	30	0	0
	After*	12.5	10	20	10	60	75	30	50	12.5	22.5
	Difference	-7.5	8.5	20	10	27	15	30	20	12.5	22.5

Farmers' ages range from 46 to 71 (Table 5). Most farmers interviewed started working in agriculture during childhood with their parents, the latest started at the age of 18. Two farmers took over the farm at age 19, the other farmers began to possess an own farm in their 20ies or early 30ies. Two farmers were retired at the time of the interviews. The rest of the farmers either did not know the retirement age yet or plan to retire at age 65 to 68. One retired farmer had his son taking over the farm, and one farmer plans to hand over the farm to his nephew. The other farmers do not have a successor. Three farmers had or have carried out little non-agricultural occupational activity throughout their life, but all farmers had or have agriculture as their main income-generating activity.

From the time of taking over their own farm until retirement or the time of the interview, all farms increased in size (Table 5). Most farmers started with 1.5 to 17.5 hectares, while two farmers already worked 30, respectively 36, hectares when they started working in agriculture. Farm size increased progressively as stated in interviews, coinciding with the retirement of other farmers. According to SMI01, a phase of early retirements around 2010 financially supported by the European Union accelerated the number of retirements. The greatest overall farm size increase of the sample was by 81.5 hectares. One farmer shows an increase from 10 to 13 hectares for the displayed time range, but this farmer chose active retirement and mentioned a peak farm size of 47 hectares.

Four farmers did not have any property at the beginning. The percentage of own to leased land increased for all farmers but one (SMI01) during life in agriculture. In absolute numbers, owned lands of SMI01 increased as well. The percentage increased successively according to farmers interviewed, buying lands from retiring farmers, to reduce rent expenses. At the time of the interview or retirement, the percentage of owned land ranged from 10 to 75 percent. All farmers leased the lands from individuals and denounced any influence of the land tenure type on land use practices.

5.2 Irrigation Development since 1970

Regarding the irrigation development at the two study sites, the following aspects were analysed and are presented in the corresponding order: Where the water comes from, irrigation system trajectories, relation to land consolidation and administrative procedure, and irrigation practices. The interviews conducted served as main data source, complemented by online sources referred to and photos taken during field work.

5.2.1 Where the Water Comes from

During the period analysed, the main water source at both study sites is surface water, provided by reservoirs. Farms in SMP are supplied by the *Barrios de Luna* reservoir, which began to operate in 1956 and has a water capacity of 300 million cubic meters (CHD, 2019c). A total of 50,000 irrigated hectares are supplied by the *Barrios de Luna* (ibid). At the study site in SMI, farms located on the left bank of the river *Tuerto* are supplied by the *Barrios de Luna* reservoir, while farms on the right bank are supplied by the *Villameca* reservoir. The latter was commissioned in 1947 and can store up to 20 million cubic meters of water (CHD, 2019d), irrigating a total of 5’000 hectares (CHD, 2009). The location of the reservoirs is visible in Figure 1 in chapter *1.4 Case Study Sites*. From the reservoirs, the water is transported downstream through rivers and channels, passing multiple counter reservoirs that serve the production of hydropower.

5.2.2 Irrigation System Trajectories

Figure 7 shows the development of irrigation systems and infrastructure used to distribute the reservoir water since the 1970s, juxtaposing the two study sites. Regarding the spatial levels at which irrigation systems and infrastructure operate, landscape and farm level are differentiated. The figure hence provides an overview of how water for irrigation is distributed through the landscape and on farms, after having travelled downstream from the reservoir. The irrigation systems and corresponding infrastructure are elaborated on and illustrated in detail below Figure 7.

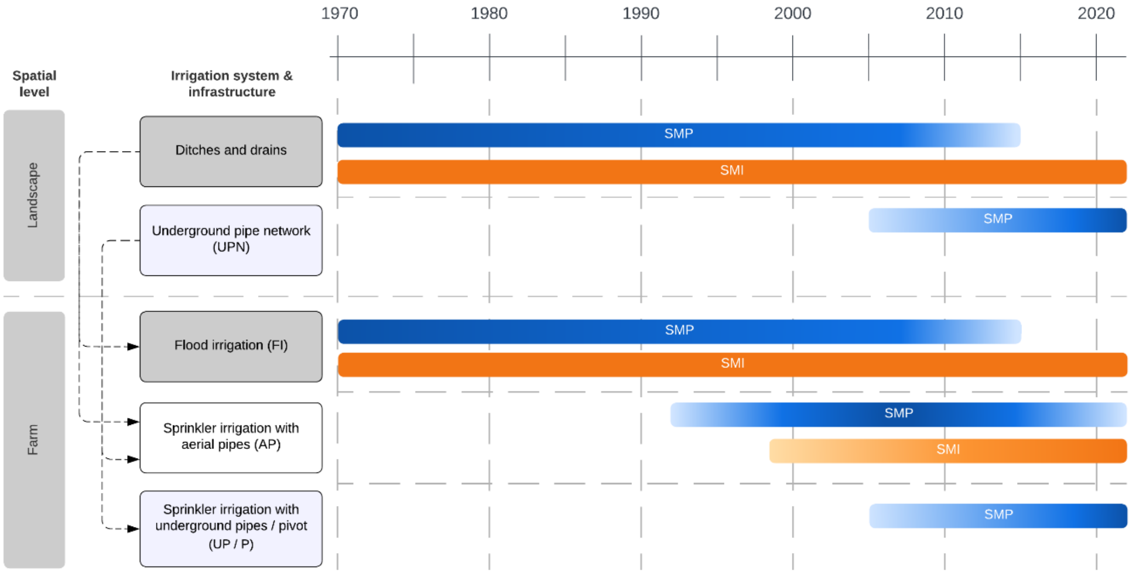

Figure 7: Development of irrigation systems and infrastructure on the landscape and farm level at the SMP and SMI study sites since 1970. Affiliations between landscape and farm level are displayed with dotted arrows. Colour gradients indicate increasing and decreasing use of irrigation systems and infrastructure at the study sites (own figure).

Flood Irrigation (FI)

Farmers interviewed grew up seeing their parents irrigating with wells. From 1970 onwards, all interviewees had their own farms and irrigated them by flood (Figure 7). Farmers of the SMP sample recounted that the transport of the water up to the farm was at first through earth ditches, which were then transformed into ditches of cement (Figure 8A). In SMI, some ditches were still of earth at the time of the interviews, while others had been cemented. Surplus water that has collected in drains after irrigation can also be used by farmers whose lands are located adjacent to drainage ditches.

For on-farm distribution, farmers create furrows on their plots where the water from irrigation ditches flows through when the flood gate is opened (Figure 8B&C). Using shovel and hoe, farmers direct the water through the furrows and move the soil in such a way that the water is periodically diverted to different sectors.

Farmers in SMP completely stopped irrigating by flood between 2010 and 2017 (Figure 7), depending on the locations of their farms. In SMI, the farmers were still irrigating by flood at the time of the interviews.

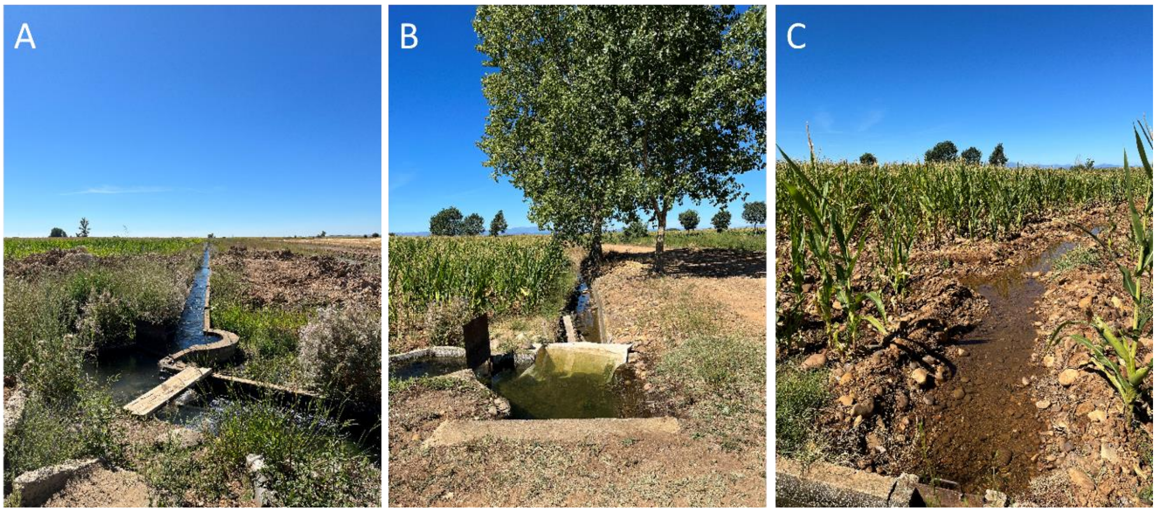

Figure 8: Flood irrigation infrastructure. From left to right: Cemented irrigation ditch transporting water to fields (A), open flood gate during irrigation (B), on-field furrows filled with irrigation water (C) (photos taken by Fabienne Frey in the area of SMI, 2022).

Aerial Pipes (AP)

Aerial pipes were introduced on farms in SMP approximately six years prior to the introduction of AP in SMI (Figure 7). The first two farmers of the sample began with the introduction in 1992, the other farmers in SMP followed in the later 1990s. The first farmer in SMI introduced aerial pipes in 1998, and the rest of the SMI farmers followed from 2000 onwards. Overall, the ratio of land irrigated by aerial pipes to flood-irrigated lands ranged from 10 to 50% per farmer. This ratio gradually increased over time as farmers bought more pipes.

The pipes consist of aluminium. Diesel-fuelled motor pumps or engines take water out of an irrigation or drainage ditch and pump the water through the attached pipes (Figure 9A). The aerial pipes are laid on the farm in a grid (Figure 9B). When watering, a farmer must open and close the keys for the different sections of the field (Figure 9C). A sprinkler is connected to the aerial pipes every 12 to 15 meters. The heads of the sprinklers distribute the water on the farm (Figure 10). After every irrigation campaign, farmers need to remove aerial pipes from their plots for the harvest.

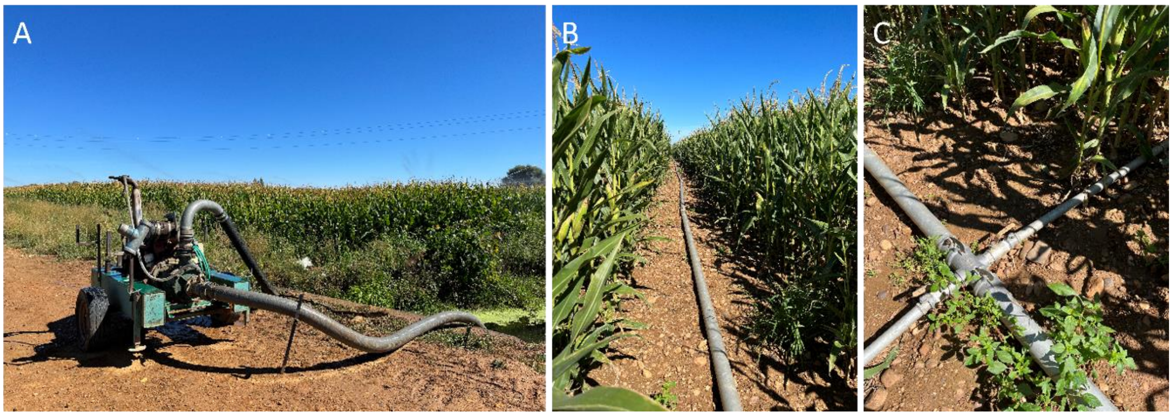

Figure 9: Aerial pipe irrigation infrastructure. From left to right: Engine pumping water out of ditch (A), aerial pipe transporting water to field (B), cross of aerial pipes with keys for different sections (C) (photos taken by Fabienne Frey in the area of SMI, 2022).

Figure 10: On-farm sprinkler irrigation (photo taken by Fabienne Frey in the area of SMI, 2022).

Aerial pipes are still used at both study sites, but the ratio decreased at the SMP site since the establishment of the UPN (Figure 7).

Underground Pipe Network (UPN)

Colloquially, interview partners used the term "modernization" to refer to the UPN establishment. The establishment of such a large-scale underground pipe network solely concerns the SMP study site. This study site forms part of the *Comunidad General de Regantes del Canal del Páramo*, where the first installations started in 2005. The installations continued to be executed sector-wise in the following years. The farmer couple interviewed had their farms connected to the network around 2010, and the remaining four farmers of the sample followed between 2014 and 2016. The entire community with its extension of 17,000 hectares is expected to be completed for the irrigation campaign in 2023.

The reservoir water is transported to rafts through the previous channels. For the UPN establishment, additional rafts are constructed (Figure 11A) and from the rafts, the water is redirected to pumping stations (Figure 11B) through underground pipes. Along with pumping stations and rafts, further power lines are constructed. At the pumping stations, the water is pressurized using electricity. A network of underground pipes then transports the water to hydrants on farms (Figure 11C&D). This underground pipe network replaces the previous network of ditches.

A farmer can choose to install on-farm underground pipes, which are connected to sprinklers distributing the water on the field. The watering with underground pipes can be controlled remotely on demand with a phone application. According to farmer statements, the same sprinklers as with aerial pipes can be used (Figure 10). It is also possible to connect the removable aerial pipes to the hydrant, or to irrigate with a pivot (Figure 11E). One farmer in SMP is solely using underground pipes and completely stopped using aerial pipes, while the rest of the sample still uses aerial pipes on leased plots, or to a small percentage on the edges of a circular pivot. Three farmers interviewed used or use a pivot.

Figure 11: Underground pipe network irrigation infrastructure. From left to right: Raft (A), pumping station (B), underground pipes being installed (C), hydrant (D), pivot (E) (photos taken by Fabienne Frey in the area of SMP, 2022).

Other Irrigation Infrastructure

One farmer interviewed mentioned having used a self-invented irrigation system for some years, which was a combination of flood irrigation and aerial pipes. The other farmers did not use any other irrigation infrastructure.

5.2.3 Relation to Land Consolidation and Administrative Procedure

Formerly, both study sites experienced a land consolidation between 1960 and 1975. Farmers reported that some areas were consolidated before the arrival of the reservoir water and other areas were left 10 to 15 years without a consolidation after the arrival. According to interview partners, the consolidations were carried out to increase parcel size and join properties, as well as implement new ditches and paths. The first land consolidations were hence irrigation-related because they allowed for a more efficient flood irrigation. Simultaneously, they served to increase the overall efficiency of agricultural practices according to interview statements.

In SMP, second land consolidations started to take place from 2005 onwards. As an obligatory precondition for the establishment of the UPN, these consolidations are tied to a change in irrigation. Parcel size is further increased, properties are joined, small paths are eliminated, roads are widened, ditches are eliminated, and underground pipe infrastructure is installed. According to the member of the regional government interviewed, such a land consolidation is necessary to install the UPN, but also serves to further increase the efficiency of agricultural practices, as for example wider roads allow for bigger machinery.

The land consolidation with an UPN installation requires an approval by landowners in a general assembly. After a positive vote, irrigation communities place a request to the *Junta de Castilla y León* regional government, based on article *37 de la Ley 1/2014, de 19 de marzo* (Junta de Castilla y León, n.d.c). The request includes the submission of information on farm properties and extensions to the regional government, which needs to approve the start of the installation. Engineering companies are involved in the planning process. Between a positive vote and the finalized UPN, five to six years pass on average, as stated in interviews.

In the case study region, votes began to be held in the year 2000. In the irrigation community of SMP, the first vote turned out negative. In the second vote, two sectors approved of the land consolidation with the UPN installation. The other sectors followed in the next votes. In the area of SMI, multiple votes turned out negative. In 2018, the vote turned out positive for the side supplied by the *Barrios de Luna* reservoir and in 2021, the side supplied by the *Villameca* reservoir approved of the UPN. The former side is expected to be finished between 2023 and 2025, while the latter side is not expected to be finished before 2029.

5.2.4 Irrigation Practices

Ratio and Types of Irrigated Crops

Farmers interviewed talked of how their parents had rainfed vines and fewer irrigated hectares when watering only with wells. The arrival of the reservoir water led to an increase in the ratio of irrigated crops per farmer, as farmers started to irrigate all crops. Every farmer interviewed irrigated 100 percent of the crops since the start of their agricultural activity.

Formerly, flood-irrigated crops included beans, beetroot, wheat, potatoes, sunflower, and alfalfa. When aerial pipes were introduced from 1992 onwards, they were first used for beetroot, later for beans and potato. While some farmers began to use aerial pipes for corn, others kept irrigating corn by flood. Wheat kept being irrigated by flood in all cases, until the establishment of the UPN in SMP. With the UPN installed, farmers use sprinklers connected to aerial or underground pipes or a pivot to irrigate all types of crops cultivated, namely wheat, corn, barley, beans, sunflower, and potato (see chapter *5.4.1 Land Use* for further information on crops).

Irrigation Period

Farmers explained that the begin of the yearly irrigation period depends on spring weather and varies for different crops. On average, farmers start to irrigate cereal crops in April. If spring precipitation is not sufficient and reservoir water levels allow for it, farmers begin watering beetroot between March and May. The main irrigation period for the rest of crops lasts from June to September. The end of irrigation is again dependent on reservoir water availability and weather conditions but does not exceed mid-October. As stated by farmers, sprinkler irrigation allows to choose an earlier start than flood irrigation, but the irrigation period does not differ considerably between irrigation systems.

Irrigation Frequency

The frequency of irrigation depends on the irrigation system used. Irrigation by flood is organized in turns, so that each farmer gets to irrigate every 8 to 17 days, after the upstream neighbour. This frequency is dependent on the number of farms supplied in a whole turn, and on reservoir water availability. In dry years, a turn can take up to 20 days. At the beginning of a campaign, the irrigation frequency is generally higher than at the end of the campaign, due to decreasing water needs of crops.

Irrigating with aerial pipes without a connection to an UPN can theoretically be done at a self-chosen time point. However, this possibility depends on surplus water flowing through the ditches, which tends to be less frequent during dry years. On average, interview partners irrigate crops every 7 to 8 days with aerial pipes.

With the UPN installed, irrigation is organized in shifts. Every farmer can irrigate weekly. The irrigation community organizes the shifts, but farmers can decide over the amount of water spent in each shift.

Drainage

During the first land consolidations, drainages were implemented into the network of ditches to drain the water left over from flood irrigation. During the second land consolidation in SMP, drains have also been implemented. The drainage network turned out to be partly insufficient and hence three SMP-farmers reported to have further drained some parcels themselves. In SMI, no farmer has drained lands on his own up to the time point of the interview.

5.3 Perceived Driving Forces of Irrigation System Trajectories since 1990

Based on the interviews conducted, the perceived driving forces of irrigation system trajectories were categorized into political and institutional, economic, technological, cultural and personal, and natural and spatial driving forces. The temporal start of the driving forces analysed was set to 1990, to focus on the introduction of new systems and associated infrastructure. The introduction of flood irrigation lied outside the scope of the analysis because farmers interviewed were either not yet born or very young when the flood system was introduced. The first subchapter provides an overview of the categorized driving forces differentiated into spatial scales. In the subsequent chapters, the driving forces of each category are grouped thematically and elaborated on. Driving forces for study site differences of irrigation trajectories are then presented, before an overview of intercategorial relations and the involvement of actors synthesizes this chapter.

5.3.1 Categorial and Spatial Overview of Driving Forces

For the driving forces analysis, the irrigation development was also differentiated into the landscape level water distribution and the on-farm irrigation, as explained in the previous chapter. The following Table 6 shows the driving forces on the landscape level, hence concerning the underground pipe network (UPN). Table 7 focuses on the driving forces of on-farm infrastructure. Both tables display the categories the driving forces were attributed to and the spatial scales at which these driving forces operate.

Table 6: Overview of categorized driving forces of the underground pipe network (UPN) establishment, differentiated into spatial scales.

Underground Pipe Network (UPN)					
	National (Spain) and international	**Regional (Castilla y León)**	**Landscape (study perimeters)**		**Individual/ farm level**
			SMI	**SMP**	
Political and institutional driving forces	– Agricultural policies – Environmental activism – International contracts – Financial incentives	– Agricultural policies – Rural development – Transformation of the agricultural sector – Financial incentives – Information campaigns	– Irrigation community structure – Merging of irrigation communities – Personal disputes – Individual action – Pandemic – Land ownership	– Irrigation community structure – Land ownership	– Land ownership
Economic driving forces		– Water use efficiency – Crop diversification – Market growth and commer-cialization – Interests of agro-industrial companies	– Irrigation costs – Interests of agro-industrial companies	– Irrigation costs	– Water use efficiency – Land value – Crop diversification – Productivity – Investment rentability – Irrigation costs – Farm size – Parcel size
Technological driving forces				– Irrigation infrastructure age	
Cultural and personal driving forces			– Population age structure – Neighbourhood effect	– Population age structure – Irrigation history – Neighbourhood effect	– Motivation to move forward – Motivation to save resources – Skepsis towards the new – Mentality – Work comfort and quality of life – Interprofessional exchange
Natural and spatial driving forces	– Climate change	– Droughts	– Water availability – Extent of irrigated area	– Farm location – Extent of irrigated area	

Table 7: Overview of categorized driving forces of on-farm irrigation infrastructure, differentiated into spatial scales.

On-farm Irrigation Infrastructure

	National (Spain) and international	Regional (Castilla y León)	Landscape (study perimeters)		Individual/ farm level
			SMI	SMP	
Political and institutional driving forces	– Financial incentives – Agricultural policies	– Financial incentives			– Land ownership
Economic driving forces		– Interests of agro-industrial companies		– Farm size	– Water use efficiency – Productivity – Irrigation costs – Optimization of crop conditions
Technological driving forces					– Irrigation system characteristics – Irrigation infrastruc-ture availability
Cultural and personal driving forces				– Neighbour-hood effect	– Work comfort and quality of life – Interprofessional exchange – Decrease in family help
Natural and spatial driving forces				– Farm topography	– Farm topography – Soil characteristics

5.3.2 Political and Institutional Driving Forces

Agricultural Policies, International Contracts, and Environmental Activism

Members of the regional government and irrigation unions talked about water management policies to prevent water losses. The UPN was mentioned as being indispensable to prevent water losses, because the new system is supposed to save up to 30 percent of water compared to flood irrigation. The ambitions to prevent water losses are inter alia driven by an international contract, according to which Spain needs to let a fixed amount of water pass through to Portugal. This contract was said to increase the need for an efficient reservoir water management, especially in dry years.

Farmers noticed these water management ambitions, as for example SMP05 stated: “Well, the rules, what they tell us is that (...) what we have always been told is that we must save water. That water must be optimized (...) optimize and save as much as possible […]”. For an efficient water use, the UPN establishment was “almost obligatory” (SMP01). In this context, farmers also used phrases such as “we have been forced” (SMP01), “They [irrigation works] have to be imposed, vertically” (SMP02) or “you had no choice” (SMP01) to describe governmental water management policies.

Once an UPN is established, flood irrigation infrastructure is removed. Farmers can followingly not irrigate by flood anymore and therefore said to be obliged to irrigate by sprinkling. According to farmers, environmental activists preventing the construction of additional reservoirs increased the need to prevent water losses by replacing flood irrigation.

The agricultural department of the regional government furthermore aims for a reduction of contamination by pesticides and fertilizers. According to interview statements, a reduction can be achieved with an UPN, as flood irrigation is associated with higher infiltration of fertilizers and pesticides.

Rural Development and Transformation of the Agricultural Sector

Fostering rural development and preventing emigration from the countryside are further goals of the regional agricultural department, as stated by RG01. The establishment of an UPN is viewed as a measure to achieve these two goals. The regional government and the irrigation community in SMI also aim at transforming the agricultural sector in Castilla y León towards more horticultural production. For the horticultural production to be profitable, an UPN is perceived indispensable. In the words of IU01: “without modernization (...) it does not go anywhere”.

Institutional Collaboration, Information Campaigns, and Financial Incentives

The driving forces group of institutional collaboration, information campaigns, and financial incentives can be viewed as actions undertaken related to driving forces rather than driving forces per se. This group is presented separately nonetheless because these actions seemed to have notably influenced farmers, and because motivations that lay behind these actions were not specifically mentioned in interviews. Motivations that may have influenced actors to pursue institutional collaboration, information campaigns, and financial incentives were presented in the previous two groups of driving forces.

At both study sites, the regional government collaborated with irrigation communities and irrigation companies to convince farmers of the UPN. Informative talks were held in villages, because according to IC01 “[…] the modernization process requires good communication with farmers. There is a part that is psychological, because you have to convince them […]”. The effort was successful, as RG01 recounts: “[…] little by little, changing the mentality of the farmers, this [the UPN establishment] began to bear fruit.”

The Spanish national government, the regional government of Castilla y León, irrigation companies, and banks also started to provide funds, loans, and special tariffs for farmers to foster the UPN establishment. The financial support was higher at the beginning than for the following projects. At the time of the interviews, the financial scheme for the UPN establishment was divided as follows: The regional government provided 26%, irrigators paid 24%, and the *SEIASA* irrigation company provided 50% of the costs. Funds of the rural development program of the European Union contributed to the latter 50%. Half of these 50% were provided without any return, the other half needs to be paid back by irrigators over 50 years. To a smaller extent, funds and subsidies were also provided in the 1990s for aerial pipes.

Land Ownership

Farmers do not own all the agricultural land they work (see chapter *5.1.3 Farm-level Actors*), but all landowners vote on the establishment of the UPN, including non-agricultural landowners. The project needs to be approved by the majority of owners (see chapter *5.2.3 Relation to Land Consolidation and Administrative Procedure*). According to irrigation union members, irrigation community members, and farmers interviewed, non-agricultural landowners are often not willing to invest in irrigation infrastructure, as they for example live outside the countryside and do not see the necessity for change. Non-agricultural landowners therefore tended to reject the project at both study sites and delay a positive vote in the communities.

Land ownership was not only found to influence the large-scale network, but also on-farm irrigation infrastructure. Once underground pipes have been installed up to the farms, as in the case of SMP, some landowners decided not to install on-farm underground pipes, for the above-mentioned reasons. In these cases, farmers need to continue to irrigate with aerial pipes on their rented farms.

5.3.3 Economic Driving Forces

Optimization of Crop Conditions and Water Use Efficiency

From 1992 onwards, farmers introduced aerial pipes to prevent fruits from rotting due to standing water in the land. Farmers also mentioned having introduced aerial pipes as sprinkler irrigation implies less evaporation and is more water efficient than flood irrigation.

Farmers, irrigation community members, and the interviewee of the regional government mentioned to favour the establishment of an UPN to further increase water use efficiency. With the remotely controlled system, irrigation can be better adjusted to the water need of crops than with the fixed flood irrigation cycle. An UPN allows having water at disposal when a crop needs it, which can also reduce the water stress of a crop according to interview statements.

Productivity, Crop Diversification, and Land Value

In accordance with the goal to optimize crop conditions, farmers were motivated to introduce aerial pipes for increased productivity. They successively bought more pipes as production increases were notable, in comparison to fields irrigated by flood.

A further productivity increase can be achieved through the connection of farms to the UPN, as for example IU01 stated: “[…] what is clear (...) is the increases in production with modernization, nobody doubts that." Production increases were mentioned by seven farmers as driving forces for irrigation system changes. In this context, the option for crop diversification was also named by a farmer and the interviewees of the regional government and the irrigation union as an advantage of the UPN compared to flood irrigation. A farmer furthermore mentioned the increase in land value through an UPN, which motivated his approval of the new system.

Farm and Parcel Size

As illustrated in chapter *5.1.3 Farm-level Actors*, farm size increased since farmers started working in agriculture. According to IC03 and farmers, farm size increase contributed to the change from negative to positive votes to establish an UPN, as this system allows to irrigate a larger area. The establishment of the UPN then allowed farmers in SMP to further increase farm size, as SMP05 stated: "[…] now since we have automated irrigation and all this, because there I also saw another pull, because irrigation in those conditions allows you to work more hectares […]".

Farmers also mentioned the joining of properties in the scope of the land consolidation as a reason to approve of the UPN. A fragmentation of farms is associated with higher production costs than larger parcels joined at the same location, as explained by RG01.

Market Growth and Commercialization

The regional government and irrigation union members mentioned the aim to increase the competitiveness of the agricultural sector in Castilla y León. To achieve this aim, the establishment of an UPN is seen as indispensable, and the associated land consolidation was also mentioned to increase farm viability: "We do not modernize if it is not concentrated. Why? Well, because what we want to do are farms which are as viable as possible, in surface, having the least number of farms possible, of the largest area, trying to concentrate by farms […]" (RG01).

Farmers noticed governmental economic interests, in relation to an expansion of the irrigated area enabled through an UPN establishment: "[…] I say it was kind of a trap. Put the sprinklers, we give you subsidies so that you put sprinkler, but all with an interest, which we realized later, with the aim of expanding irrigation" (SMP03). "[…] why do they put those 5000 hectares more? It is not that you have to feed people, no, it is that those 5000 hectares more (...) produce a lot of money." (SMI 02).

Interests of Agro-industrial Companies

As mentioned by a farmer and IU01, interests of irrigation companies influenced the introduction of aerial pipes, considering that the companies put in notable effort to sell the pipes to farmers.

Irrigation companies such as *SEIASA* also took part in informative talks to convince farmers of the UPN and they provided funds for its establishment. Furthermore, agro-industrial companies were said to be interested in a future UPN establishment in SMI. As IU01 stated, an increase in vegetable production in the region would be of interest for the companies, to decrease the number of refrigerated transports and imports from the south of Spain.

Irrigation Costs and Investment Rentability

Farmers at both study sites rejected the UPN establishment at first due to its high costs and due to doubts on investment rentability. Once these doubts had been overcome in SMP (see chapter *5.3.5 Cultural and Personal Driving Forces*), irrigation costs continued to influence the project realization. The high costs of the UPN establishment led to a sector-wise project realization in SMP, because funds could not be provided simultaneously for the whole irrigation community. Money was still mentioned as a limiting factor for the vote approval in SMI, additionally in relation to rising electricity expenses. The communities in SMI that have approved of the UPN need to wait for funds being available, hence irrigation infrastructure costs can also lead to delays of project realizations.

Eight of ten farmers mentioned irrigation costs influencing their on-farm infrastructure decisions. When aerial pipes were first introduced, farmers only used them for certain crops, as the purchase of the pipes was more expensive than irrigating by flood. Furthermore, farmers mentioned that not all farmers could or can afford an engine that is needed for the use of aerial pipes. High diesel costs, as for example in the year 2021, have influenced farmers in SMI to punctually reduce the ratio of aerial pipes used. The costs of a pivot prevented some farmers in SMP from buying one. As previously mentioned, the costs of underground pipes can prevent non-agricultural landowners from installing them on farms.

5.3.4 Technological Driving Forces

Irrigation Infrastructure Age and Availability

The availability of new infrastructure fostered the introduction of aerial pipes. Farmers stated that they bought the first aluminium tubes and diesel-powered pumps when they became available.

In the irrigation community of SMP, the establishment of the UPN began where flood irrigation infrastructure was the oldest. At locations within the community where ditches were new, irrigators saw less of a necessity for an UPN. Farmers who were then connected to the UPN said to prefer the new technology of on-farm underground pipes operated by phone rather than connecting their aerial pipes to the hydrant.

Irrigation System Characteristics

Characteristics of irrigation systems were mentioned by farmers to influence their decisions about on-farm infrastructure. Farmers first introduced aerial pipes because the pipes allow for a more homogenous water distribution than flood irrigation. After the UPN establishment, some farmers in SMP introduced a pivot because it is easy to move, not sensitive to wind, and can be less of an obstacle than pipelines. Farmers with a circular pivot in SMP still use a small percentage of aerial pipes to cover the corners that the pivot cannot reach. Other farmers decided against a pivot due to its high maintenance compared to underground pipes.

5.3.5 Cultural and Personal Driving Forces

Population Age Structure, Mentality, and Skepsis towards the New

According to the SMI irrigation community member, the conservative mindset of people in the countryside contributed to the resistance towards the UPN. As mentioned by the interviewee of the regional government, changing the mentality of farmers was a big challenge. Farmers, especially of older age, were sceptical towards the new system, as affirmed in interviews by farmers themselves. The doubts concerned the unknown and its rentability. According to RG01, when more young people began to be incorporated into agriculture in SMP, a change in mentality started. The younger farmers were said to be riskier and more willing to invest money, while farmers close to retirement were less willing to invest.

Interprofessional Exchange and Neighbourhood Effect

Seeing other farmers irrigating with aerial pipes encouraged farmers interviewed to introduce aerial pipes themselves. SMP02 stated that "[…] in other places they already existed, then you were realizing that you could improve your situation".

This neighbourhood effect also occurred with the establishment of the UPN. Farmers in SMP overcame their doubts regarding the investment amortization by talking to irrigators in the nearby Páramo Bajo, which already had the network established. Farmers in SMI later became aware of the UPN benefits in the Páramo. The exchange with other farmers further helped interviewees with decisions about on-farm irrigation infrastructure, as whether to install a pivot or underground pipes after the UPN establishment.

Motivation to Move Forward and to Save Resources

Amongst the reasons for the UPN approval, farmers mentioned the motivation to move forward, seeing the system as an advance. The wish to leave something behind for future generations was mentioned as well in this context. A farmer furthermore perceived water as a scarce commodity that must be taken care of through the UPN.

Decrease in Family Help, Work Comfort and Quality of Life

Farmers talked of flood irrigation's high labour-intensity. Irrigating by flood not only requires physical effort but is also costly in time, including irrigations during night-time. According to IU01, "[…] the farmers who (...) who irrigate by foot, those are slaves. They are slaves. The irrigation seasons arrive and that, and there are people who walk like zombies […]". Farmers introduced aerial pipes to reduce work effort and gain quality of life, reporting that sprinkler irrigation is notably more comfortable than flood irrigation.

The same reasoning was identified for the following approval of the UPN and introduction of underground pipes or pivots on farms in SMP as "it is much more comfortable to have it buried than not (...) putting and removing it every year […] and then you also have the farm (...) when you go to work it, and to cultivate it, you have the farm all free" (SMP05). The decision for underground pipes was mentioned in combination with the decrease in the amount of family help. The yearly installation and removal of aerial pipes requires help and since working with less family members, farmers found underground pipes to be more convenient. Work comfort was mentioned by eight of ten farmers to motivate irrigation system changes.

Farmers in SMI additionally mentioned the increase in comfort through the land consolidation as a motivation for the UPN approval. The positive vote for the UPN of a SMI-farmer was furthermore motivated by the wish to gain independence in irrigation and decrease mental stress caused by flood irrigation.

5.3.6 Natural and Spatial Driving Forces

Farm Topography and Soil Characteristics

Farmers began to introduce aerial pipes on less levelled farms, while they kept the more levelled farms with flood irrigation. Soil characteristics also played a role in the introduction of aerial pipes on farms. As farmers stated, the compact type of soil turned out to be better supported by aerial pipes than by flood irrigation.

Droughts and Climate Change

According to farmers and irrigation communities, droughts accelerated the approval of the UPN at both study sites. In SMP, a change to a positive vote occurred after a year of drought, as a farmer recounted. While the farmers were not convinced of the necessity of the UPN beforehand, the water scarcity enhanced their willingness for a change. Climate change and the associated increasing water scarcity were then also mentioned as increasing the motivation to establish an UPN in SMI.

Farm Location

In the community of SMP, farm locations influenced the approval of the UPN and the sequence of project realizations. When irrigating by flood, farmers downstream are disadvantaged compared to farmers upstream. Hence farmers downstream already approved of the new system while farmers upstream still rejected it. Projects therefore also began to be carried out downstream.

5.3.7 Driving Forces for Differences between the Study Sites

The driving forces that were perceived to contribute to differences in irrigation trajectories between the two study sites are presented separately at this point. Since these driving forces are smaller in number than the driving forces in the previous chapters, they are not presented in thematic groups, but directly attributed to the study site differences. The driving forces are highlighted in bold.

Aerial Pipes (AP)

As displayed in chapter *5.2.2 Irrigation System Trajectories*, aerial pipes were introduced in SMP six years prior than in SMI. According to IC01, this time difference was related to **farm topography** and **farm size**. Because farms in SMP are generally less levelled, SMP-farmers stated that they saw the necessity to introduce aerial pipes earlier than farmers in SMI. Farms in SMP had already been larger than in SMI in the 1990s, hence the necessity for aerial pipes to attend the larger surface was said to have been more prevalent in SMP.

Underground Pipe Network (UPN)

The temporal difference of the UPN approval between the two study sites was for one attributed to the **irrigation history** of the SMP community. According to RG01, farmers in SMI had already been irrigating with the river, while the Páramo used to be one of the poorest regions in the province of León until the water from the *Barrios de Luna* reservoir became available in 1956. Subsequently, a move from subsistence economy to a larger-scale production of irrigated crops started and farmers in SMP experienced the benefits of irrigation changes, and therefore approved of the new system earlier. Furthermore, young farmers were successively incorporated into agriculture in SMP, but young people left SMI, resulting in an older **population age structure** and more resistance towards the UPN establishment, delaying the project realization in SMI.

While both study perimeters of this thesis are of the same size, their irrigated areas are managed by different irrigation communities. The irrigation communities differ in the total extent of the irrigated area they are responsible for. According to IC01, the spatial **extent of the irrigated area** belonging to the SMP irrigation community (17,000 hectares) facilitated the UPN establishment, while it was more difficult to obtain political support with the 128 irrigated hectares of the irrigation community in Santa María de la Isla. **Water availability** was also mentioned by IU01 to have contributed to study site differences. The side in SMI supplied by the *Villameca* reservoir encountered more difficulties to obtain financial support, due to its water capacity of 20 million cubic meters, compared to the 300 million cubic meters of the *Barrios de Luna* reservoir.

Not only these cultural and spatial driving forces mentioned, but also the **structure of irrigation communities** was said to play a role for the UPN establishment. According to IU01, the large size and number of personal resources of the SMP community facilitated the UPN establishment, while the smaller irrigation communities in SMI lacked personnel.

Further factors mentioned to have delayed the approval of the UPN in SMI are non-agricultural **land ownership** and **personal disputes**. According to SMI-farmer statements, owners of poplar plantations constantly voted against the UPN, since poplars do not need to be irrigated. The irrigation community member in SMI also talked of personal disputes with a counsellor who tried to impede the project. It was mentioned that the Covid-19 **pandemic** has further delayed the administrative procedure of the UPN projects.

The irrigation union member interviewed attributed the final approval in SMI to the effort of the irrigation community member in a leading position, which corresponds to the narration of the member himself: “Thanks to my career and the credibility that my person has, because I can say that very clearly and very loudly, because of that it went ahead.” (IC01). The person established “good relationships” (IC01) with people involved in the administrative process and initiated a study of the potential of an UPN in the SMI area. **Individual action** hence seemed to have played a role at the SMI study site. According to IC01, **merging the communities** in SMI in 2021 also contributed to the final UPN approval.

5.3.8 Intercategorial Relations and Involvement of Actors

Intercategorial relations between driving forces of irrigation trajectories were identified by the author based on the interview data previously presented. As Figure 12 displays, each category of driving forces is related to at least two other categories of driving forces. Cultural and personal driving forces and economic driving forces are related to all other four categories. Each driving forces group is related to at least one other driving forces group of a different category. This amount of intercategorial relations illustrates that a variety of driving forces have contributed to changes in irrigation at the study sites and indicates the complexity of interrelations. As Figure 12 furthermore illustrates, institutional actors are most involved with the political and institutional driving forces, while with the natural and spatial driving forces and the cultural and personal driving forces, farmers are the most prevalent type of actor. Economic driving forces played a role for all type of actors except for environmental organizations. Governmental entities and irrigation unions seem to be more involved with the UPN establishment than with on-farm infrastructure. Driving forces for on-farm infrastructure are mainly related to farmers.

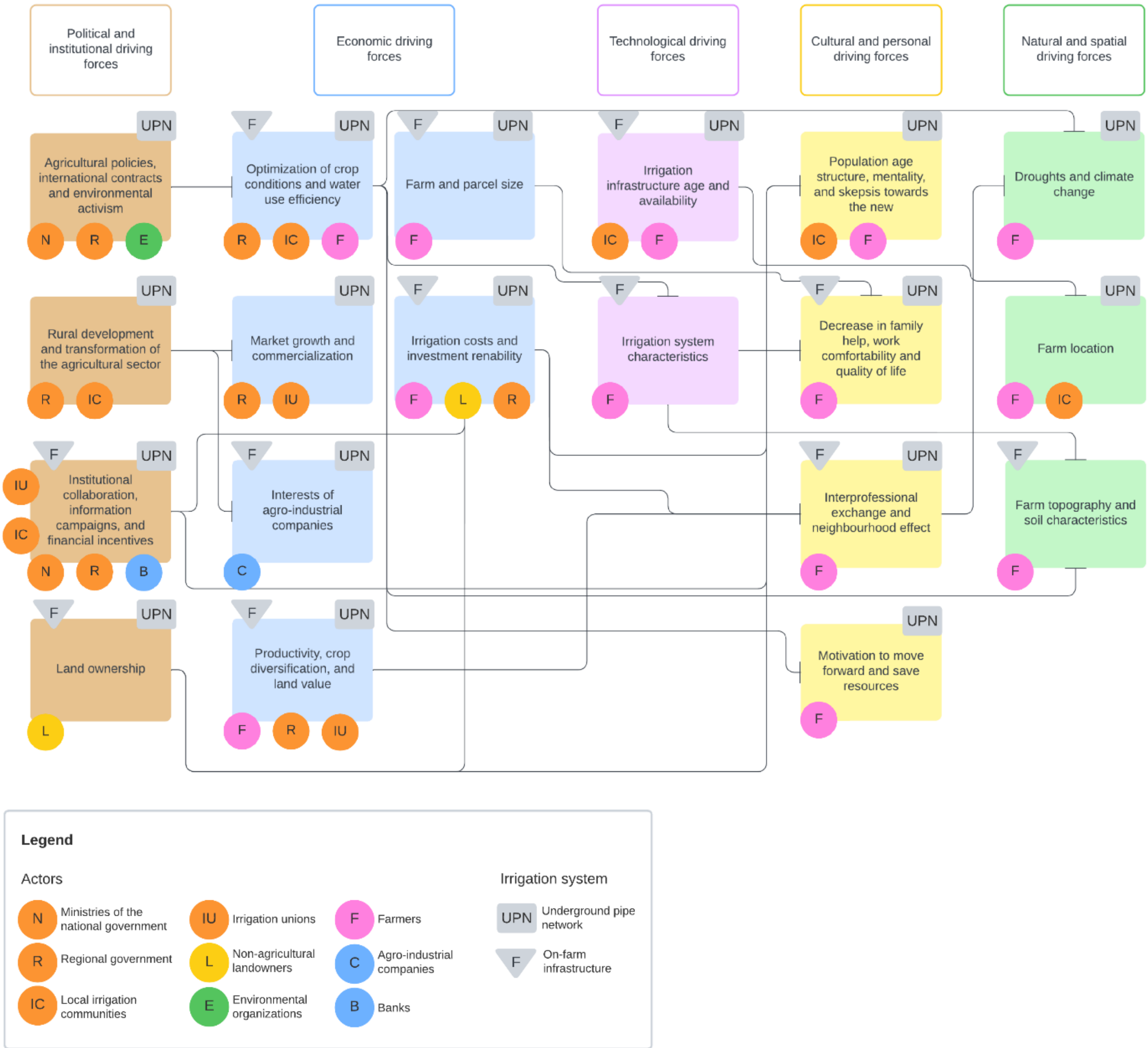

Figure 12: Intercategorial relations between thematic groups of irrigation trajectory driving forces and involvement of actors with the driving forces groups (own figure).

5.4 Landscape Changes and Relation to Irrigation System Trajectories

In this chapter, landscape changes at the study sites and their relation to the irrigation trajectories are presented. Landscape indicators presented include land use, landscape structures and elements, and vegetation greenness. The results of the aerial photograph and the satellite image analysis are combined with interview results concerning landscape changes. The last subchapter presents an overview over the main changes and their irrigation-relation.

5.4.1 Land Use

Land Use Types

Figure 13 shows the land use types at each study site in 2002 and 2017, classified according to the land use types of the SIPATH project. The number of hectares of each land use type is shown in Figure 14 and Table 8. The changes in land use are elaborated on below the figures and table.

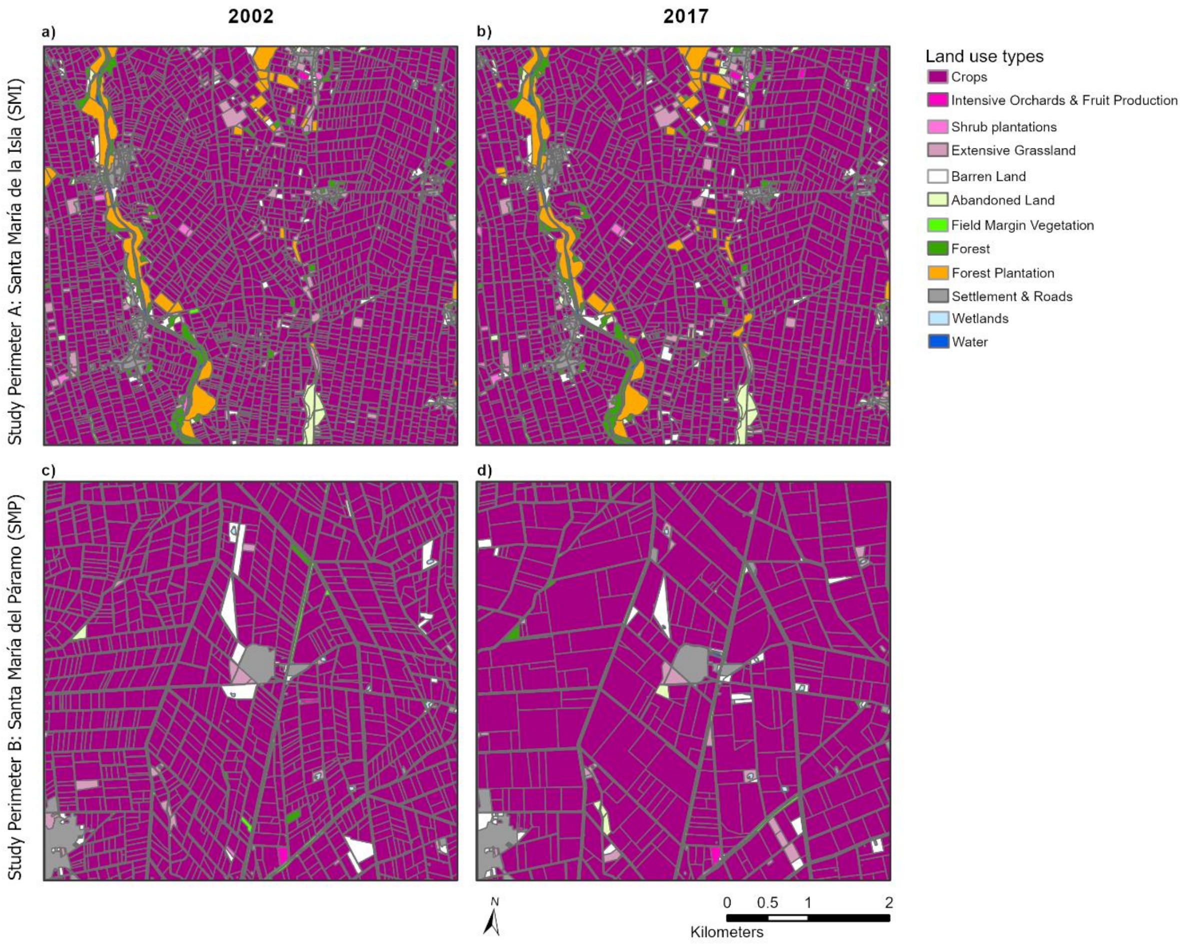

Figure 13: Land use types at both study perimeters in 2002 and 2017, categorized according to the SIPATH methodology. A study perimeter covers 25km². Maps a) and b) were created by the author, maps c) and d) were created by Samuel Hepner within the SIPATH project (own figure).

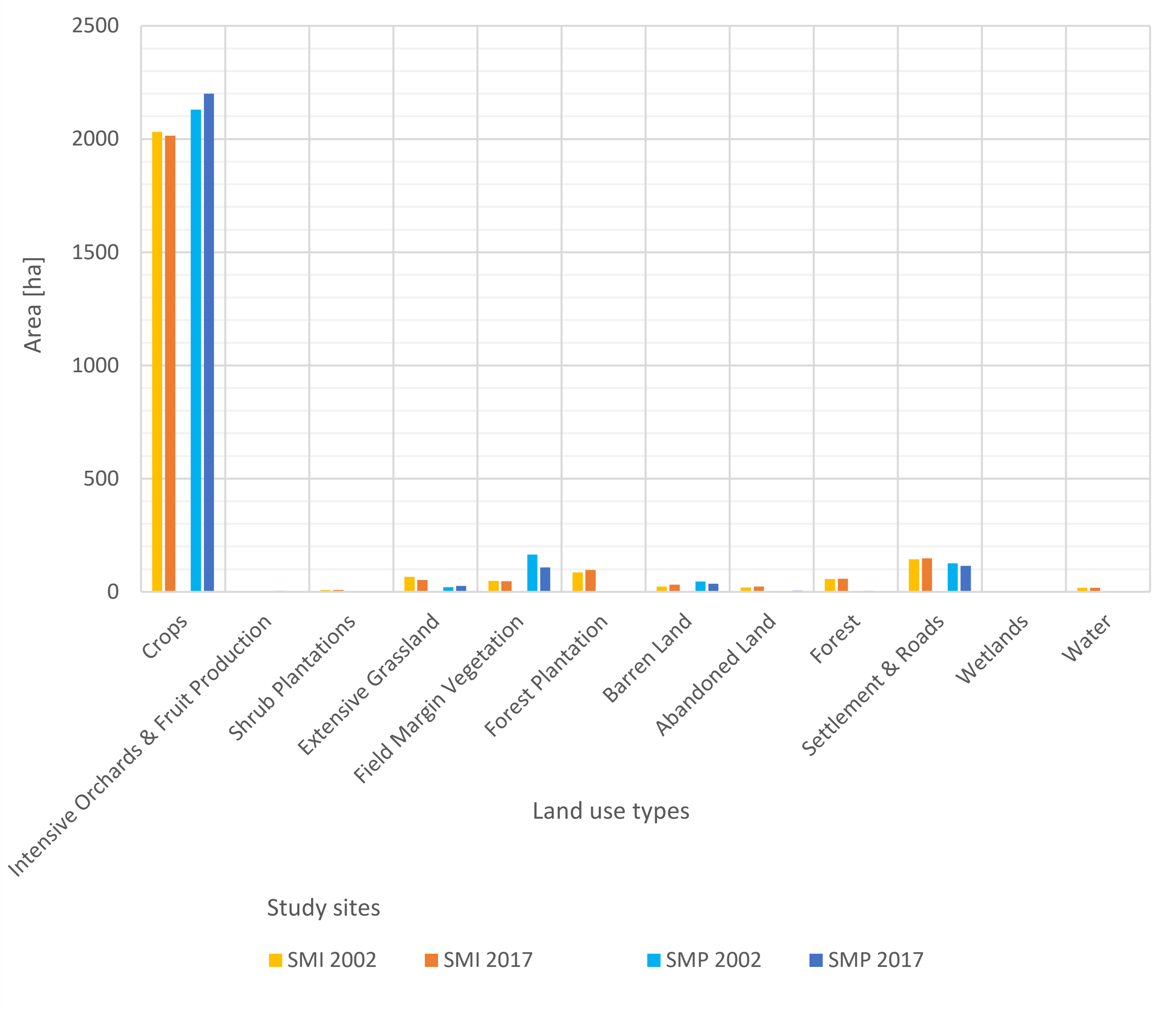

Figure 14: Area covered by each land use type at each study site in 2002 and 2017. The exact values are displayed in the table below. Land use was categorized according to the SIPATH classification (own figure).

Table 8: Area covered by each land use type (rounded to whole numbers) at each study site in 2002 and 2017.

Land use type	Area covered by land use type [ha]			
	Value SMI 2002	**Value SMI 2017**	**Value SMP 2002**	**Value SMP 2017**
Crops	2030	2014	2130	2201
Intensive Orchards & Fruit Production	1	3	3	2
Shrub Plantations	9	8	1	0
Extensive Grassland	66	53	19	25
Field Margin Vegetation	48	47	165	108
Forest Plantation	86	97	0	0
Barren Land	23	32	46	36
Abandoned Land	19	23	2	6
Forest	57	57	4	3
Settlement & Roads	143	148	125	115
Wetlands	0	0	3	2
Water	18	18	2	2

The dominance of crops at the two study sites in 2002 and 2017 is visible in both Figure 13 and Figure 14. Farmers interviewed cultivate all their land, except for the obligatory 5% fallow land. The area of crops is higher at the SMP study site, where it also increased over the 15 years between the time points of analysis, from 2130 to 2201 hectares (Table 8). As an irrigation community member explained, common areas that could not be irrigated by flood, due to soil type or orography, were transformed to irrigated crop land and incorporated into the UPN irrigation network.

Forest plantations are solely present at the SMI study site. The plantation area has increased from 86 hectares in 2002 to 97 hectares in 2017 (Table 8). According to SMI-farmer statements, these plantations consist of poplar trees. Farmers attributed the increase in poplar plantations to a rise in wood prices. Poplars are planted by the municipality and individuals who are mostly non-agricultural landowners. Worthwhile noting is that poplar trees are harvested approximately every 12 to 15 years, as explained in interviews. Hence the size of trees on these hectares varies over time to a greater extent than of the trees in the forest area. Forest area is also higher in SMI than in SMP (Figure 14). While forest covered 57 hectares at both time points in SMI, forest area in SMP covered 4 hectares in 2002 and 3 hectares in 2017 (Table 8). Most of the forest area in SMI is located in the riparian zone (Figure 13). The river passing through the SMI site possibly contributes to a higher surface water area in SMI (18 hectares) than in SMP (2 hectares). The aerial photograph analysis did not show a difference in surface water area between 2002 and 2017 at any study site.

Intensive orchards and fruit production covered between 1 and 3 hectares at both study sites in the years analysed (Table 8), hence forming a neglectable part of land use in the study perimeters. Further categories such as extensive grassland, shrub plantations, and abandoned land have been detected to a greater extent at the SMI study site. In accordance with the lower crop area and higher forest (plantation) area than in SMP, this indicates a more heterogenous land use at the SMI study site.

Field margin vegetation and barren land are more common in SMP, but showed a decrease, from 165 hectares to 108 hectares, and from 46 to 36 hectares (Table 8). Both decreases may be associated with the land consolidation tied to the UPN establishment, since plots were largened (see chapter *5.2.3 Relation to Land Consolidation and Administrative Procedure*), and the crop area was increased as described above. Wetlands were solely detected in SMP, decreasing from 3 to 2 hectares. Farmers interviewed and an environmental expert mentioned a removal of wetlands and lagoons during the second land consolidation in SMP.

Settlement and roads had already been more prevalent at the SMI site in 2002, with 143 hectares compared to 125 hectares in SMP (Table 8). In Figure 13, the greater surface covered by roads and paths in SMI is notable. The difference between study sites increased until 2017, as the area covered by settlement and roads decreased by 10 hectares in SMP. Since settlement clusters did not notably change (Figure 13), the decrease may be attributed to the elimination of paths in the scope of the land consolidation (see chapter *5.2.3 Relation to Land Consolidation and Administrative Procedure*). The aerial photograph analysis hence indicates that despite the widening of roads in the scope of the consolidation, the overall area taken up by roads and paths in SMP decreased.

Agricultural and Non-agricultural Land

To analyse the development of agricultural land use, land use types were split in two categories. The category of agricultural land includes crops, intensive orchards and fruit production, shrub plantations, extensive grassland, and field margin vegetation. The category of non-agricultural land consists of forest plantation, barren land, abandoned land, forest, settlement and roads, wetlands, and water. Figure 15 shows a study site comparison of the years 2002 and 2017. Each study perimeter includes 2500 hectares. Agricultural land visibly dominates over non-agricultural land at both study sites. The total agricultural area is higher in SMP, at both time points. It has increased from 2318 hectares to 2336 hectares, while the total agricultural area in SMI has decreased, from 2154 to 2125 hectares. The contributions of the individual land use types to these changes have been elaborated in the previous subchapter. Figure 15 furthermore indicates changes in field size over time, which are presented in more detail in the following subchapter.

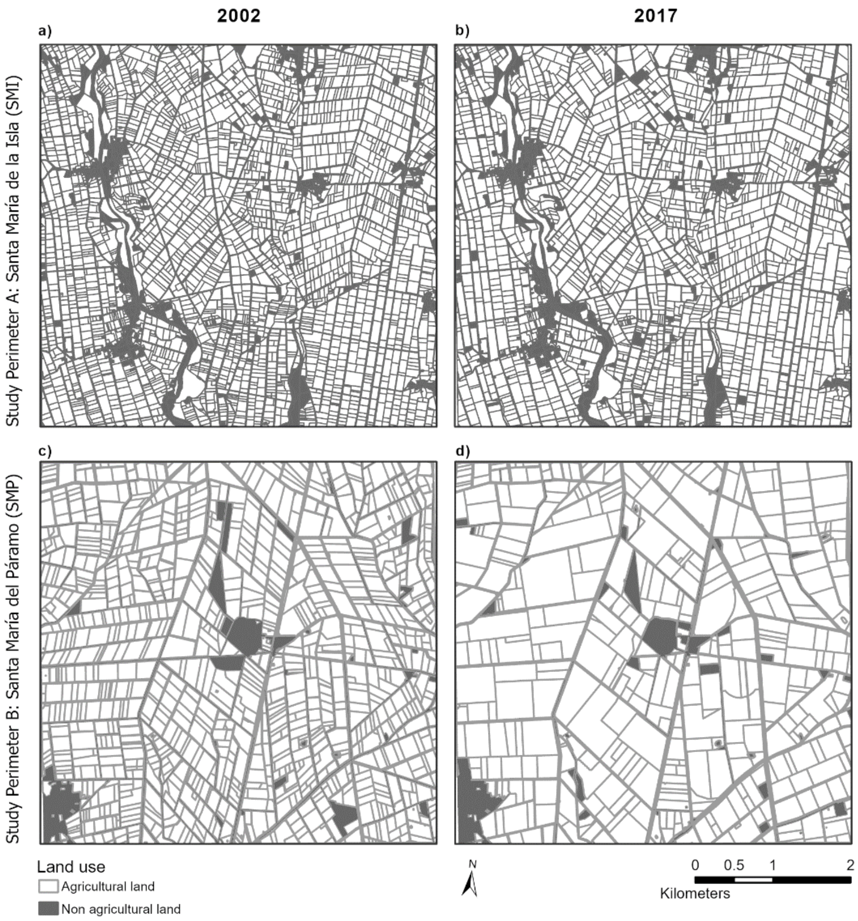

Figure 15: Agricultural and non-agricultural land use at both study perimeters in 2002 and 2017, categorized according to the SIPATH methodology. A study perimeter covers 25km². Maps a) and b) were created by the author, maps c) and d) were created by Samuel Hepner within the SIPATH project (own figure).

Field Size of Crops

Figure 16 displays the changes in field size of crops at the two study sites, with boxplots containing minimum, first quartile, median, third quartile, and maximum values. Field size has increased between 2002 and 2017 at both study sites, but to a greater extent in SMP. Whereas the median has increased from 0.65 hectares to 0.88 hectares in SMI, the median has risen from 1.69 to 4.27 hectares in SMP. Worthwhile mentioning is also the increase in maximum field size at the SMP study site, from 9.8 to 41.29 hectares. Interview statements confirmed the increases in field size and attributed them to the land consolidations, which started from 2005 onwards to install the UPN in SMP. A farmer in SMI reported that farmers in the area carried out minor land consolidations themselves by joining properties.

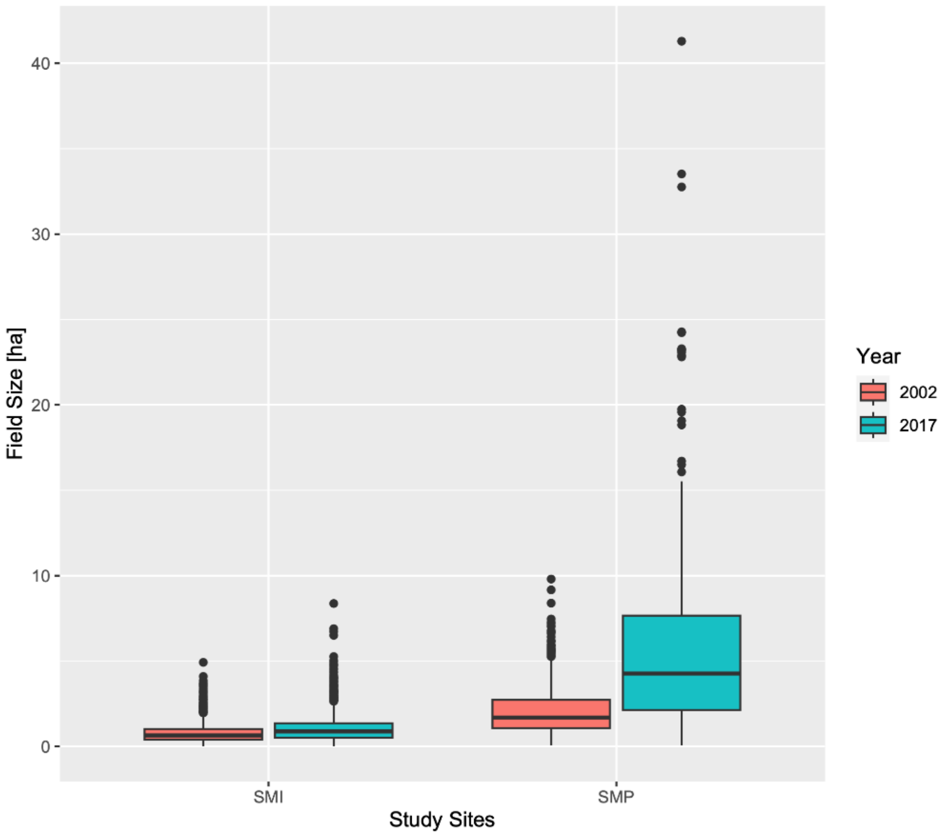

Figure 16: Boxplots of field size of crops at the SMI and SMP study sites in 2002 and 2017, based on aerial photograph analysis (own figure).

Crop Types

At the beginning of their working time in agriculture, all farmers in SMP had a rotation of beans, beetroot, and wheat. One SMP-farmer additionally planted few potatoes and sowed sunflowers. All SMI-farmers also sowed beetroot. Four of five farmers in SMI planted potatoes. As stated in interviews, potatoes were generally more common in the area of SMI than in SMP. Additionally, in SMI, two farmers sowed alfalfa while they still had livestock, two farmers sowed beans, one farmer sowed wheat, and one farmer still had vineyards at the beginning.

From 1990 onwards, farmers at both study sites began to cultivate corn, which subsequently became the main crop of farmers in SMP. At the time of the interviews, corn made up to 70% of a farmer's cultivated area in SMP, while the cultivation of beans, beetroot, and wheat has decreased, or even completely stopped in some cases. At the time of the interview or retirement, two farmers in SMP cultivated a small percentage of sunflower, barley, or potato. In SMI, corn also became popular, but potato still forms an important part of cultivation. Wheat, sunflower, barley, and beetroot are cultivated to a minor extent. One farmer sowed lettuce and spinach for some years.

The increase in corn cultivation was attributed to the work comfort, low production cost, and irrigation resistance of this crop type. SMI02 for example stated: "Well (...) because it is a relatively easy crop to manage (...) it is a crop that the first irrigation does not damage (...) later, even if some part is strained, it holds it quite well (...)". Additionally, farmers mentioned that corn does not need a crop rotation, which further increases its work comfort. The decrease in beetroot was mainly related to economic factors. As farmers and irrigation community members explained, beetroot used to be subsidized by the European Union, and sugar companies used to pay profitable prices. The prices started to fall from 2003 onwards, from 6.1 Euros to 3.7 Euros per 100 kg of beetroot in 2015 (CRCAV, 2019). As explained by farmers, beetroot requires more labour and production expenses than corn, and it is more prone to diseases, which additionally contributed to the decrease in beetroot sowed. Labour and flood irrigation effort needed for wheat and beans is also higher than for corn, hence farmers subsequently substituted these crops for corn. Farmers mentioned to sow more sunflower in years of water scarcity, as sunflower needs less irrigation water than other crops. According to interview statements, the importance of potatoes in the area of SMI is related to the prevalence of a potato cooperative in the area and is favoured by two factories that contract prices and therefore offer a certain security for farmers.

5.4.2 Landscape Structures and Elements

Irrigation Infrastructure

According to farmer statements, the number of wells at both study sites decreased since the arrival of the reservoir water. Wells lost their necessity and profitability. SMP03 for example explained: "But to irrigate a farm of 20, 30 hectares, no (...) no. A well is for irrigating two hectares. If you have to irrigate two hectares, it is not profitable to water it. Mostly because they became obsolete and because they did not give sustainability to irrigate a farm." Wells were also closed for safety reasons, as they inhibit the danger of people or animals falling into them. Furthermore, if not being used, wells were said to dry up and tend to sink. In the case of SMP, the second land consolidation led to additional closures, as wells coincided with underground pipes or were in the middle of the increased parcels.

Some wells were kept out of nostalgia or in the case of the SMI study site, as a backup during especially dry years. The closing of wells per se did not change the landscape according to farmers, but the removal and drying out of trees adjacent to former wells changed the landscape.

In the scope of the second land consolidation, pumping stations and rafts have been constructed at the SMP study site as described in chapter *5.2.2 Irrigation System Trajectories*, and most ditches were removed. At the SMI study site, no ditches had been removed at the time of the interviews.

Trees, Hedgerows, and Tree Lines

The amount of small and large trees and the length of hedgerows and tree lines analysed based on orthophotos are visualized in Figure 17. Table 9 displays the according numbers of both study sites in the years 2002 and 2017.

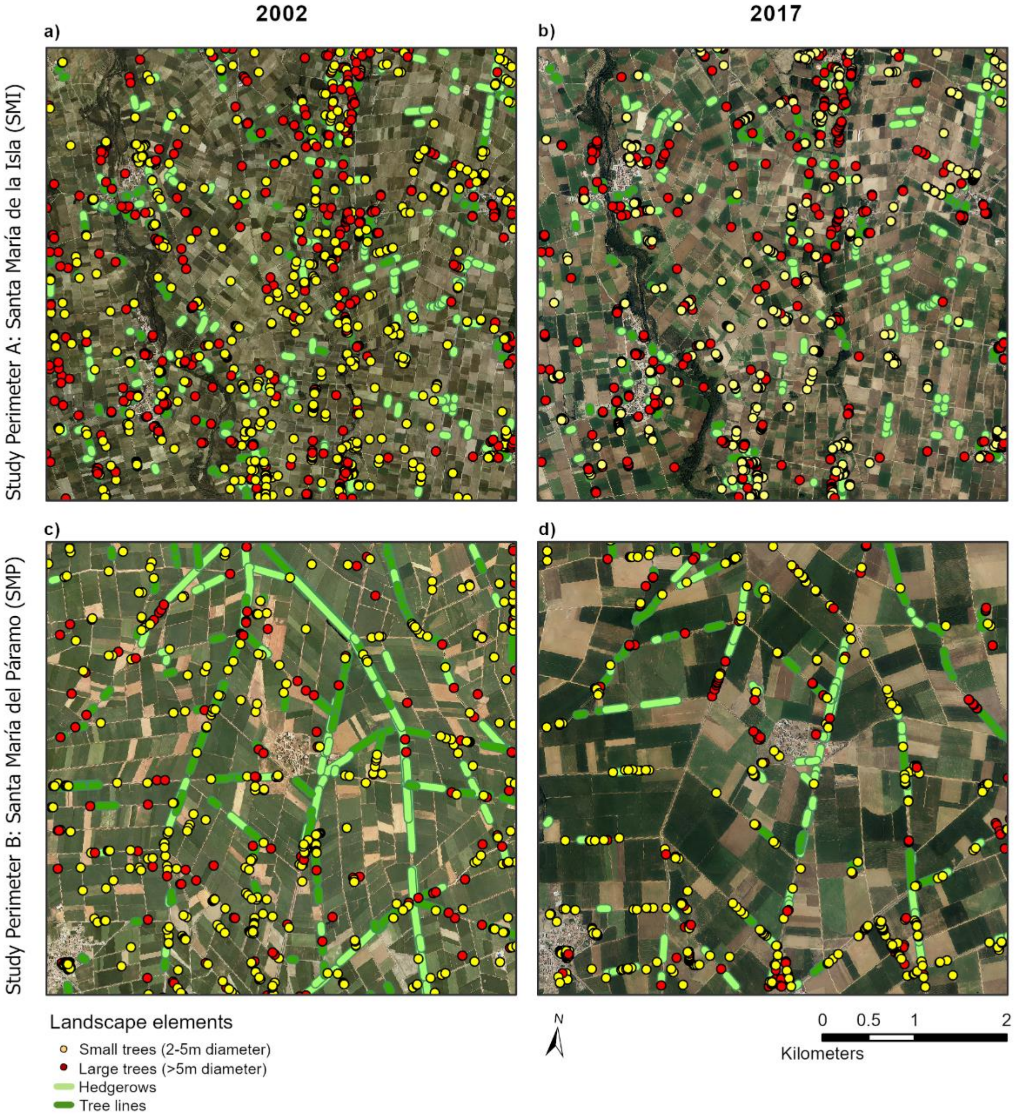

Figure 17: Small trees, large trees, hedgerows, and tree lines detected at both study perimeters in 2002 and 2017, categorized according to the SIPATH project. A study perimeter covers 25km². Maps a) and b) were created by the author, maps c) and d) were created by Samuel Hepner within the SIPATH project (own figure with orthophotos by Instituto Geográfico Nacional de España (IGN)).

Table 9: Number of small and large trees, length of hedgerows and tree lines detected at both study perimeters in 2002 and 2017, categorized according to the SIPATH project. Each study perimeter covers 25km².

Indicator	Explanation	Value SMI 2002	Value SMI 2017	Value SMP 2002	Value SMP 2017
Number of small trees	Total number of trees with a canopy diameter of 2-5m	600	540	391	344
Number of large trees	Total number of trees with a canopy diameter of >5m	453	408	116	107
Length of hedgerows	Total length of hedgerows (minimum length: 40m) [km]	6.7	7.8	17.5	7.7
Length of tree lines	Total length of tree lines (consist of at least 3 trees in a row) [km]	3.8	4.2	13.6	6.7

The number of small trees and large trees decreased in SMI and in SMP. A reason named for the removal of trees concerning both study sites is road safety. As stated by farmers and irrigation community members, trees along roads were removed to prevent car accidents. Farmers at both study sites also removed trees on their land, as either the roots of trees damaged irrigation ditches or hindered agricultural practices. As elaborated above, the removal of wells also contributed to a decrease in trees.

The number of trees was higher in SMI than in SMP at both time points. The initial difference between study sites could be related to field size, which was lower in SMI already in 2002 (see chapter *5.4.1 Land Use*), hence allowing for more individual trees between fields. Surprisingly, the length of hedgerows and tree lines was higher in SMP than in SMI in the year 2002. Based on the interviews conducted, this difference cannot be explained. However, the length of hedgerows and tree lines in SMP decreased until 2017. The decrease at the SMP study site was attributed to the second land consolidation, in the scope of which parcels were largened and trees were removed. SMP01 explained in this regard that “All the trees have also disappeared due to modernization, as the plots are large (...) to make the roads, everything was removed.” According to farmers interviewed, the hydrographic confederation subsequently prohibited to plant trees above underground pipes. Farmers in SMP also recounted that trees remaining along ditches had to be removed, as they started to dry out due to the absence of water in ditches after the UPN establishment.

Wild Animal Species

Farmers at both study sites reported changes in wild animal species since they started working in agriculture. Eight of ten farmers mentioned a decrease in the amount and diversity of species.

Farmers and an environmental expert interviewed attributed the disappearance of frogs, butterflies, and dragonflies in SMP to the absence of water in ditches and drains, and to the removal of flood irrigation infrastructure with the UPN establishment. Farmers in SMI also reported a decrease in frogs, butterflies, and dragonflies, and explained it by pesticides being increasingly applied. Furthermore, different bird species (e.g., crests, bustards, crested larks, chickadees, kestrels, jackdaws, swifts, swallows, warblers), moles, mice, crabs, fish, grasshoppers, and crickets have been decreasingly seen by farmers at both study sites. These disappearances were attributed to the increasing absence of breeding areas with the expansion in cultivated area and parcel size, the removal of trees, and to the increase in pesticides applied. According to EE03, crickets have disappeared due to the increase in corn fields.

An augmentation in other types of birds (finches, storks, magpies), flocks, rabbits, roe deer, and wild boar was mentioned by farmers. The appearance of wild boar and roe deer was related to a decrease of vegetation and increase in pastureland abandonment in the mountains, and to the increase in corn crops sowed by farmers. According to interview statements, these animals started to descend from the mountain area to feed on corn.

5.4.3 Vegetation Greenness

Figure 18 shows a 7-year period of monthly NDVI means before the establishment of the UPN (1995 to 2001), Figure 19 shows a 7-year period after the UPN establishment in SMP (2015 to 2021). Satellite image availability was lower during the earlier period displayed, especially for the SMI site, leading to data gaps for some winter months (Figure 18).

Between June and September of each year, both study sites show peaks in NDVI. NDVI values are lower in the remaining months of the year. Because the NDVI is sensitive to plant growth (see chapter *4.2 Selection of Categories and Indicators*) and crops are the main land use type at both study perimeters (see chapter *5.4.1 Land Use*), this pattern is assumed to be related to irrigated agricultural land use. As interview partners explained, irrigation begins in April and the main irrigation period lasts from June to September. Crops are therefore most dense and green during summer months, which could have contributed to the NDVI peaks. Harvest is finished in October, possibly contributing to drops in NDVI.

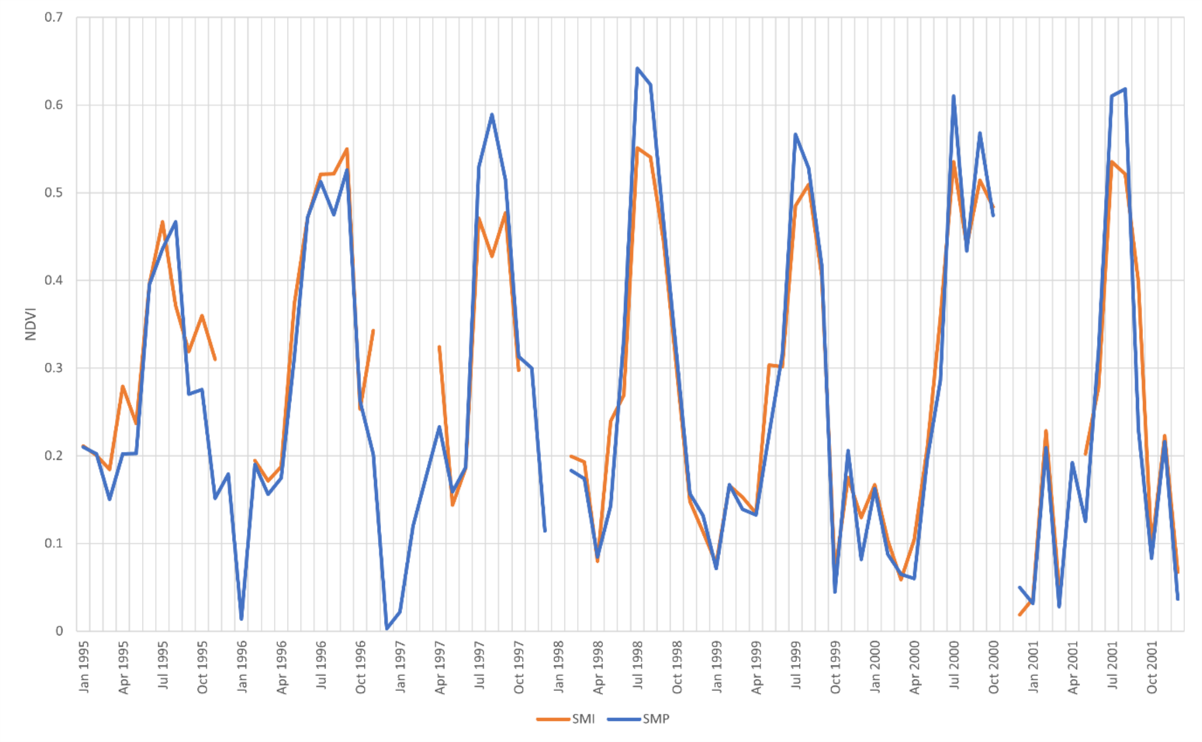

Figure 18: Monthly mean of NDVI at both study perimeters, from 1995 to 2001. Mean values available are displayed for each month, the x-axis is labelled with every third month for better chart readability (own figure).

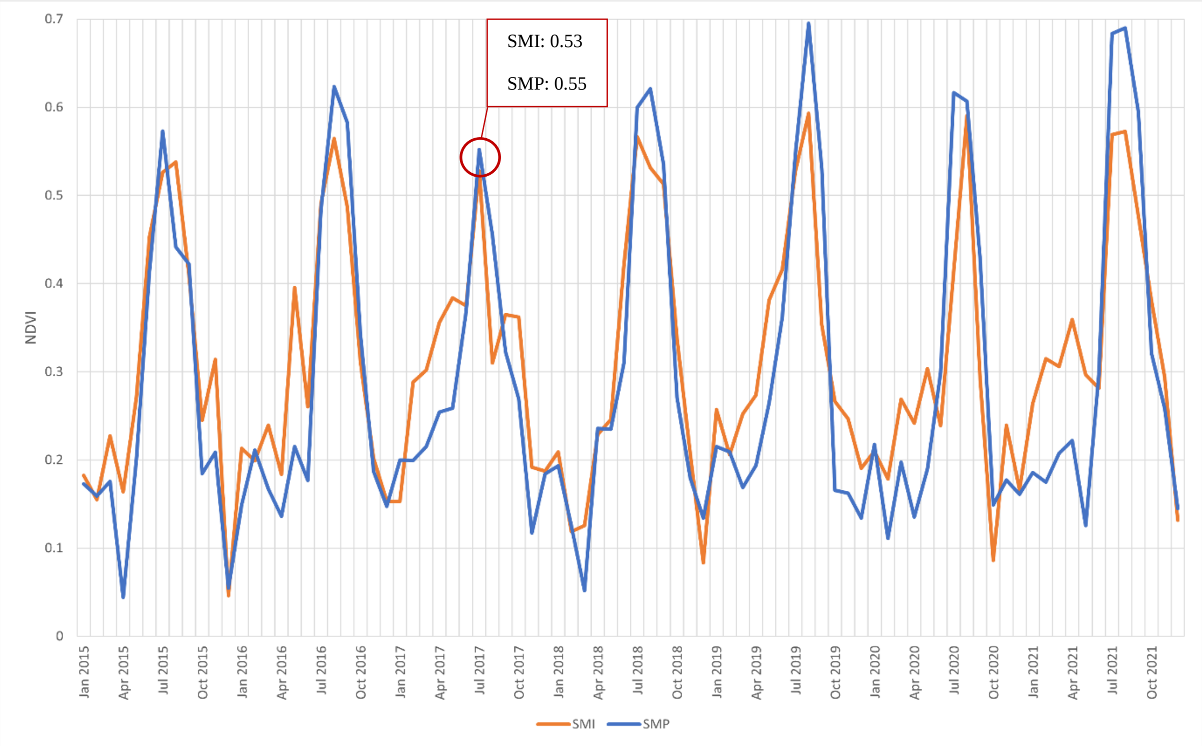

Figure 19: Monthly mean of NDVI at both study perimeters, from 2015 to 2021. Mean values available are displayed for each month, the x-axis is labelled with every third month for better chart readability. The peak summer values of July 2017 are highlighted (own figure).

Regarding study site differences, higher peaks can be observed during summer months in SMP than in SMI, for both periods of time (Figure 18 and Figure 19). Between 1995 and 2001, the NDVI mean over the main irrigation period (June to September) is 0.44 in SMI and 0.46 in SMP. Between 2015 and 2021, the mean in SMI is 0.45 and 0.49 in SMP. The study site difference in summer peaks is therefore higher during the second period displayed, mainly due to peak increases in SMP. The differences of summer means between study sites are statistically not significant, with p-values higher than 0.05 for both periods of time. Long-term NDVI averages from 1995 to 2021 over the main irrigation period are 0.46 for the SMP study site, and 0.44 for the SMI study site. Possible explanations for the study site differences are discussed in chapter *6.3 Irrigation-related Landscape Changes*. Data gaps for the SMI study site during winter months in the first period impede the comparability, but winter months generally show similar patterns between study sites. The greater homogeneity of the patterns may be due to both study sites having fallow lands during winter, and due to the dependence on rain instead of irrigation water, also considering that the two study sites are located close to each other.

A year to be pointed out in the second period displayed is 2017, because the province of León experienced slight drought conditions in 2017 according to the classification by the *Junta de Castilla y León* (MACL, 2021). NDVI summer means between 2015 and 2021 are also the lowest in 2017 (Figure 19), with the smallest NDVI peak difference between study sites (0.02) in this period. The drought conditions hence seem to be evident in the NDVI values of both study sites.

5.4.4 Relation of Main Landscape Changes to Irrigation

Based on the results on landscape changes previously presented, Table 10 provides an overview over the main changes and their irrigation-relation. Only changes with a discernible increasing or decreasing trend identified were included in the table. The changes are discussed in chapter *6.3 Irrigation-related Landscape Changes*.

Table 10: Trends of landscape changes and relation to irrigation, including declaration of data sources.

Landscape changes				**Study site**		**Irrigation-relation**	
Category	**Indicator**	**Trend**	**Data source**	**SMI**	**SMP**	**Identified**	**Data source**
Land use	Crop area [ha]	↗	Aerial photos, interviews		×	Yes	Interviews
	Forest plantation area [ha]	↗	Aerial photos, interviews	×		No	Interviews
	Field margin vegetation area [ha]	↘	Aerial photos		×	Yes	Author estimation
	Wetland area [ha]	↘	Aerial photos, interviews		×	Yes	Interviews
	Area covered by roads and paths [ha]	↘	Aerial photos, interviews		×	Yes	Interviews
	Field size of crops [ha]	↗	Aerial photos, interviews		×	Yes	Interviews
	Corn cultivation	↗	Interviews	×	×	Yes	Interviews
Landscape structures & elements	Number of wells	↘	Interviews	×	×	Yes	Interviews
	Number of ditches	↘	Interviews		×	Yes	Interviews
	Number of trees	↘	Aerial photos, interviews	×	×	Yes	Interviews

5.5 Sustainability Outcomes of Aerial Pipes and the Underground Pipe Network

Based on the interviews conducted and data provided by interview partners, environmental, social, and economic sustainability outcomes of aerial pipes (AP) and the underground pipe network (UPN) were rated by the author as presented in tables for each sustainability dimension in the following sub-chapters. Table 11 displays the colour key for the rating of sustainability outcomes. If answers of interview partners were contradictory, the outcome was marked as contested in the tables. Below each table, the information used for the rating is elaborated on, organized in themes and with indicators highlighted in bold. The initial indicator set with indicators surpassing the scope of the thesis can be viewed in annex *A: Sustainability Indicator Set*.

Table 11: Colour key for the rating of sustainability outcomes.

	No data available/ data not sufficient for rating
	No indication of outcome through irrigation system
	Indication of slight positive outcome through irrigation system
	Indication of positive outcome through irrigation system
	Indication of slight negative outcome through irrigation system
	Indication of negative outcome through irrigation system

5.5.1 Environmental Sustainability Outcomes

Table 12: Overview of environmental sustainability outcomes of aerial pipes (AP) and the underground pipe network (UPN), including the scale of assessment and contested outcomes.

Theme	Indicator	Assessment scale	Outcome AP	Outcome UPN	Contested outcome
Water	Irrigation water consumption	Regional			
	Irrigation water consumption	Community			
	Water use efficiency	Farm			
Agrochemical products	Application of fertilizers	Farm			Yes
	Application of pesticides	Farm			
Soil and Land	Salinization of soils	Farm			
	Land degradation	Farm			Yes
	Extension in irrigated area	Landscape			
Energy	Energy consumption for irrigation	Farm			
Biodiversity	Diversity in wild animal species	Landscape			Yes
	Habitat loss and fragmentation	Farm & Landscape			
	Quantity of wetlands	Landscape			

Water

The *Sindicato Central del Embalse de los Barrios de Luna* provided data of its yearly irrigation water consumption from 2001 to 2022 (Figure 20). Variations between years are visible, without any detectable trend. Members of the irrigation union and irrigation communities explained that the annual water quantity consumed for irrigation depends on the amount of water available in a reservoir, and that the variations between years are related to climatic conditions, not to irrigation systems. In years of drought, the final reserve may even be lowered by the hydrographic confederation, allowing to empty the reservoir further than in other years, to secure irrigations. On the regional level, the new irrigation systems therefore seem to not have influenced the **annual water consumption**.

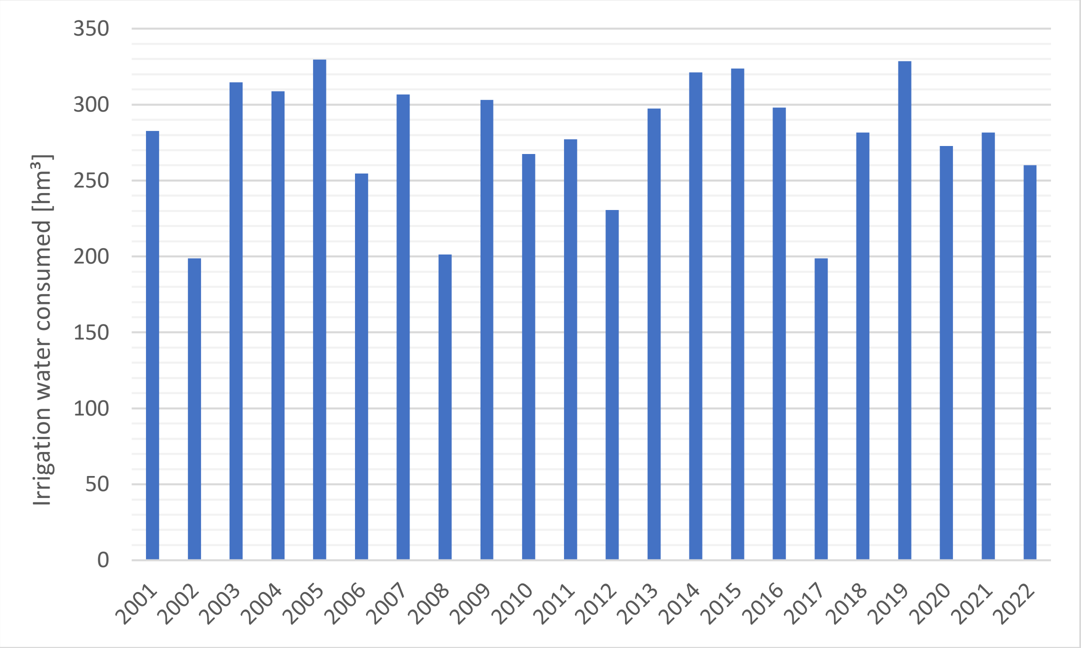

Figure 20: Irrigation water consumed in irrigation communities supplied by the Barrios de Luna reservoir from 2001 to 2022. Data provided by the Sindicato Central del Embalse de los Barrios de Luna (own figure).

The size of a reservoir in proportion to the irrigation area supplied influences the amount of water available for an irrigation community. As stated in interviews, communities supplied by the smaller *Villameca* reservoir could irrigate with 2500 cubic meters per hectare in 2022, while communities supplied by the larger *Barrios de Luna* could irrigate with 5000 cubic meters per hectare. If supplied by the same reservoir, farmers who irrigate without an UPN and farmers connected to an UPN approximately receive the same amount of water per irrigation campaign. However, according to IC02, the UPN establishment has led to an overall reduction in water consumption in the community of SMP.

Accordingly, some farmers connected to an UPN reported a reduction of irrigation water consumed compared to the time they used to irrigate by flood. As explained by irrigation communities and environmental experts, the reduction in water consumption on farm level is related to the higher **water use**

efficiency of sprinklers compared to flood irrigation. According to the interviewees, a first water use efficiency increase occurred with the introduction of aerial pipes. The sprinklers connected to aerial pipes are the same as the sprinklers connected to underground pipes. However, aerial pipes are not used on more than 50 percent of irrigated fields (see chapter *5.2.2 Irrigation System Trajectories*), while all fields can be irrigated with sprinklers once an UPN is established. The UPN establishment hence led to a further increase in water use efficiency. According to RG01 and SMP03, the increase was by 20 to 30 percent.

Agrochemical Products

The amount of mineral **fertilizers** applied generally increased since farmers interviewed started working in agriculture, to foster productions and because manure ceased being used. According to interview partners of the irrigation union and communities, the application of fertilizers decreases with the transition from flood to sprinkler irrigation, as absorption by plants increases and filtration of products applied decreases. While farmers in SMI reported not having decreased doses, farmers in SMP reported having decreased doses since the UPN establishment. EE03 believes that while sprinkler irrigation theoretically allows to lower doses, the amount of fertilizer applied does not decrease in practice. Fertilizer prices were mentioned by farmers to also influence the amount they apply.

When they started working in agriculture, farmers interviewed did not use herbicides, fungicides, or insecticides. Weeds were removed manually. Product applications started when **pesticides** (including insecticides, herbicides, and fungicides) became available, if farmers could afford them. The amount applied increased over time according to some farmers, others reported applying less than before. No relation to irrigation systems was mentioned.

Soil and Land

Seven farmers talked of punctual areas where **salinization** issues impede crop production. These issues have existed since farmers started working in agriculture. Farmers mentioned that with irrigation, the issues improve, as the salt is washed down to the subsoil, and they mentioned that salinization is more prevalent during dry years. Changes in irrigation systems were not mentioned to influence the extent of salinization.

When asked about **land degradation**, farmers reported not having encountered any issues. Environmental experts returned to talk about agrochemicals. EE02 mentioned a possible decrease in land degradation with sprinkler irrigation compared to flood irrigation, due to higher fertilizer plant absorptions. This statement was supported by RG01, who especially attributed a land degradation improvement to the UPN, since this system implies sprinkler irrigation on a larger scale than the irrigation with aerial pipes without a connection to an UPN. According to EE01, the amount of pesticides applied is more decisive over land degradation than the irrigation system used. EE01 mentioned that land degradation increases with an extension in irrigated area.

The *Sindicato Central del Embalse de los Barrios de Luna* provided data of the irrigated area supplied by the reservoir, which shows an increase in hectares from 2013 onwards (Figure 21). The **extension in irrigated area** may have been caused by the UPN establishment, as suggested by interview data illustrated in chapter *5.4.1 Land Use*. Regarding the extension in irrigated area, IU01 highlighted a differentiation: In areas that are irrigated already prior to an UPN, such as the two study sites, the increase in extension of the irrigated area is minor. If areas are transformed from rainfed to irrigated in the scope of an UPN establishment, as for example in the nearby Payuelos region, the extension is of greater scale.

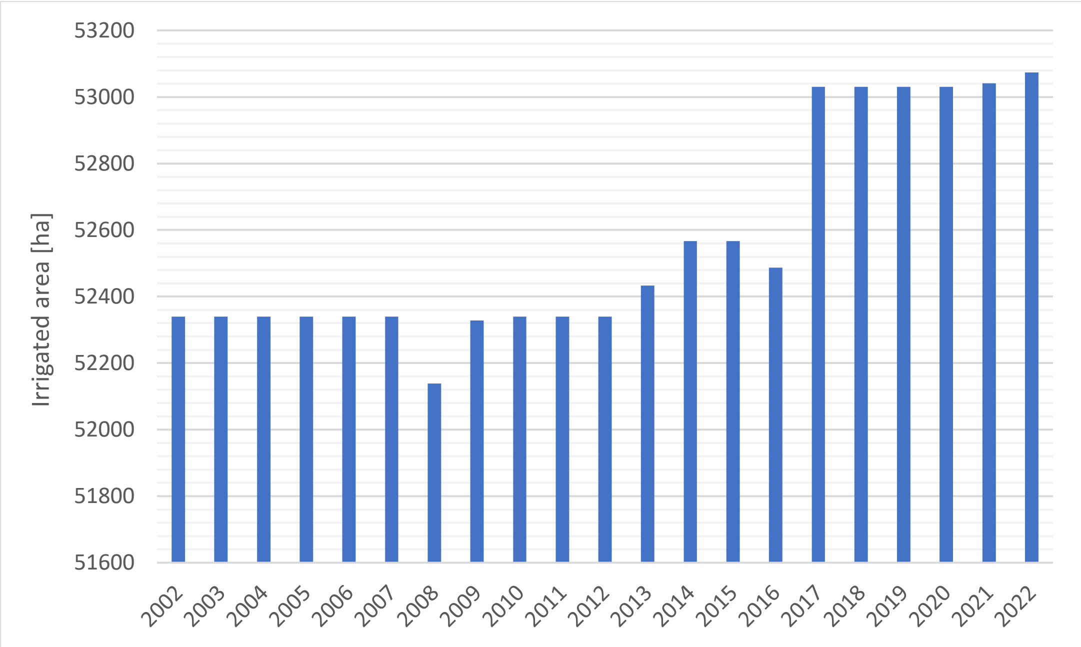

Figure 21: Irrigated area supplied by the Barrios de Luna reservoir from 2002 to 2022. Data provided by the Sindicato Central del Embalse de los Barrios de Luna (own figure).

Energy

The outcome of irrigation systems on **energy consumption** cannot be estimated because no data that covers the period of interest could be provided by interview partners. Furthermore, a comparison was impeded because aerial pipes without an UPN are fuelled by diesel, while the energy source of the UPN is electricity.

Biodiversity

As elaborated in chapter *5.4.2 Landscape Structures and Elements*, a decrease in certain wild animal species was attributed to the UPN establishment. Other species were mentioned to have increased. Since no specific quantitative data could be provided and due to the contested answers regarding **species diversity**, the indicator is not rated.

However, environmental experts unisonously related the UPN establishment and its land consolidation to biodiversity losses, as **habitat loss and fragmentation** occur through the removal of trees or ditches and the increase in parcel size in the scope of the UPN establishment. The absence of surface water with the UPN was also mentioned to negatively impact flora and fauna.

According to farmers and an environmental expert, **wetlands** were removed during the land consolidation for the UPN establishment.

5.5.2 Social Sustainability Outcomes

Table 13: Overview of social sustainability outcomes of aerial pipes (AP) and the underground pipe network (UPN), including the scale of assessment and contested outcomes.

Theme	Indicator	Assessment scale	Outcome AP	Outcome UPN	Contested outcome
Population dynamics	Emigration	Community			
Good governance	Accountability of authorities	Regional & community			
	Participation	Farm			
	Conflict management	Community			
	Fairness of water allocation	Farm & community			
	Organizational efficiency	Community			
Social commitment	Water conflicts	Farm & community			
	Sense of community	Farm & community			
Equity	Perceived income distribution	Farm & community			
Food security	Food security of farm households	Farm			
Farmer's well-being	Occupational well-being	Farm			
	Working hours	Farm			Yes
	Occupational stress	Farm			Yes

Population Dynamics

The *Comunidad de Regantes del Bajo Tuerto* irrigation community provided population data. Figure 22 shows that the municipalities of the *Comunidad de Regantes del Bajo Tuerto*, which were without an UPN at the time of the interview and of which the SMI study site forms part of, constantly decreased in population after 1990. Meanwhile, the population stayed stable in Santa María del Páramo. RG01 stated that the establishment of the UPN has been central for the prevention of emigration from the Páramo region, and a farmer also mentioned that people tend to stay in the countryside where UPNs are established. The UPN establishment therefore seems to have the potential to prevent **emigration**.

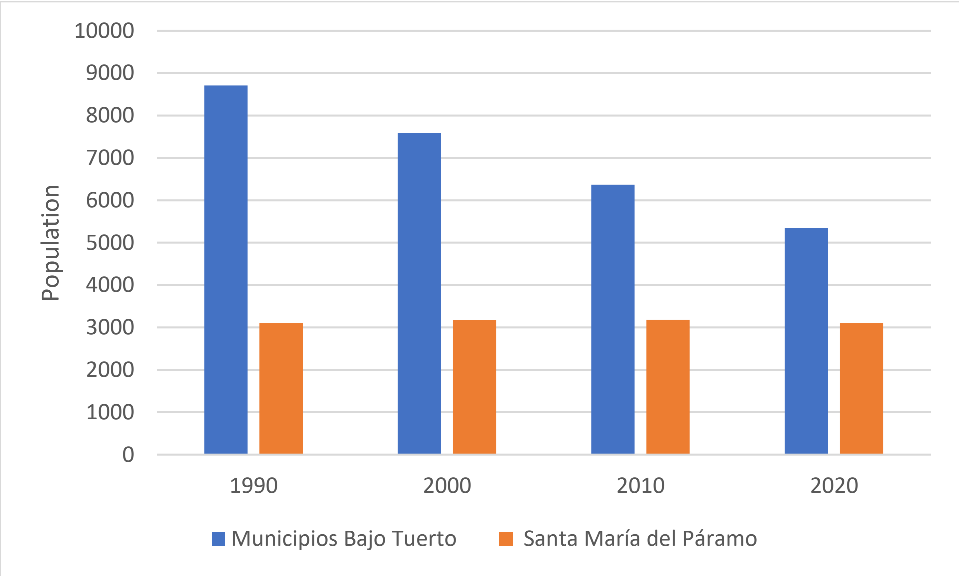

Figure 22: Population of the Municipios Bajo Tuerto, to which SMI belongs, and Santa María del Páramo from 1990 to 2020 (own figure, data source: CRBT (2021)).

Good Governance

According to irrigation community members, local authorities such as town and city councils are not much involved in the topic of irrigation. Farmers mentioned the importance of leading positions in irrigation communities being occupied by farmers, to secure their interests. This is the case at both study sites. While interview partners of the irrigation union talked positively about the water management of the confederation, some farmers expressed complaints about the confederation prioritising economic interests over the needs of farmers. Concerning the establishment of the UPN, irrigation communities and farmers mentioned the inefficiency of authorities to respond to their requests. It was also mentioned that individuals in positions with decision power can impede collaboration and hinder the UPN project realization. The **accountability of authorities** therefore seems to have a slight negative outcome with the UPN, while no influence regarding AP was noted.

According to farmers' statements, farmers can participate in decisions about water management to a minor extent, independently of irrigation systems. The main decision power lies with members in leading positions of irrigation communities and with the hydrographic confederation. According to farmers, this has not changed over the years. **Participation** consists of irrigators being able to vote on issues proportionally to their irrigated farm area, as for example concerning the UPN establishment. Farmers interviewed rated this system as fair and stated that they would not like to participate more. Dealing with conflicts and satisfying the needs of all stakeholders were mentioned as reasons for the satisfaction with a low participation. However, wishes for more transparency were expressed.

According to the interview partners of both irrigation communities, conflicts around water are managed by the irrigation communities themselves, irrigation unions, or on a larger scale by the tribunal of irrigators. Hence formal institutions for **conflict management** exist independently of the type of irrigation system used.

Farmers and irrigation community members interviewed described the **fairness of water allocation** to be higher for the UPN than for irrigation without an UPN. Each farmer is allocated the same amount of water with the UPN, while farmers downstream are disadvantaged regarding water quantity compared to farmers upstream if there is no UPN, despite paying the same annual contribution. Furthermore, if there is no UPN, aerial pipes can only be used on farms adjacent to ditches. The use of AP therefore depends on farm location and the water is not equally allocated, as explained by farmers.

Two employees of the irrigation community in SMP mentioned that the UPN has facilitated the work of the irrigation community and improved its **organizational efficiency**, as for example water quantities can be better managed.

Social Commitment

Farmers talked about **water conflicts** when irrigating by flood, which for example led to manipulating each other's shifts or not notifying the subsequent farmer. Good relationships were said to be important for flood irrigation, particularly to communicate the start and end of irrigation shifts. As farmers in SMP and IC03 stated, the quality of relationships between farmers loses its importance with the establishment of an UPN, as dependence between farmers is reduced. Conflicts around water were accordingly mentioned to have reduced with the UPN. In the words of SMP04: "It used to be more complicated. […] Now there is no problem, because you have your water supply, you have your rain, you have everything, and you do not have to depend on anyone. […] But before yes, there were many problems. There was some (...) some fighting."

However, farmers at both study sites experienced a decrease in solidarity, communication, and collaboration since they started working in agriculture. Farmers mentioned to have become more individualistic with the increase in farm size and machines. Hence **sense of community** seems to have decreased independently of irrigation systems.

Equity

Compared to people not working in agriculture, some interviewed farmers did not notice a change in the purchasing power of farmers, some could not give an estimation, and some farmers noted an improvement since they started working in agriculture. No relations of the **perceived income distribution** to irrigation systems were mentioned.

Food Security

No farmer interviewed but one encountered difficulty with **food security**. The farmer did not relate it to irrigation. Some farmers recounted punctual difficulties with harvests, droughts, or low market prices, but these were balanced out in the following years and not mentioned to be related to specific irrigation systems.

Farmer's Well-being

Farmers at both study sites noted an increase in **occupational well-being** with the introduction of aerial pipes. Farmers in SMP reported a further increase in well-being with the UPN establishment. SMP02 described the change as follows: "From crawling to being a man. It was a change, come on, great. Much better. […]. And from flood to aerial pipe, it was a big change but even bigger from aerial to underground." SMP02 wished that the UPN was established 40 years ago and SMP03 described the UPN as the "ideal" irrigation system. Farmers in SMI expressed their wish for an UPN. SMI03 for example stated: "Well, I always tell my wife, that the worst of my profession is irrigation. It's the hardest thing, you don't depend on yourself, you depend on other people, many things, that's why you want them to concentrate, to modernize (...) because I see, I have friends who already have the modernization and their life is much easier. In fact, when we start the work that is in the summer, they are more relaxed."

Accordingly, with the establishment of the UPN, farmers in SMP reported a decrease in **working hours** and a change in working time, not having to irrigate during the night anymore. Since farmers started working in agriculture, working hours also decreased independently of irrigation changes, through a reduction in manual work and an increase in the use of machines and agrochemicals. These aspects were also mentioned to have contributed to increased possibilities for vacations and greater occupational well-being, at both study sites. However, SMI04 and SMI03 mentioned that their increase in farm size impeded a reduction in net working hours. Furthermore, farmers from both study sites mentioned that rather than the net working hours, the type of work changed notably since they started working in agriculture. The change from physical to machinery work was not perceived as positive by all farmers.

Farmers experienced **occupational stress** independently of irrigation systems due to weather conditions, low reservoir water levels, subsidies, and product price variations. Stress related to water allocation prior to an UPN was also mentioned: "[…] when you do not get water, when your plants, when your farm needs water and it does not reach you because (...) it has been poorly distributed or because (...) the irrigation has started late, because the organization has been poorly planned (...) you see your farms that need water, that you are losing production, because it does not reach you and I do not get to (...) that is (...) for those who love this work […] that is very very stressful. I struggle with my heart because of that, I tell you." (SMP03). SMP04 furthermore stated about flood irrigation: "So, I always (...) and when it was by the foot, I no longer slept two days or three days before, I no longer slept." However, one SMP-farmer stated that he feels less free in his decisions concerning sowing practices since the UPN: "They tell you, if you don't sow this (...) you have to sow this, this and this, because you have so many liters of water. You can no longer sow what you want. You have to sow what they give you to water. There is no more. You are no longer totally free as when we watered by the foot, you are limited" (SMP03). Besides this farmer, all farmers stated that irrigation stress disappeared with the UPN, while farmers without an UPN mentioned to still experience irrigation stress.

5.5.3 Economic Sustainability Outcomes

Table 14: Overview of economic sustainability outcomes of aerial pipes (AP) and the underground pipe network (UPN), including the scale of assessment and contested outcomes.

Theme	Indicator	Assessment scale	Outcome AP	Outcome UPN	Contested outcome
Vulnerability and risk minimization	Bargaining power	Farm			
	Vulnerability to climate change	Farm			Yes
	Risk minimizing strategies	Farm			
Self-reliance	Subsidies	Farm			
Revenue and costs	Crop yield	Farm			
	Irrigation expenses	Farm			
	Net farm income	Farm			Yes

Vulnerability and Risk Minimization

Some farmers said that formerly, they could negotiate about prices. Others never negotiated. At the time of the interviews, farmers stated that they cannot negotiate about the prices anymore. **Bargaining power** therefore seems to have decreased, but no relation to irrigation systems was mentioned.

Farmers stated that they periodically feel vulnerable to climate change, which is the case during dry years. While some farmers have always felt vulnerable to climate change, some SMP-farmers perceived **their vulnerability to climate change** to have decreased with the UPN, as this system provides them with an increased security in terms of water quantities.

The UPN allows farmers to adapt the distribution of irrigation water on plots during dry years. Farmers explained that they can for example choose to irrigate 50 hectares with a sufficient water quantity instead of 100 hectares with an insufficient water quantity. **Risk minimizing strategies** independent of irrigation systems were also mentioned to be adapted during years of drought, such as changing crop types or postponing farm investments.

Self-reliance

For the introduction of aerial pipes, farmers could receive **subsidies**. Subsidies were also provided for the establishment of the UPN and associated on-farm irrigation installations. Farmers were hence financially supported in the case of both irrigation systems. With the previous flood irrigation, they were totally self-reliant.

Revenue and Costs

The introduction of aerial pipes led to an increase in **crop yield**. According to SMP03 and SMI05, the increase was by 25 to 30 percent, compared to flood irrigation. A further yield increase was related to the UPN, as farmers mentioned. RG01 also stated: “Productions are increased tremendously, to the point that for example a hectare of corn in an unmodernized area gives you 11 thousand, 12 thousand kilos per hectare. In a modernized area it reaches 16 thousand.” This corresponds to an increase by 33 to 45 percent. The changes in irrigation systems led to increased productions through higher water and fertilizer use efficiency, as explained in interviews. According to farmers, changes in seeds and farm size also contributed to increased productions.

All members of irrigation communities pay an annual contribution that has not changed significantly since farmers started working in agriculture. However, in addition to the annual contribution, farmers began to have expenses for new irrigation infrastructure and its use. Aerial pipes were mentioned to be costly for some farmers, and SMI-farmers have noted the increase in diesel costs. Communities with an UPN have additional expenses for its establishment and followingly for its electricity supply. Furthermore, as stated by irrigation community members, the price of electricity has significantly increased. **Irrigation expenses** have therefore increased with both irrigation systems, but to a greater extent with the UPN.

Related to increased irrigation expenses, **net farm income** has decreased despite higher yields according to some farmers. Market prices were also mentioned to have influenced farm incomes. Other farmers could not give an estimation on changes in net income and some farmers reported an increase in income. The relation of irrigation systems to net farm income can hence not be determined in the scope of this sustainability assessment.

5.5.4 Stakeholder Perspectives on Sustainability Outcomes

The assessment of stakeholder perspectives concerns all sustainability indicators of the previous chapter that outcomes related to irrigation systems were identified for. Interview questions guided the indicators discussed, so Table 15 shows which indicators stakeholders were directly asked questions about. The interviews with the members of the regional government and irrigation union were for example focused on drivers of irrigation trajectories and hence sustainability outcomes were not addressed in the interview questions. Table 15 furthermore provides an overview of which indicators stakeholder groups provided information for, and which outcomes they expressed their opinion about.

Table 15: Prevalence of sustainability indicators that irrigation-related outcomes were identified for in stakeholder interviews. A=Interviewees were directly asked about an indicator. I=Interviewees provided information on outcome. O=Interviewees expressed their opinion on the outcome discussed.

Theme	Indicator	Regional government	Irrigation union	Irrigation community	Farmers	Environmental experts
Water	Irrigation water consumption		I, O	A, I, O	A, I	A, I, O
	Water use efficiency	I, O		I	A, I	I, O
Agrochemical products	Application of fertilizers	I, O	A, I	A, I, O	A, I	A, I
Soil and land	Land degradation	A, I, O			A, I	A, I
	Extension in irrigated area		A, I	I	O	I, O
Biodiversity	Habitat loss and fragmentation					I, O
Population dynamics	Emigration	I		I	I	
Good governance	Accountability of authorities			A, I, O	A, I, O	
	Fairness of water allocation			A, I, O	A, I, O	
	Organizational efficiency			I, O		
	Water conflicts			A, I, O	I, O	
Farmer's well-being	Occupational well-being	I, O		I, O	A, I, O	
	Working hours				A, I, O	I, O
	Occupational stress				A, I, O	
Vulnerability and risk minimization	Vulnerability to climate change			I, O	A, I, O	
	Risk minimizing strategies				A, I, O	
Self-reliance	Subsidies	A, I, O		A, I	A, I, O	
Revenue and costs	Crop yield	I, O		I	A, I, O	O
	Irrigation expenses			A, I, O	A, I, O	

Interview partners of the irrigation communities, farmers, and environmental experts were furthermore asked about the sustainability of irrigation systems and about possibilities to move towards more sustainability. Their answers are presented in the following, together with elaborations on opinions of stakeholder groups on sustainability outcomes as indicated in Table 15.

Environmental Experts

Environmental experts did not rate a specific irrigation system to be the most sustainable. They rather talked about negative outcomes such as rebound effects of an increased water use efficiency and positive outcomes such as the increased ability to control water use with the UPN. Furthermore, criteria to consider regarding the sustainability of irrigation were discussed. EE02 and EE01 highlighted the importance of water availability in relation to the sustainability of irrigation systems. In their point of view, an irrigation system can only be sustainable if water is sufficiently available in a region, and if the water resource is not overexploited. In this context, the ecological flow of rivers should be guaranteed. As a suggestion towards more sustainability of agricultural irrigation, changes to less water intense crops were suggested. According to EE01, the irrigated area should be reduced for agricultural irrigation to be more sustainable. All environmental experts interviewed lamented losses in biodiversity that occur with the UPN establishment in their perspective. EE03 suggested the naturalization of areas less optimal for production.

Environmental experts were not asked about social and economic sustainability outcomes. However, some expressed an understanding of the need for the economic security and well-being of farmers. EE03 for example mentioned the labour intensity of flood irrigation and talked positively about labour savings with the UPN.

Farmers

Nine farmers interviewed named the UPN as the most sustainable irrigation system, one farmer did not specify his answer further than sprinkler irrigation. Three farmers specified that they perceive underground pipes or pivots connected to an UPN to be more sustainable than aerial pipes. These stances were explained by farmers with criteria such as higher water use efficiency, savings of water resources, reduction in labour, increases in productivity, and decreases in fertilizers applied. Farmers furthermore mentioned that they need to receive financial support for irrigation expenses for an irrigation system to be sustainable and they highlighted the importance of a fair water distribution amongst irrigators. SMI02 criticized expansions of irrigation, since it may lead to a decrease in water availability for his own production: “They are expanding more and more hectares, more hectares and more hectares. And of course, if before you had four (...) now you still have three and a half, and each time demanding more, demanding more, demanding more. And in the end, of course, there will come a point that maybe you cannot (...) take out certain crops because it has a lot of demand for water.” Some farmers expressed discontent about the decreased accountability of authorities in relation to the

UPN establishment. However, increases in occupational well-being and decreases in occupational stress were talked positively about. Farmers furthermore welcomed the increased possibility to apply risk minimizing strategies and the decreased vulnerability to climate change with the UPN, as it increases their economic security.

Irrigation Communities

When asked for criteria of a sustainable irrigation system, the interviewees of both irrigation communities talked about the UPN. IC02 described improvements of farmers who are connected to an UPN as follows: "Those who irrigate by flood, are in a league and those who are (...) those who irrigate with pressure are in the champion league, you know." IC01 mentioned doses of fertilizers applied being reduced with the UPN, which is favourable in his point of view. IC03 perceives the water allocation with the UPN as the "fairest in the world" and when talking about water conflicts, IC01 stated that "Everything is solved with modernizations." Two employees of the SMP community expressed their contentment about the improvement of organizational efficiency since the UPN establishment. IC03 furthermore talked about the increase in occupational well-being with the UPN: "There is no colour, but not only (...) what does a modernized community give you? It's a simple thing. It's not (...) the first thing it gives you is quality of life. My life would not be the same modernized as not modernized." The decrease in vulnerability to climate change was also mentioned by IC03 as an advantage of the UPN. Concerns about the accountability of authorities and rising electricity prices were expressed. For the UPN to be more sustainable, IC01 suggested solar power as energy source. To conclude, irrigation community members perceived the UPN as the most sustainable irrigation system. Similarities to the perspective of farmers can be noted. The similarities may be related to the fact that the irrigation community employees are farmers themselves.

Regional Government

The interviewee of the regional agricultural department described the higher water use efficiency of the UPN as "tremendous" advantage. RG01 also rated the potential of the UPN to reduce fertilizer applications to be beneficial regarding land degradation and concluded in this regard: "I think it is (...) environmentally it is very positive, the modernization of irrigation." Increases in quality of life of farmers and productions were named as further advantages of the UPN, and the interviewee described the financial support of farmers with subsidies to be helpful.

Irrigation Unions

The member of the irrigation union interviewed perceived the UPN as environmentally beneficial, because water is saved in his perspective. The interviewee did not express his opinion on other sustainability outcomes that he provided information for.

6 Discussion

The methodology of this thesis allowed to answer the research questions raised in the beginning. The results are discussed subsequently according to the order of the research questions. Afterwards, the results are discussed in the context of (sustainable) agricultural intensification, suggestions towards more sustainability are made, and the methodological limitations are pointed out.

6.1 Irrigation Development

The irrigation development at the two study sites was analysed for the period from 1970 onwards. At the beginning of the period analysed, farmers who were interviewed all irrigated their farms by flood through ditches and furrows. For the SMP study site, this finding is in line with research conducted by García Martínez (2020) in the Páramo region, the region that the study site forms part of. The author depicted flood-irrigated farms after the arrival of the *Barrios de Luna* reservoir water in 1959. For the SMI study site, no specifications on irrigation systems used had been encountered in literature. According to the interviews conducted within my thesis, SMI-farms were irrigated by flood with water from the *Barrios de Luna* and the *Villameca* reservoir. A further new finding concerning the irrigation development is the introduction of aerial pipes (AP), which occurred on farms at both study sites from 1992 onwards. The absence of this irrigation system in literature may be related to the spatial scale at which the system was introduced. Aerial pipes were introduced for sprinkler irrigation on the farm scale, but the irrigation infrastructure on the landscape level kept on consisting of the network of ditches and drains (see Figure 7 in chapter *5.2.2 Irrigation System Trajectories*). Furthermore, the ratio of land irrigated by AP ranged from 10% to 50% per farm. Hence the introduction of aerial pipes was only a partial transformation. However, farmers interviewed perceived the introduction of aerial pipes as beneficial, which will be further discussed in chapter *6.4 Sustainability Outcomes of Irrigation Systems*.

An irrigation development identified that occurred on a larger scale is the establishment of the underground pipe network (UPN) for pressurized water distribution at the SMP study site from 2005 onwards. This result is in line with research conducted in the region the study site belongs to. García Martínez (2020) described sector-wise installations of underground pipes in the Páramo region from the mid-2000s onwards, and Rodríguez (2011) mentioned increasing replacements of ditches with underground pipes in the Duero River basin in the 2000s. The results of this thesis indicated future projects to establish an UPN at the SMI study site, which points to the relevance of research concerning this irrigation development. These landscape-level UPN establishments also fit into the development on the national level, as increasing replacements of ditches with pressurized distribution networks have been reported in Spain (Carrillo Cobo et al., 2014; Fernández García et al., 2016). According to Tarjuelo et al. (2015), the switch from open-channel to pressurized distribution networks is the most common approach to renew irrigation systems in Spain. Likewise, in other arid and semi-arid countries, pressurized water distribution has become common in the recent decades (Díaz et al., 2012; Fernández García et al., 2020; Sanchis-Ibor et al., 2021).

The on-farm irrigation development in the case study region from flood to sprinkler irrigation also fits into the national, and partly international, trend. In semi-arid regions of Spain and other semi-arid countries, transitions from flood irrigation as the most common irrigation system towards sprinkler irrigation have increased, especially since the 2000s (Casterad et al., 2018; Herrero et al., 2007; Nogués & Herrero, 2003). Another on-farm irrigation system that has gained national and international prominence in replacing flood irrigation is drip irrigation (Fernández García et al., 2013; Lopez-Gunn et al., 2012; Pool, Francés, Garcia-Prats, Puertes, et al., 2021). Drip irrigation was not prevalent in the case study region, but for example became dominant in irrigated agriculture in Eastern Spain, where fruit orchards prevail (Pool, Francés, Garcia-Prats, Pulido-Velazquez, et al., 2021). While the new on-farm irrigation systems may hence differ, an increasing replacement of flood irrigation is shared by the case study region with numerous other regions in Spain. The term *modernization* is often encountered in literature to refer to the introduction of new on-farm irrigation systems, such as drip or sprinkler irrigation, but also to refer to pressurized water distribution networks on the landscape level, and sometimes to refer to technological improvements of existing irrigation systems. To avoid confusion, the term will not be used in the following discussion sections. The irrigation systems will be referred to directly.

6.2 Driving Forces of Irrigation System Trajectories and Involvement of Actors

Perceived driving forces of the irrigation trajectories at the two study sites since 1990 were identified for all categories considered, namely political and institutional, economic, technological, cultural and personal, and natural and spatial driving forces. The driving forces were further differentiated into spatial scales and presented separately for the irrigation trajectories on the landscape and farm level. The number of driving forces identified on the landscape level was considerably greater than the number of driving forces identified for on-farm irrigation. This indicates that the change to the underground pipe network (UPN) may have been of greater relevance for the interview partners at the time of the interviews than new on-farm infrastructure. The greater relevance may for one be related to the actuality of the irrigation system change. While the first aerial pipes were introduced in the 1990s, the UPN establishments started from 2005 onwards at the SMP study site. Future UPN establishments were approved at the SMI study site in 2018 and 2021, hence concerning the near future of interview partners. The greater relevance may also be related to the spatial level at which the new irrigation systems are introduced, and to the amount of actors who are accordingly involved. While on-farm infrastructure mainly concerns the farm-scale, UPNs are established on the landscape scale. An UPN establishment was found to be of interest for a diversity of actors, from ministries of the national government to the regional government, irrigation communities, irrigation unions, agro-industrial companies, banks, and farmers. With on-farm infrastructure, governmental entities and irrigation unions were not involved. The driving forces are discussed hereinafter for each of the five categories, including interrelations of driving forces that have been found relevant to be discussed. The involvement of actors is discussed in more detail at the end of this chapter.

The category with the highest number of driving forces identified is the one of political and institutional driving forces. This finding is in accordance with Plieninger et al. (2016) who identified political and institutional driving forces as the most prevalent category across 144 case studies on land use and landscape change in Europe. Correspondingly, irrigated agriculture has been found to occupy a privileged position in Spanish policy (Lopez-Gunn et al., 2012). The results of my thesis show that interview partners perceived the UPN as measure to foster rural development and transform the agricultural sector. This is in line with the argumentation of Lopez-Gunn et al. (2012) who talk of a "strong social legitimacy of irrigation in many regions as a policy to settle population in rural areas and generate employment" (Lopez-Gunn et al., 2012: 85). According to the authors, the goal to settle rural population through irrigation development especially accounts for inland Spain, which includes both study sites. A political driving force that was not directly mentioned by interview partners but was influential for the replacement of flood irrigation according to Lopez-Gunn et al. (2012), García Martínez (2020), Fernández García et al. (2016), and Berbel et al. (2019) was the National Irrigation Plan – Horizon 2008 (NIP 2008). The NIP 2008 was enacted in 2002 with the goal to renew and replace irrigation infrastructure in one third of the irrigated area in Spain, and the plan was followed by the *Plan de Choque 2006* to accelerate the implementation (Berbel et al., 2019; Lopez-Gunn et al., 2012). For the Páramo region, García Martínez (2020) mentioned the Comprehensive Agrarian Plan of Castilla y León 2007-2013 to have continued the implementation of the national plans. While these national and regional plans were not directly mentioned in interviews, the financing scheme that stems from the NIP 2008 was mentioned. Loans under preferential conditions and direct collaborative financial contributions by regional governments, state-owned companies, and the EU were provided, which fostered the UPN establishment in SMP. This thesis not only found institutional collaboration regarding finances, but also regarding convincing farmers through informative talks to approve of the UPN. García Martínez (2020) noted a reluctance of farmers to change. However, the psychological aspect of convincing farmers to change was not encountered in literature, which may be related to the rather informal nature of the measure. As a final note on political and institutional driving forces, land ownership was therein identified as relevant driving force slowing down UPN establishments. Land ownership continued to influence on-farm irrigation infrastructure on rented farms after UPN establishments. This was not encountered in literature, probably because the authors referred to above focused on driving forces intensifying the irrigation development. Driving forces that impeded changes were additionally incorporated into the analysis of my thesis.

Irrigation infrastructure costs were also found to delay UPN establishments and impact on-farm infrastructure decisions of farmers. This impeding economic driving force in turn seems to have fostered the previously mentioned financial contributions to support farmers with irrigation installations. As Sanchis-Ibor et al. (2021) and Tarjuelo et al. (2015) pointed out, transitions from open-channel to underground pipe networks call for large public investments. Contrastingly, the possibility to increase water use efficiency with the UPN seems to have played a central role for its approval and establishment. Water use efficiency was also identified as an economic driving force for the introduction of aerial pipes on farms in the 1990s. This finding is in line with research by Lopez-Gunn et al. (2012) who noted a push in Spain towards measures to increase water efficiency in the 1990s, especially targeting agricultural water use. Furthermore, Berbel et al. (2019) identified ambitions to increase water efficiency and foster the competitiveness of irrigated agriculture in Spain. In this context, the authors mentioned the EU strategy for resource-use efficiency to which Spanish efficiency goals were aligned to (Berbel et al., 2019). Political and economic driving forces hence seem to be strongly related. Such interrelations were also recognized in chapter *5.3.8 Intercategorial Relations and Involvement of Actors*. In addition to national and regional governmental pursuits to increase water use efficiency, interviews conducted pointed to farmers striving to increase water use efficiency. Their ambitions were inter alia related to the optimization of crop conditions and productivity increases. Productivity increases seem to be another shared objective across spatial levels and actors. Sanchis-Ibor et al. (2021) and Tarjuelo et al. (2015) identified them as economic driving force to replace flood irrigation on the regional and national governmental level. Aims to increase productivity further fit into agricultural land use changes in Europe, as they were identified as economic drivers especially for management intensity increases in the last decades (Levers et al., 2016; van Vliet et al., 2015).

The category with the least amount of driving forces identified is the one of technological driving forces. This finding may be related to the research object itself, which is an irrigation development that comprises technological changes. Jepsen et al. (2015) inter alia identified irrigation per se as a technological driving force of land use change in Europe. While technological drivers were found to be of great importance in European land use change (Jepsen et al., 2015; van Vliet et al., 2015), the small number of technological driving forces identified for the irrigation trajectories may also mean that these played a less significant role than other driving forces. The results showed nonetheless that the age of infrastructure influenced the spatial development of where UPNs began to be installed. The resulting time point of installation seems to be relevant on the farm scale. Some farmers for example would have preferred an earlier installment due to perceived advantages that will be further discussed in chapter *6.4 Sustainability Outcomes of Irrigation Systems*. Irrigation system characteristics were also identified as technological driving force, especially influencing decisions about on-farm irrigation infrastructure. The characteristics found to influence farmers' decisions were either related to the driving forces farm topography, work comfort, or water use efficiency. In literature, irrigation system characteristics are discussed mostly with a relation to water use efficiency (see i.e., Fernández García et al., 2013; Lopez-Gunn et al., 2012; Morani et al., 2022; Tarjuelo et al., 2015).

As explained in chapter *3.2 Driving Forces of Land Use and Landscape Change*, personal driving forces were incorporated into the category of cultural driving forces. Personal motivations of farmers to move forward and save resources were found to foster UPN approvals. Aspirations to increase work comfort and quality of life were found to influence the introduction of aerial pipes, were again found to foster UPN approvals, and to further influence on-farm infrastructure decisions. The objective to improve farmers' working conditions in Spain through the replacement of flood irrigation has also been recognized by Berbel et al. (2019), Tarjuelo et al. (2015), and Lopez-Gunn et al. (2012). According to the results of this thesis, a neighbourhood effect contributed to farmers becoming aware of the possibilities to improve quality of life through changes in irrigation. The exchange with other farmers seemed to have played a relevant role on the personal level. This driving force had not been encountered in literature. However, neighbourhood effects are a driver often identified in studies on land use change (Sutherland et al., 2012; van Vliet et al., 2013; Verburg et al., 2004; Zhou & Kockelman, 2008). Population age structure was identified as a further cultural driving force at the study sites. Farmers close to retirement were found to be less willing to invest in the UPN than young farmers. This is in line with findings by Fernández García et al. (2020), that the early adopters of new technologies are usually younger farmers, and by van Vliet et al. (2015), that young farmers are more inclined towards considerable farm changes than old farmers. The latter authors explained this intergenerational difference with the fact that young farmers have a longer career ahead for investments to become rentable. Interviews conducted at the study sites indicated that older farmers were also generally more skeptical towards the new irrigation system.

According to Lopez-Gunn et al. (2012) and Berbel et al. (2019), severe droughts in Spain enhanced the public and political will from the mid-1990s onwards to save water and increase irrigation efficiency. Lopez-Gunn et al. (2012) noted a subsequent shift in the public debate from specific concerns over droughts towards concerns over climate change, which is associated with more frequent droughts though (Lopez-Gunn et al., 2012). The results of my thesis also identified droughts and climate change to motivate farmers to approve of UPN establishments. This finding is further supported by research that found farmers to increasingly value and pay for guaranteed water supplies as climate change adaptation measure (Berbel et al., 2019; Mesa-Jurado et al., 2012). For on-farm irrigation infrastructure, the natural driving forces farm topography and soil characteristics were detected within this thesis. A relation to optimization of crop conditions seemed to be prevalent because the compact type of soil was said to be better supported by sprinkler irrigation than by flood irrigation. High soil quality has indeed been associated with high yields (Levers et al., 2016). Furthermore, soil quality and farm topography have been found to generally influence agricultural land use changes in Europe (van Vliet et al., 2015).

Farm topography has also contributed to the study site differences identified within my thesis. Farms in SMP were said to be less flat and hence farmers saw the necessity for aerial pipes earlier than farmers in SMI. Regarding the study site differences of the UPN approval, the larger extent of the irrigated area in SMP was said to have fostered political support for an earlier establishment. Research conducted by Lopez-Gunn et al. (2012) shows that funds were also not distributed equally between irrigated regions in Spain. The Duero River basin with its large irrigated area was amongst the regions that received the highest investments (Lopez-Gunn et al., 2012). A well-established irrigation community structure was found to have contributed to the earlier UPN establishment in SMP as well, and the merging of small communities in SMI seems to have contributed to the final UPN approval at this study site. This finding fits into studies that identified changes in social organization contributing to land-use/cover change (Axinn & Ghimire, 2011; Lambin et al., 2003; van Dijk et al., 2015). The relevance of irrigation communities as actors will be further discussed below. Another driving force identified to have influenced the time difference in the UPN approval is the non-agricultural land ownership in SMI. This result is supported by studies highlighting the influence of land tenure configuration on land use change trajectories in Europe (Hartvigsen, 2014; James Millington, 2008; Trukhachev et al., 2015). For the final UPN approval at the SMI study site, the engagement of an individual was said to have been relevant. García Martínez (2020) identified a former president of the irrigation community in SMP as a fundamental actor for the implementation of the Comprehensive Agrarian Plan of Castilla y León 2007-2013. This indicates that individual action also played a role for the UPN approval at the SMP study site, and not only at the SMI study site.

The involvement of actors in irrigation development is prevalent in literature, as partly pointed out before. Berbel et al. (2019) named national and regional governments as main promoters of the replacement of flood irrigation, while Lopez-Gunn et al. (2012) see the lead with the Spanish State. National and regional governmental involvement was also recognized within this thesis. According to Lopez-Gunn et al. (2012), farmer organisations and the main national irrigation union then became active campaigners for the replacement of flood irrigation in Spain. The main national irrigation union was only referred to in interviews as bringing together central irrigation boards and communities, but more detailed results on the role of a central irrigation board and irrigation communities were conducted. According to the results of this thesis, both actors have contributed to the replacement of flood irrigation with UPNs, and they have collaborated with the regional government, driven by joint political and economic ambitions. Other farmer organisations were not mentioned in interviews. Sanchis-Ibor et al. (2021) point out that the participation of farmers' associations in irrigation development in Mediterranean countries exhibits regional differences. The authors furthermore mentioned companies being involved in the replacement of flood irrigation, as also suggested by the results of this thesis. A state-owned company to be highlighted is *SEIASA*. García Martínez (2020) attributed the company with a fundamental role in the UPN approvals in the Páramo region due to its financial contributions.

According to the results of this thesis, the company additionally participated in informative talks to convince farmers of UPN approvals. As already mentioned previously, a relevant distinction to be made seems to be one across the spatial levels at which a new irrigation system is implemented. Governmental entities and irrigation unions were found to be particularly involved with fostering changes on the landscape level, whereas individual farmers were partly sharing similar interests but were also found to impede UPN establishments, especially at the beginning. Hence it also needs to be noted that farmers cannot be viewed as a unified actor. The role of the age of farmers was already elaborated on above. Berbel et al. (2019) additionally mentioned that the level of entrepreneurship of farmers influenced their engagement for the replacement of flood irrigation. However, farmers interviewed within this thesis were identified as main agents regarding on-farm irrigation changes, a spatial level where governmental entities and irrigation unions did not interfere.

6.3 Irrigation-related Landscape Changes

According to Farina (2000), agriculture is one of the main factors contributing to the formation of landscapes in Europe. The results of this thesis indicate that agricultural irrigation therein contributes to landscape changes. In the following, the landscape changes identified and their relation to the irrigation trajectories at the study sites are discussed.

Certain irrigation-related landscape changes were detected at both study sites. They include decreases in trees and wells and increases in corn cultivations. As the interviews indicated, trees were removed because they damaged irrigation ditches. The removal of wells, which lost their necessity and profitability, contributed to the removal of trees. This finding is in line with research conducted by García Martínez (2020) who mentioned the limited potential of wells for a productive agriculture, and the loss of “green spots” (García Martínez, 2020:14) with the removal of wells. The author also elaborated on increases in corn cultivation, which he attributed to the market potential of the crop that was accelerated by the introduction of sprinkler irrigation and semi-arid climatic conditions allowing high yields (García Martínez, 2020). Salmerón et al. (2011) agree that semi-arid conditions allow high yields of irrigated corn, and according to Jlassi et al. (2016), the increase in corn cultivation in Spain coincided with the increase in sprinkler irrigation from 1990 onwards. Considering that corn is a crop with high water needs (Salmerón et al., 2011; Segovia-Cardozo et al., 2019), it makes sense that new irrigation possibilities such as sprinkler irrigation with aerial pipes can contribute to an increasing prominence of the crop. The interviews conducted within this thesis furthermore indicated that the work comfort, low production cost, and irrigation resistance of the crop contributed to the cultivation increase. As mentioned in chapter *2.3 Irrigated Agriculture in the Case Study Region*, Rodríguez (2011) found that increases in corn cultivation led to a homogenization of the landscape in the Duero River basin, to which both study sites belong.

At the SMP study site, more landscape changes were identified than at the SMI study site, and the changes in SMP were all found to be related to irrigation. In the scope of the underground pipe network (UPN) establishment and its associated land consolidation, crop area and field size of crops increased, while field margin vegetation, wetlands, and the number of wells, ditches, and trees decreased. These results are in line with research that had been conducted in the region. For the Páramo region, to which the SMP study site belongs, similar landscape changes have been mentioned in relation to UPN establishments and associated land consolidations. This is the case for field size increase (García Martínez, 2020; Rodríguez, 2011) and the elimination of ditches and wells (García Martínez, 2020). Field margin vegetation and field trees were not mentioned by the authors to have decreased, but Blanco et al. (2016) mentioned land consolidations having reduced the natural vegetation in Castilla y León, the autonomous community the study site belongs to. The findings regarding decreases in field margin vegetation and field trees also make sense considering the enlargement of field size detected at the study site, and considering that agricultural land consolidations have been associated with the removal of landscape elements such as trees and hedgerows (Baudry et al., 2000; Denac & Kmecl, 2021; Jan Benthem, 1969; Papanastasis et al., 2009). Zhong et al. (2020) mentioned a reduction in surface vegetation that can occur with road constructions in agricultural land consolidations. Interestingly, roads were said to have been widened at the SMP study site, but the overall area taken up by roads and paths in the study perimeter was found to have decreased. The area taken up by paths was most likely transformed to agricultural land, as parcels have been enlarged in the study perimeter where paths previously connected fields (see chapter *5.4.1 Land Use*). Two further landscape changes that can occur with such irrigation-related land consolidations worthwhile pointing out are an increasing amount of rectangular shaped plots, and eliminations of infrastructure with a heritage value (Rodríguez, 2011). What also needs to be noted is that the landscape changes elaborated on above are not exclusively irrigation-related. As mentioned in the interviews, the land consolidation at the SMP site simultaneously served to increase the efficiency of other agricultural practices. This is in line with studies that identified land consolidations as tools to increase agricultural efficiency (Gedefaw et al., 2019; Vries & Timo, 2022; Yaslioglu et al., 2009). The SMI study site had not experienced an UPN establishment nor a second land consolidation at the time of the interviews, which may explain the smaller amount of landscape changes detected at this site.

In conclusion, it can be said that sprinkler irrigation with aerial pipes contributed to landscape changes at both study sites, but the UPN establishment in SMP seems to have had more far-reaching landscape impact. This result is in line with Rodríguez (2011), who conducted research in the river basin the study site belongs to. The author called the UPN establishment with land consolidations “one of the actions with the greatest territorial magnitude and landscape impact that is being carried out in the region” (Rodríguez, 2011:63).

Two landscape-level indicators with potential links to changes in irrigation did not show a clear trend, i.e., the number of wild animal species and vegetation greenness (NDVI). The results of my thesis show that the number of some wild animal species decreased, while other wild animals increased in number. Interviews conducted indicated that the replacement of flood irrigation, especially with the establishment of the UPN, seems to have partly contributed to changes in species compositions. Similarly, Jiménez-García et al. (2014) found that a few wildlife species can benefit from the introduction of high technique irrigation systems, but most species cannot survive in the altered conditions. Moulton et al. (2022) found that flood-irrigated agriculture provides a habitat for certain bird species that cannot be provided by sprinkler-irrigated agriculture, and Ferreira & Beja (2013) pointed out that only generalist species may be able to deal with irrigation habitat changes such as the elimination of surface water. However, what also needs to be noted is that before the arrival of the reservoir water, the Páramo region was a dry land with low water availability (García Martínez, 2020).

The results on study site differences in NDVI summer means were not significant, but higher NDVI summer means were detected at the SMP than at the SMI site for both periods of time considered. Peak differences between study sites may be related to crop types. As interview partners declared, more corn is sown in SMP, while more potatoes are planted in SMI. A greater amount of corn sown could have contributed to higher NDVI values, considering that corn has been found to have longer lasting NDVI peaks than potatoes (Johnson, 2016; Tasumi & Allen, 2007). The river passing through the SMI study site may have also influenced peak differences, because water bodies imply a low or even negative NDVI (Huang et al., 2021). Focusing on the SMP study site, its increase in summer means for the period of 2015 to 2021 compared to the period of 1995 to 2001 could be related to the UPN establishment. As stated by interview partners, the new irrigation system allowed for a more efficient irrigation water usage by plants and led to higher corn yields. Considering that the NDVI has been found to correlate with crop yields (Benedetti & Rossini, 1993; Johnson, 2016; Poudel et al., 2021), higher corn biomasses could have indeed contributed to the higher NDVI values. As stated by interview partners, the amount of corn crops at the study site increased over time. Therefore, an increase in the amount of corn crops could have added to the higher NDVI values in the second period. Considering that the NDVI is sensitive to droughts (Sruthi & Aslam, 2015) and that both study sites showed the most similar values during the year with drought conditions, the new irrigation system in SMP seems to not have been able to buffer the water constraints. This is in line with the finding of García-Garizábal et al. (2017) for another river basin in Spain. The authors found that the implementation of on-demand irrigation systems in the Ebro basin did not prevent water deficits for corn crops during drought conditions. The authors mentioned that it nonetheless allowed for a better adjustment to the water needs of crops, and underground pipe networks have been mentioned to help farmers deal with droughts (Lecina et al., 2010; Lopez-Gunn et al., 2012). Droughts are further discussed in the next chapter in the context of vulnerability and risk minimization.

6.4 Sustainability Outcomes of Irrigation Systems

The environmental, social, and economic sustainability outcomes that were analysed for aerial pipes (AP) and the underground pipe network (UPN) are discussed hereinafter for each dimension. Results on stakeholder perspectives are incorporated in this discussion chapter.

Environmental Sustainability Outcomes

An increase in water use efficiency was identified on the farm level with the introduction of sprinkler irrigation, especially in the scope of the UPN establishment. Water efficiency improvements with transitions from flood to sprinkler irrigation have been frequently highlighted in literature (Carrillo-Cobo et al., 2014; Eldeiry et al., 2016; Fernández García et al., 2013; Herrero et al., 2007; Venn et al., 2004). However, the results of this thesis indicated that the annual water consumption has not been reduced with the new systems on the regional level. Berbel et al. (2019) found that some regions in Spain have achieved decreases in water consumption with new irrigation systems, but the authors recognized rebound effects preventing overall net water savings or even increasing water consumption in other regions, as also further authors recognized (González-Cebollada, 2015; Lecina et al., 2010; Lopez-Gunn et al., 2012; Nogués & Herrero, 2003; Tarjuelo et al., 2015). According to Díaz et al. (2012), increases in irrigation efficiency contributed to the introduction of more water-demanding crops, which have in turn counteracted water savings (Díaz et al., 2012). Extensions in irrigated area, as they have been found at the SMP study site, have also been suspected to counteract water savings (Berbel et al., 2019; Hoffmann & Villamayor-Tomas, 2023; Lopez-Gunn et al., 2012). What furthermore needs to be pointed out is the reduction of irrigation returns associated with a higher water use efficiency. This was mentioned in interviews and by Lopez-Gunn et al. (2012), according to whom a reduction in irrigation returns reduces aquifer recharge and is disadvantageous for areas downstream. The increase in water use efficiency identified is hence not necessarily a positive outcome, and it was accordingly criticized by environmental experts interviewed.

However, the results indicated a higher efficiency in fertilizer absorption with the UPN leading to farmers in SMP lowering doses of fertilizer applied. This effect was similarly found for the La Violada irrigation district (Barros et al., 2012) and the Jucar river basin (Berbel et al., 2019) in Spain. Berbel et al. (2019) pointed out that such reductions in fertilizer applications improve water quality and Yang et al. (2019) found that they reduce emissions of the atmospheric pollutant N_2O. Jimenez Aguirre et al. (2014) recognized possibilities to reduce nitrogen applications with the passage from flood to sprinkler irrigation, but favour case by case assessments because nitrogen contaminations also depend on the nitrogen management and characteristics of local water bodies.

Data conducted within this thesis was not sufficient to rate sustainability outcomes regarding energy consumption. Research suggests that new pressurized irrigation systems have resulted in significant energy use increases in Spain (Berbel et al., 2019; Carrillo-Cobo et al., 2014; González-Cebollada, 2015; Jlassi et al., 2016; Khadra & Sagardoy, 2019). Such energy use increases are viewed as a global environmental concern for the coming decades. Additionally, the energy costs for farmers are increasing rapidly (Berbel et al., 2019; Lopez-Gunn et al., 2012; Moreno et al., 2010). Irrigation costs are discussed further below in the context of economic sustainability outcomes.

Wada et al. (2014) mentioned that salinization issues can increase with the passage from flood to sprinkler irrigation. At the study sites, replacements of flood irrigation did not seem to have influenced salinization issues, which is in line with the results of a study comparing soil salinity of flood and sprinkler irrigation conducted by Casterad et al. (2018). According to Lecina et al. (2010), the salinity of underlying geological strata rather determines salinization issues.

Biodiversity indicators considered include diversity of wild animal species, habitat loss and fragmentation, and the quantity of wetlands. Negative outcomes were identified especially for the UPN. As elaborated in the previous chapter, changes in species compositions were prevalent, which may be related to altered habitats as surface water practically disappears with the complete replacement of flood irrigation. Similarly, Rodríguez (2011) associated a high biological diversity with the presence of water in flood-irrigated fields. Results of my thesis furthermore indicated that the UPN establishment contributed to habitat loss and fragmentation through the removal of trees and ditches, and the enlargement of parcels. Scattered trees are considered an important habitat in agricultural landscapes (Gibbons et al., 2008), and landscapes of structural complexity were found to be important for diversity in agroecosystems (Tscharntke et al., 2005). Tscharntke et al. (2021) argue that the structural complexity of agricultural landscapes and small parcels are even more important for biodiversity than organic farming. This is in line with the finding that land consolidations can negatively impact biodiversity (Denac & Kmecl, 2021), and is of relevance considering that half of all species in Europe are dependent on agricultural habitats (Stoate et al., 2009). Wetlands are also crucial for biodiversity (Getzner, 2002; Kingsford et al., 2016). Wetlands were found to have decreased with the UPN establishment. A study commissioned by the municipality of SMP furthermore reported a degradation of wetlands in the area inter alia related to changes in irrigation (Sánchez, 2021). Irrigation systems with a high efficiency were also found to damage wetlands in other European regions (Pérez-Blanco & Sapino, 2022).

Social Sustainability Outcomes

In the social sustainability dimension, the smallest number of negative outcomes was found. This result is supported by Borrego-Marín & Berbel (2019) who rated the replacement of flood irrigation with large-scale sprinkler irrigation as a good social investment. While Antunes et al. (2017) found an unequal water distribution as a main sustainability issue for two study sites in Spain without an UPN, a social sustainability outcome to be highlighted is the increased fairness of water allocation that seems to be associated with UPNs. The outcome was found to be valued by both irrigation communities and farmers, which is in line with the finding that from the perspective of farmers, fairness means that every farmer can irrigate with the same frequency (Reig, 2015; Delos Reyes & Schultz, 2021). Similarly, Rey et al. (2019) characterized the distribution based on queuing, as it is the case with flood irrigation, as unequal. A study by Esteban et al. (2018) conducted in southeastern Spain found that users' perspectives on fairness differ based on upstream vs. downstream location, a difference that tends to disappear with the replacement of flood irrigation (Esteban et al., 2018). Regarding the performance of authorities, the authors found that the opinion is similar amongst users. The performance of authorities was ranked as "not bad" (Esteban et al., 2018), while the results of this thesis indicated a slight discontent with the accountability of authorities concerning the UPN establishment. However, farmers interviewed expressed satisfaction with their participation. Ortega-Reig et al. (2017) classified the participation of farmers in decision making processes on irrigation as low, but nonetheless noted a high satisfaction of farmers with their participation, due to high confidence towards the irrigation communities. Villamayor-Tomas (2017) found that participation of local stakeholders in energy planning of irrigation is lacking.

Irrigation community members interviewed talked of an increased organizational efficiency with the UPN. Management efficiency gains and management improvements with the new irrigation system were also mentioned in literature (Berbel et al., 2019; Playán & Mateos, 2006; Sanchis-Ibor et al., 2016). Berbel et al. (2019) explained the efficiency gains with a professionalization of irrigation community staff in the scope of the establishment of new irrigation systems, and with the increasing automation and remote control of irrigation. The automation and remote control have also contributed to an increase in farmers' well-being according to the authors. An increase in farmers' well-being was detected within this thesis already for the aerial pipes, but to a greater extent for the UPN. The increased well-being was attributed to decreases in working hours and occupational stress. Reductions in the amount of work and improved quality of life have been recognized for UPN establishments in other regions in Spain as well (Khadra & Sagardoy, 2019). The decrease in water conflicts mentioned in interviews may have added to the increase in farmers' well-being, as also Lecina et al. (2010) speak of reduced labour tensions and improved working conditions for farmers with UPNs. Furthermore, Mesa-Jurado et al. (2012) found that farmers' welfare increases with guaranteed water supplies, which is the case with an UPN. However, a farmer interviewed felt less free in his decisions than during the time when he used to irrigate by flood. Similarly, Albizua & Zaga-Mendez (2020) recognized a reduced autonomy to self-organize with the new irrigation system and Sanchis-Ibor et al. (2017) found water saving technologies removing the autonomy of users in the name of collective well-being.

The results of this thesis furthermore indicated that the UPN establishment may have the potential to prevent emigration from the countryside. While this potential is politically frequently highlighted as an advantage of the UPN (Berbel et al., 2019), Lopez-Gunn et al. (2012) highlighted labour reductions associated with the UPN and therefore questioned whether the irrigation system can prevent rural depopulation. García Martínez (2020) speaks of a demographic decline in the Páramo region due to the mechanization of agricultural practices. According to the author, Santa María del Páramo forms an exception to the demographic decline, which is related to its irrigation development but also to the economic diversity of the municipality. The larger size of the Santa María del Páramo municipality compared to the Santa María de la Isla municipality (see chapter *1.4 Case Study Sites*) may also counteract a demographic decline. The UPN establishment alone therefore does not seem to prevent emigration, but it may still contribute to settling rural population through increasing the attractiveness of farming (Khadra & Sagardoy, 2019), especially for young farmers (Tarjuelo et al., 2015).

Economic Sustainability Outcomes

In the economic dimension, productivity increases were noted with aerial pipes, and to an even greater extent with the UPN. This result fits into research that found sprinkler irrigation to be associated with a higher beneficial water use than flood irrigation (Nogués & Herrero, 2003), and there seems to be a scientific consensus that large scale underground pipe networks further increase productivity (Ahmad & Khan, 2017; Berbel et al., 2019; González-Cebollada, 2015; Hoffmann & Villamayor-Tomas, 2023; Lecina et al., 2010; Playán & Mateos, 2006; Tarjuelo et al., 2015). Farmers interviewed talked of crop yield increases by 25 to 45 percent, which is similar to the 25 to 33 percent that Tarjuelo et al. (2015) recognized. What needs to be noted is an adequate management of the available water resource and further production techniques are also relevant factors influencing productivity (Tarjuelo et al., 2015).

Results indicated that productivity increases did not necessarily lead to a higher net income of farmers. Especially the UPN was associated with high expenses, not only for its establishment but also for the subsequent electricity supply. González-Cebollada (2015) argue that the amortizing costs can threaten the economic viability of a farm, and the high energy cost dependence has been mentioned to increase the economic vulnerability of farmers (Sanchis-Ibor et al., 2021). The subsidies farmers can receive for irrigation infrastructure may counteract these expenses, but future energy price fluctuations may continue to influence economic farm viability (Lecina et al., 2010). It therefore makes sense that farmers interviewed perceived the financial support for irrigation expenses as a component of irrigation sustainability.

Regarding the vulnerability of farmers to droughts, Gómez & Pérez-Blanco (2014) argue that irrigation systems with a higher efficiency do not decrease vulnerability, nor do they reduce water scarcity. The authors explain their stance with the rebound effect of irrigation efficiency and a resulting higher water use. In this context, Lopez-Gunn et al. (2012) pointed to a possible decrease in the overall resilience of the agricultural system, to which the increasing reliance on water-intense crops contributes. Farmers interviewed within this thesis perceived their vulnerability to climate change to have decreased with the UPN, and it allowed them to adopt risk minimizing strategies during droughts. Water users interviewed by Esteban et al. (2018) agreed that the replacement of flood irrigation would be the best policy to deal with water scarcity. From the perspective of irrigators, vulnerability to droughts and climate change may therefore be reduced with UPN establishments. However, long-term vulnerability may be questioned, and the exposure to droughts may increase despite more efficient irrigation (Lopez-Gunn et al., 2012). The long-term development is of great relevance considering the forecast of more frequent droughts (Berbel et al., 2019).

6.5 Irrigation Development in the Context of (Sustainable) Agricultural Intensification

Based on the conceptualization of agricultural intensification adopted (see chapter *3.3 Agricultural Intensity Change (AIC) and Sustainable Intensification (SI)*), the results indicate that the irrigation trajectories at the two study sites form part of agricultural intensity changes. Investments in irrigation infrastructure and adjustments of water use were identified, which are both mechanisms of agricultural intensity change operating in Europe (Diogo et al., 2022). Furthermore, irrigation equipment was replaced and renewed, and water efficiency was increased. These indicators speak for an increased agricultural intensity (Diogo et al., 2022). Especially the UPN establishment seems to form part of agricultural intensity changes, considering its more far-reaching effect compared to AP. Furthermore, the UPN was associated with an increase in irrigation area and with a land consolidation, which are also mechanisms of agricultural intensity change (Diogo et al., 2022). Similarly, the elimination of landscape structures and elements and increasing field sizes are seen as typical landscape changes of agricultural intensification (Helfenstein et al., 2020; van Vliet et al., 2015).

Regarding the sustainability of agricultural intensification processes, increased productivity is viewed as a pivotal component to meet the increasing global food demand, and is hence often perceived as promising to contribute to a sustainable intensification (Diogo et al., 2022; Helfenstein et al., 2020). Irrigation-related increases in productivity have been detected at the study sites. According to Playán & Mateos (2006), the magnitude of irrigation-related increases in productivity is not sufficient considering the increases in projected global food demand. Furthermore, negative environmental outcomes have been detected at the study sites, especially related to the UPN establishment. These do not seem to comply with the aim of SI to protect the environment (Diogo et al., 2022; Weltin et al., 2018). However, increases in farmers' well-being have been clearly attributed to the irrigation systems at the study sites, and the social sustainability dimension was found to have various positively rated outcomes. The promotion of a good quality of life as a goal of SI (Diogo et al., 2022; Janker et al., 2019) thus seems to be prevalent for the irrigation development researched. Overall, it can be said that the irrigation development at the study sites led to trade-offs, as it is often the case with sustainable intensification processes (Diogo et al., 2022; Helfenstein et al., 2020). While further sustainability indicators were assessed as presented in the previous chapter, there is a range of indicators that have not been considered but would be relevant for a more thorough SI assessment (Diogo et al., 2022). On a final note, Weltin et al. (2018) perceive increases in water use efficiency as the field of action for a sustainable intensification in the context of irrigation. As elaborated on in the previous chapter, water use efficiency increases are not necessarily a positive sustainability outcome. It hence seems of importance to expand this perception by other fields of action. Suggestions are made in the following chapter.

6.6 Towards More Sustainability

In this chapter, suggestions towards more sustainability are made based on the previously presented sustainability outcomes and findings from research in this context.

Clough et al. (2020) recommend considering the ecological effects of changes in parcel size into the design of land consolidations. Parcel size should hence only be reduced as much as necessary to install underground pipes. To further prevent biodiversity losses with an UPN establishment, preserving landscape elements such as trees, hedgerows, and wetlands wherever possible would be beneficial. Tscharntke et al. (2021) suggest preserving at least 20% seminatural habitat in agricultural landscapes. Therein, a focus should also be put on landscape connectivity (Tscharntke et al., 2021). The authors stress that collaborations between farmers and other stakeholders are needed for such a landscape design, together with governmental schemes.

Even though drip irrigation has been found to be more water use efficient than sprinkler irrigation (Ahmad & Khan, 2017; Couto et al., 2013), a conversion to drip irrigation may not be the solution to achieve water savings, as it may also lead to rebound effects (Velasco-Muñoz et al., 2019). Lecina et al. (2010) suggest a shift from the focus on on-farm irrigation efficiency towards evapotranspiration management to achieve water savings. Deficit irrigation may also serve as a strategy in water-stressed times (Velasco-Muñoz et al., 2019). Considering the prevalence of crops with high water needs in the case study region, a switch towards less water intense crops may be beneficial. Velasco-Muñoz et al. (2019) and Sanchis-Ibor et al. (2021) point to the potential of unconventional water sources for water savings, like water derived from desalination or from reuse and rainwater harvesting systems. The use of unconventional water sources may also prevent the further degradation of wetlands (Velasco-Muñoz et al., 2019). The authors stress that the production processes of unconventional water sources should be improved, and attention needs to be paid to the final price of water for farmers not to increase. According to Gómez & Pérez-Blanco (2014), a comprehensive policy mix is needed to achieve water savings without reducing agricultural income. Hoffmann & Villamayor-Tomas (2023) suggest involving irrigation associations more actively into these decision-making processes because of their ability to encourage collective action. As a final note on water savings, Berbel at el. (2019) stress preventing further expansions of the irrigation area. A prevention of further expansions was valued by farmers and environmental experts interviewed, and according to Gómez-Limón & Gómez Ramos (2007) also by the regional society.

Considering the increasing vulnerability of farmers to energy price fluctuations, more public funding and a new funding scheme may be necessary (González-Cebollada, 2015). To reduce energy costs and lessen the environmental impacts of energy consumption, fostering the switch towards renewable energy sources, especially solar energy, is suggested (Carrillo-Cobo et al., 2014; Sanchis-Ibor et al., 2021; Tarjuelo et al., 2015). Local stakeholders should also be more involved in energy planning to decrease their vulnerability to price fluctuations (Villamayor-Tomas, 2017).

Overall, the incorporation of various stakeholder perspectives, developing a common vision of sustainability, and the negotiation of the sustainability trade-offs is crucial on the path towards more sustainability (Helfenstein et al., 2020). Therein, more attention should be paid to the influence of power relations and the capacity of users to self-organize (Albizua & Zaga-Mendez, 2020). Considering the results of this thesis, this seems to be of great relevance especially for future UPN establishments. The irrigation sector has a certain responsibility (Perret & Payen, 2020), and considering the sustainability outcomes that irrigation systems can have, the sector plays a crucial role towards more sustainability.

6.7 Methodological Limitations

The aerial photograph analysis conducted within the SIPATH project was integrated into the landscape assessment of this thesis, which allowed to save time resources. However, this meant that the analysis of the study perimeters was carried out by two different people. The same landscape assessment protocol was followed and the SIPATH analysis was repeatedly consulted, but it may not have been avoided that the visual interpretation of certain features differed slightly. Different visual interpretations of hedgerows and tree lines could have inter alia contributed to the unexplainable study site difference noted in chapter *5.4.2 Landscape Structures and Elements*. The different spatial resolution of the aerial photographs of 2002 and 2017 may have also impacted the comparability of the results.

For the remote sensing analysis, the NDVI was chosen as indicator for reasons elaborated on in chapter *4.2 Selection of Categories and Indicators*. The limitations of the indicator must be made transparent as well, which include atmospheric, aerosol, and sensor effects, high variability, and low repeatability (Bellón et al., 2017; Huang et al., 2021). However, the atmospheric effect is minimal (Guo et al., 2019; Huang et al., 2021), and choosing Tier 1 data with inter-calibrated images reduced the influence of these effects. The comparability of the two study sites was limited by the different availability of satellite images though. Furthermore, the boundaries of the two study perimeters for the landscape assessment did not coincide with the municipal boundaries nor with the delineations of the irrigation communities interviewed. The difference in boundaries made the integration of results of the landscape assessment and interviews more complex.

Regarding the interview partners, a dominance of male perspectives must be pointed out. While this selection of the interview partners allowed to reconstruct the irrigation development and drivers of the irrigation trajectories, sustainability outcomes concerning non-male individuals may have been left out. The interview partners were not selected randomly but mainly found through snowball sampling. This may have led to a selection of interview partners with rather similar perspectives. Furthermore, due to differing time resources of interview partners, not all stakeholder groups were asked in equal depth about their perspective on sustainability outcomes. The differing depth of the data restricted the analysis of stakeholder perspectives.

The analysis of the drivers of the irrigation trajectories was focused on perceived driving forces. The scope of the thesis did not allow to research external drivers in more detail, but it must be noted that these may have been more influential than the results suggest. For the sustainability assessment, integrating three sustainability dimensions allowed to prevent a dominance of the environmental dimension, as it is often the case in research on sustainable irrigation (Velasco-Muñoz et al., 2019). This broadening of the scope however impeded to analyse the individual dimensions in more detail. The sustainability outcomes should therefore not be regarded as exhaustive.

The initial document analysis carried out was impeded by the different availability of documents for the two study sites. The initial document analysis nonetheless pointed to driving forces in the legislative and political context that were not mentioned in interviews. The interviews alone were also not sufficient for the sustainability assessment. Additional data provided by stakeholders was incorporated, and the contextualisation of the outcomes with literature seemed pivotal because interview partners could not provide data detailed enough to rate certain indicators. The interviews rather allowed to capture on-farm irrigation developments and drivers that were not found in documents nor in literature. The combination of the methods hence allowed to compensate certain limitations of the individual methods. Lastly it needs to be mentioned that a focus on the knowledge transfer of the results surpassed the scope of the thesis, a focus that would increase the application of knowledge generated (Bürgi et al., 2022).

7 Conclusions and Outlook

This thesis could provide insight into the irrigation development at two study sites in Spain. The irrigation system trajectories of both study sites since 1970 and associated drivers for the period after 1990 were reconstructed, and irrigation-related landscape changes were identified (RQ I). Furthermore, sustainability outcomes of two systems used, namely aerial and underground piped irrigation, were identified concerning the environmental, social, and economic dimensions (RQ II). The research questions could be answered with a mixed-methods design consisting of document analysis, interviews, aerial photograph analysis, and satellite image analysis.

The first change in irrigation recognized was the partial transition from flood irrigation to sprinkler irrigation with aerial pipes (AP). This on-farm development started in the 1990s at both study sites, but seven years earlier at the SMP than at the SMI study site. The second change recognized concerned the SMP study site. After an approval per vote in the irrigation community, sector-wise establishments of underground pipe networks (UPNs) for pressurized water distribution were carried out on the landscape level from 2005 onwards. This development led to a complete replacement of flood irrigation and was tied to a land consolidation. On-farm irrigation infrastructure subsequently consisted of a combination of underground pipes, aerial pipes, and pivots. At the SMI study site, UPN establishments were approved per vote prior to the interviews, and the installations are expected to be finished by 2029. The replacement of flood with sprinkler irrigation and the establishment of large-scale pressurized distribution networks fit into the trend of semi-arid regions in Spain and in further semi-arid countries. Furthermore, the irrigation development analysed, and therein especially the UPN establishment, can be viewed as forming part of agricultural intensity changes.

Some driving forces were perceived to have fostered both the introduction of AP and the UPN, such as water use efficiency, productivity, work comfort and quality of life, the neighbourhood effect, and interprofessional exchange. However, the number of driving forces identified was larger for the landscape-scale development than for the on-farm development considered. The same accounts for the number of actors involved in the developments, which was considerably larger in the case of the UPN. Political and institutional driving forces were especially influential, and an interconnection between political and economic driving forces was evident. The UPN establishment was driven by national and regional agricultural policies, ambitions to foster rural development, the goal to transform the agricultural sector, and market growth and commercialization. Driving forces impeding the UPN establishment were also recognized. These include land ownership, investment costs, and skepticism towards the new irrigation system. To reduce resistance of non-agricultural landowners and farmers, institutional and economic actors collaborated carrying out informative campaigns and providing financial incentives. For farmers to approve of the UPN, personal driving forces such as the motivation to move forward and save resources then also played a role. Furthermore, droughts and climate change enhanced the political and personal will for change in irrigation. Regarding the temporal difference in the development between the study sites, natural and spatial factors such as farm topography, water availability, and the extent in irrigated area played a role, but also differences in irrigation community history and structure were influential. Furthermore, differences in land ownership configuration and population age structure contributed to the later development at the SMI site.

The increasing use of aerial pipes contributed to landscape changes at both study sites, which include decreases in the number of trees and wells and increases in corn cultivation. The UPN establishment at the SMP study site was found to have had a more far-reaching landscape impact. Together with the associated land consolidation, it contributed to the removal of more trees, the elimination of ditches, increases in crop area and field size, and decreases in wetlands and field margin vegetation.

A reduction in the structural diversity of the agricultural landscape was accordingly associated with the UPN establishment, and biodiversity losses were recognized in the environmental sustainability dimension. Increases in water use efficiency with aerial pipes and the UPN were associated with rebound effects. However, a higher fertilizer absorption efficiency after the UPN establishment seems to have lowered doses of fertilizers applied. The social dimension was the most positively rated sustainability dimension, especially considering the outcomes of the UPN. Fairness of water allocation, irrigation community efficiency, and farmers' well-being therein increased, and the amount of water conflicts decreased. Furthermore, the UPN seems to have the potential to contribute to settle rural population and increase the attractiveness of farming. Regarding economic sustainability outcomes, productivity increases were noted with both the AP and the UPN. However, increases in irrigation costs, especially in the case of the UPN, impeded an overall increase in net income and may continue to threaten economic farm viability. From the perspective of farmers, the UPN decreased their vulnerability to climate change and allowed to adopt risk minimizing strategies during droughts. Results from the landscape assessment indicated that the UPN was not able to buffer water constraints during a drought year, and long-term vulnerability to droughts may increase nonetheless, considering the water efficiency rebound effects. Overall, sustainability trade-offs seem to be associated with the irrigation development researched, as it is also the case with sustainable intensification processes. The negotiation of these trade-offs is crucial on the path towards more sustainability. Further suggestions towards more sustainability include the preservation of seminatural habitats in agricultural landscapes, a shift from efficiency increases towards evaporation management and the use of unconventional water sources, the prevention of further expansions in the irrigated area, a switch towards solar energy, and a new funding scheme for irrigation costs.

To conclude, this thesis contributed to a better understanding of agricultural irrigation development, resulting landscape changes, and associated sustainability outcomes, which helps to understand the mechanisms of agricultural development in Europe and may indicate potential pathways towards more sustainability.

Further studies on sustainability outcomes seem pivotal to gain more detailed knowledge about the impact of the development researched. This thesis indicated that data is scarce regarding wildlife species diversity, energy consumption for irrigation, and net farm income. Furthermore, long-term vulnerability to climate change and farm viability have been found to be contested. More research would therefore be beneficial, also on how to prevent water use efficiency rebound effects and achieve water savings in semi-arid regions. In future studies, a focus on the UPN seems important considering the actuality of this irrigation development. To gain a more complete understanding of the driving forces contributing to the irrigation development, external drivers should therein be incorporated. Detailed knowledge is also still needed on the perspectives of stakeholders, in order to incorporate the perspectives in future planning and policy processes of irrigation development.

8 References

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Declaration of Consent

on the basis of Article 30 of the RSL Phil.-nat. 18

Fabienne Laura Frey

16-103-921

Master of Science in Geography

Agricultural Irrigation Development in Castilla y León (Spain): Driving Forces, Landscape Changes, and Sustainability Outcomes

Supervisors: Prof. Dr. Matthias Bürgi (WSL)

Franziska Mohr (WSL)

Co-Supervisor: Dr. Felicia O. Akinyemi (UniBe)

I declare herewith that this thesis is my own work and that I have not used any sources other than those stated. I have indicated the adoption of quotations as well as thoughts taken from other authors as such in the thesis. I am aware that the Senate pursuant to Article 36 paragraph 1 letter of the University Act of 5 September, 1996 is authorized to revoke the title awarded on the basis of this thesis. For the purposes of evaluation and verification of compliance with the declaration of originality and the regulations governing plagiarism, I hereby grant the University of Bern the right to process my personal data and to perform the acts of use this requires, in particular, to reproduce the written thesis and to store it permanently in a database, and to use said database, or to make said database available, to enable comparison with future theses submitted by others.

Bern, 12 September 2023

Signature: Frey

Annex

A: Sustainability Indicator Set

Indicators that were excluded prior to/ during field work are marked in grey.

Environmental Sustainability Outcomes

Theme	Indicator	Description	Selection based on	Assessment scale	Data collection methodology	Reason for exclusion of indicator
Water	Irrigation water consumption	Development of annual irrigation water consumption	Antunes et al. (2017)	Regional, community	Interviews, data provided by stakeholder	
	Water use efficiency	Development of water use efficiency	Antunes et al. (2017)	Farm	Interviews	
	Wastewater reuse	Development of share of wastewater reused for irrigation	Antunes et al. (2017)	Farm		No data available
Agrochemical products	Application of fertilizers	Development of fertilizer application	Previous inter-views within the SIPATH project	Farm	Interviews	
	Application of pesticides	Development of application of pesticides	Previous inter-views within the SIPATH project	Farm	Interviews	
Soil and Land	Salinization of soils	Development of salinization issues	Antunes et al. (2017)	Farm	Interviews	
	Soil structure	Development of share of soils with poor structure	Antunes et al. (2017)	Farm		Beyond scope of the thesis
	Land degrada-tion	Development of land degra-dation	Antunes et al. (2017)	Farm	Interviews	
	Extension in irrigated area	Development of extension in irrigated area	Interview analysis (inductive indicator)	Landscape	Interviews, data provided by stakeholder	
Energy	Energy con-sumption for irrigation	Development of amount of energy used for irrigation	Antunes et al. (2017)	Farm	Interviews	
Biodiversity	Diversity in species	Development of species diversity	Previous inter-views within the SIPATH project	Landscape	Interviews	
	Habitat loss and fragmenta-tion	Development of habitat loss and fragmenta-tion	Previous inter-views within the SIPATH project	Landscape	Remote sensing	
	Quantity of wetlands	Development of number of wetlands	Exchange with local project partner	Landscape	Interviews	

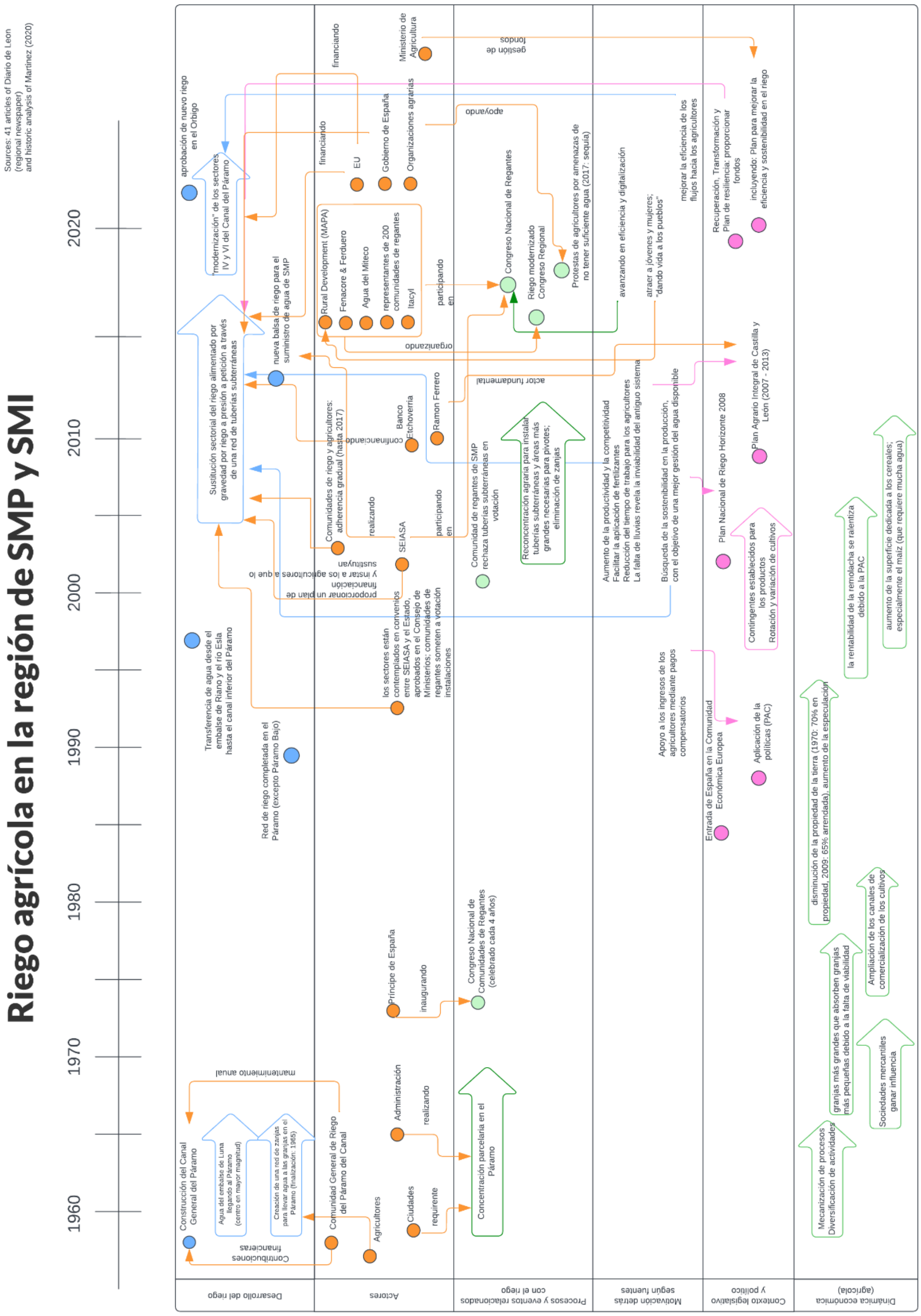
Social Sustainability Outcomes

Theme	Indicator	Description	Selection based on	Assessment scale	Data collection methodology	Reason for exclusion of indicator
Population dynamics	Emigration	Development of emigration in the area	Antunes et al. (2017)	Community	Interviews, data provided by stakeholder	
Good govern-ance	Accountability of authorities	Development of accountability of authorities	Antunes et al. (2017)	Regional & community	Interviews	
	Participation	Development of degree of par-ticipation in decision-making in water management & satisfaction regarding par-ticipation	Antunes et al. (2017)	Farm	Interviews	
	Conflict management	Development of formal/ informal institutions for conflict management	Antunes et al. (2017)	Community	Interviews	
	Fairness of water alloca-tion	Development of perceived fair-ness of water allocation	Antunes et al. (2017)	Farm & community	Interviews	
	Organizational efficiency	Development of organizational efficiency with-in community	Interview analysis (inductive indicator)	Community	Interviews	
Social com-mitment	Water conflicts	Development of water conflicts	Antunes et al. (2017)	Farm & commu-nity	Interviews	
	Sense of com-munity	Development of perceived sense of community	Antunes et al. (2017)	Farm & commu-nity	Interviews	
Equity	Perceived in-come distribu-tion	Development of perceived in-come distribu-tion	Antunes et al. (2017)	Farm & commu-nity	Interviews	
Food security	Food security of farm house-holds	Development of perceived food security of farm households	Diogo et al. (2022)	Farm	Interviews	
Farmer's well-being	Occupational well-being	Development of occupational well-being	Diogo et al. (2022)	Farm	Interviews	
	Working hours	Development of working hours	Previous inter-views within the SIPATH project	Farm	Interviews	
	Occupational stress	Development of occupational stress	Diogo et al. (2022)	Farm	Interviews	

Economic Sustainability Outcomes

Theme	Indicator	Description	Selection based on	Assessment scale	Data collection methodology	Reason for exclusion of indicator
Vulnerability and risk minimization	Bargaining power	Development of bargaining power	Previous interviews within the SIPATH project	Farm	Interviews	
	Vulnerability to climate change	Development of perceived vul-nerability to climate change	Antunes et al. (2017)	Farm	Interviews	
	Risk minimizing strategies	Development of adoption of risk minimizing strategies	Antunes et al. (2017)	Farm	Interviews	
Self-reliance	Subsidies	Development of irrigation subsi-dies	Antunes et al. (2017)	Farm	Interviews	
	Capacity to pay for water	Development of maximum ca-pacity to pay for water in irrigation	Antunes et al. (2017)	Farm		Too detailed for data collection
Revenue and costs	Crop yield	Development of crop yield	Antunes et al. (2017)	Farm	Interviews	
	Irrigation ex-penses	Development of irrigation ex-penses	Antunes et al. (2017)	Farm	Interviews	
	Value of water tariffs	Development of value of water tariffs	Antunes et al. (2017)	Community		Too detailed for data collection
	Revenue of irrigation costs	Development of revenue from irrigation/ total operational and management costs for irriga-tion	Antunes et al. (2017)	Farm		Too detailed for data collection
	Net farm in-come	Development of net farm in-come	Antunes et al. (2017)	Farm	Interviews	
	Economic out-put agriculture	Development of GVA agriculture	Diogo et al. (2022)	Regional		Beyond scope of the thesis
	Regional eco-nomic output	Annual growth of GDP per capita	Diogo et al. (2022)	Regional		Beyond scope of the thesis
(Un)employment	Regional un-employment	Development of regional unem-ployment rate	Diogo et al. (2022)	Regional		Beyond scope of the thesis
	Agricultural employment	Development of employment in agriculture rate	Diogo et al. (2022)	Regional		Beyond scope of the thesis

B: Document Analysis Based Chronosystemic Timeline



C: Interview Guidelines

The guidelines for the different interview partners are presented in the following order :

1. Farmers
2. Irrigation communities
3. Environmental experts
4. Regional government
5. Irrigation union

The declaration of consent is presented after all the guidelines. The content was slightly adapted to fit the interview partners. The passages that were adapted are marked in grey.

Desarrollo de sistemas de regadío: Preguntas de la entrevista (Farmers)

Entrevistador:	
Código del entrevistado:	
Fecha y hora de la entrevista:	
Lugar de la entrevista:	
Tipo de entrevista::	□ Cara a cara □ Otro: _______________
Duración de la entrevista:	
Comentarios sobre la situación de la entre-vista (ambiente, molestias, observaciones):	
Sexo del entrevistado:	□ mujer □ hombre □ otro □ sin respuesta
Edad del entrevistado:	
Papel en la agricultura:	
Tipo de explotación:	□ Granja agrícola □ Otro________

Note:

The questions marked in green have already been asked to the farmers in SMP. For those farmers who are interviewed again, they can be omitted.

Parte 1: Preguntas abiertas sobre la vida en la agricultura

A: ¿Podría describir su vida en la agricultura?

- *¿En qué época trabajó en la agricultura?*
- *¿Cómo ha cambiado la profesión de agricultor entre la época en que se hizo cargo de sus tierras y la actualidad?*

B: ¿Qué papel ha desempeñado el regadío en su vida agrícola?

- *¿Cuándo se produjeron los principales cambios? ¿Cómo le afectaron?*
- *¿Qué desventajas se asocian al regadío? ¿Y qué ventajas?*

*Las preguntas en cursiva pueden hacerse si el agricultor no se explaya demasiado por sí mismo.

Parte 2: Preguntas específicas sobre los cambios en la explotación y el regadío

1 **Biografía y antecedentes**

1.1 ¿Cuándo empezó a trabajar en la agricultura y cuándo se hizo cargo de sus propias tierras?

1.2 ¿Ha cambiado de explotación a lo largo de los años? En caso afirmativo, ¿cuándo?

1.3 ¿Cuándo planeó (/ plane) a jubilarse?

1.4 ¿Ha tenido (/ tiene) un sucesor?

2 Características de la explotación

2.1 Tamaño de la explotación

2.1.1 ¿Cuál era el tamaño de la explotación en ha cuando empezó y cuando dejó de trabajar allí?

2.1.2 *Si es relevante:* ¿Cuándo cambió el tamaño de la explotación? ¿Por qué?

2.2 Uso de la tierra

2.2.1 ¿Qué proporción de la superficie de la explotación se destinaba a tierras de labranza/praderas/cultivos permanentes/bosques cuando empezó y cuando dejó de trabajar en la explotación?

2.2.2 *Si es relevante:* ¿Cuándo cambiaron estas acciones? ¿Por qué?

2.2.3 ¿Cuáles eran los cultivos más importantes cuando empezó y cuando dejó de trabajar en la explotación? *Si es relevante*: ¿Cuándo cambió esto? ¿A qué? ¿Por qué?

2.3 Tenencia de la tierra

2.3.1 ¿Qué proporción de la tierra de cultivo era propia / arrendada / común (%) cuando empezó y cuando dejó de trabajar en la explotación?

2.3.2 *Si es relevante:* ¿Cuándo cambió esto? ¿A qué? ¿Por qué?

2.3.3 Tierra alquilada: ¿A quién se lo ha arrendado (a un particular, a una finca, a un municipio, etc.)? ¿Ha cambiado esto alguna vez*? En caso afirmativo*: ¿Cómo? ¿Cuándo? ¿Por qué?

2.3.4 ¿Cómo influyó el tipo de tenencia de la tierra en su utilización? ¿Por qué? *Si no se ha mencionado ya:* ¿Cómo influyó en el tipo de sistema de regadío utilizado?

3 Desarrollo de sistemas de regadío

3.1 Desarrollo tecnológico

La siguiente tabla puede rellenarse durante la entrevista, por lo que no es necesario transcribir esta parte. Las preguntas que aparecen a continuación sirven para rellenar la tabla y pasar rápidamente por esta parte. Compruebe después de la primera entrevista con la comunidad de regantes si se pueden omitir algunas preguntas tecnológicas.

Tipo	Princip io	Infraestructura transporte	Infraestructura aplicación	Fuente de energía	Fuente de agua	Superficie irrigada (%)	Cultivos de regadío	Superficie drenada (%)

3.1.1 ¿Cuándo empezó a regar sus tierras?

3.1.2 ¿Qué tipo de regadío utilizó al principio?

Si no empezó con la inundacion, sigue con la pregunta 3.1.7

3.1.3 ¿Qué sistema ha utilizado para transportar el agua a sus tierras? ¿Cuando el agua ya estaba en las tierras, como se regaba ?

3.1.4 ¿Qué fuente de agua se utilizó?

3.1.5 ¿Qué proporción (%) de sus tierras de cultivo ha regado con inundación? ¿Qué cultivos regó?

3.1.6 ¿Cuándo acabó de regar con inundación ?

3.1.7 ¿Cuándo introdujo tuberías aéreas ?

Si no introdujo tuberías aéreas, sigue con la pregunta 3.1.13 en caso de SMP ; en casa de SMI : Cuando preveen cambiar su sistema de regadio ? y sigue con la pregunta 3.1.18

3.1.8 ¿Qué sistema ha utilizado para transportar el agua a sus tierras? ¿Cuando el agua ya estaba en las tierras, como se regaba ?

3.1.9 ¿Qué fuente de agua se utilizó?

3.1.10 ¿Qué fuente de energía se ha utilizado?

3.1.11 ¿Qué proporción (%) de sus tierras de cultivo ha regado con las tuberías aéreas? ¿Qué cultivos regó con esto?

3.1.12 ¿Cuándo acabó de regar con las tuberías aéreas?

3.1.13 *Para SMP* :¿Cuándo introdujo tuberías subterraneas?

3.1.14 ¿Qué sistema ha utilizado para transportar el agua a sus tierras? ¿Cuando el agua ya estaba en las tierras, como se regaba ?

3.1.15 ¿Qué fuente de agua se utilizó?

3.1.16 ¿Qué fuente de energía se ha utilizado?

3.1.17 ¿Qué proporción (%) de sus tierras de cultivo ha regado con las tuberías subterraneas? ¿Qué cultivos regó con esto?

3.1.18 ¿Había usado algun tipo o alguna infraestructura de regadío que no se ha mencionado ?

3.1.19 ¿Cuántas de sus tierras de cultivo fueron drenadas cuando empezó a regar sus tierras y cuando dejó de trabajar en la explotación? *Si es relevante*: ¿Cuándo cambió esto? ¿A qué? ¿Por qué?

3.2 Impulsores de los cambios

3.2.2 ¿ Quién pagó para que se pudiera usar el sistema por inundación en tus tierras? ¿ Recibiste alguna ayuda economica ?

¿Qué parte del sistema por inundación hiciste tú ? ¿ Y las acequias?

3.2.3 *Si el agricultór usó las tuberías aéreas (si no, sigue con la pregunta 3.2.7)* : Centrémonos ahora en la introducción de las tuberías aéreas. ¿Puede explicar por qué se han introducido estas?

3.2.4 ¿Cuál ha sido su papel en el comienzo con la tubería aérea? ¿Qué le hizo introducir las tuberías aéreas? ¿Qué otros personas, organizaciones y acontecimientos influyeron? ¿Cómo?

3.2.5 ¿Qué partes de las tuberías aéreas pagaste tú ? ¿Para qué partes recibiste subvenciones? ¿De quién ? ¿Hasta cuando las tuvieron ? ¿Quién más te ayudó con la financiación?

Qué parte de las tuberías aéreas instalaste tú ? ¿ Y el resto, quién lo instaló?

3.2.6 ¿Cómo cambió la introducción de tubería aérea su vida agrícola?

3.2.7 *Por SMP*: Centrémonos ahora en la introducción de las tuberías subterraneas. ¿Puede explicar por qué se han introducido estas?

3.2.8 ¿Cuál ha sido su papel en el cambio a las tuberías subterraneas? ¿Qué le hizo introduir las tuberías subterraneas? ¿Qué otros personas, organizaciones y acontecimientos influyeron? ¿Cómo?

3.2.9 ¿ Qué partes de las tuberías subterraneas pagaste tú ? ¿ Para qué partes recibiste subvenciones ? ¿De quién ? ¿Hasta cuando las tuvieron ? ¿Quién más te ayudó con la financiación?

Qué parte de las tuberías subterraneas instalaste tú ? ¿ Y el resto, quién lo instaló?

3.2.10 ¿Cómo cambió la introducción de tubería subterranea su vida agrícola?

3.2.11 *Si es relevante* : ¿Por qué has dejado de regar por inundación ?

Si otro tipo había sido usado, también pregunta 3.2.7 hasta aquí por este tipo.

3.2.12 ¿Ha pasado por el mismo desarrollo del sistema de regadío que sus vecinos? Si no es así: ¿Qué fue diferente y por qué? ¿Y en comparación con otras zonas que ha occurrido?

6.1 Agua *(forms part of the sustainability dimension but fits better here for the flow of the interview ; the numbering was kept in this order to facilitate the analysis)*

6.1.1 ¿Cuántos y qué meses al año regaba cuando empezó y cuando dejó de trabajar en la explotación?

Si es relevante: ¿Cuándo cambió esto? ¿Por qué?

6.1.2 ¿Con qué frequencia regaba cuando empezó y cuando dejó de trabajar en la explotación?

Si es relevante: ¿Cuándo cambió esto? ¿Por qué?

6.1.3 ¿Cuánta agua utilizó para el regadío al año cuando empezó y cuando dejó de trabajar en la explotación?

Si es relevante: ¿Cuándo cambió la cantidad? ¿Por qué?

6.1.4 ¿Cómo ha cambiado a lo largo de los años la producción obtenida por la agricultura en comparación con la cantidad de agua necesaria? ¿Cuándo se produjeron los principales cambios? ¿Por qué?

6.1.5 ¿Cuál es la proporción de aguas sobrantes o agua que ha sido utilizado por otros agricultores que usa para regar?

¿Ha cambiado esto con el tiempo? *En caso afirmativo:* ¿Cómo? ¿Cuándo? ¿Por qué?

6.1.6 ¿Adónde va a parar el agua que ha utilizada para el regadío? ¿Cómo ha cambiado su calidad a lo largo de los años? *Si no se ha mencionado ya*: ¿Hay más / menos / la misma cantidad de residuos en el agua?

6.1.7 ¿Ha cambiado la calidad del agua de regadío que usa a lo largo de los años? *En caso afirmativo:* ¿Cómo? ¿Cuándo? ¿Por qué?

6.2 Energía

6.2.1 ¿Desde el momento en el que empezaste a usar energía para el regadío, como cambió la cantidad usada a lo largo de los años ?

3.2.13 ¿Cuáles fueron las normas importantes que el gobierno aplicó durante sus años de trabajo en relación con el desarrollo de los sistemas de regadío? ¿Por qué fueron importantes?

3.2.10 ¿Ha participado alguna vez en una asamblea en la que se votara sobre infraestructuras de regadío? En caso afirmativo: ¿Cuándo? ¿De qué se trataba? ¿Cómo votó? ¿Ha cambiado su opinión? ¿Por qué (no)?

3.2.11 ¿Está satisfecho con estos cambios en el regadío? En caso negativo: ¿Qué le hubiera gustado que fuera diferente? ¿Está satisfecho con el tipo de regadío actual? Si no es así, ¿qué le gustaría cambiar? ¿Cómo le gustaría cambiarlo? *Para SMI* : ¿Por qué el cambio al sistema de tubería subterranea se hará mucho más tarde que en otras zonas ? ¿Para cuándo está previsto ?

3.3 El papel de las administraciones

3.3.1 ¿En qué medida cree que son justas las normas de asignación de agua? ¿Han cambiado a lo largo de los años? *En caso afirmativo:* ¿Cuándo? ¿Cómo? ¿Por qué?

3.3.2 ¿Qué grado de participación crees que tienes en la toma de decisiones sobre la gestión del agua en esta zona? ¿Ha cambiado esto a lo largo de los años? *En caso afirmativo*: ¿Cuándo? ¿Cómo? ¿Por qué?

3.3.3 ¿Cuál es su grado de satisfacción con respecto a la participación? ¿Ha cambiado a lo largo de los años? *En caso afirmativo*: ¿Cuándo? ¿Cómo? ¿Por qué? ¿Dónde le hubiera gustado/le gustaría tener más voz?

3.3.4 ¿Cuál es el grado de compromiso de las autoridades locales para responder a sus necesidades? ¿Ha cambiado esto a lo largo de los años? *En caso afirmativo:* ¿Cuándo? ¿Cómo? ¿Por qué?

4 Perspectivas de los agricultores sobre la sostenibilidad

4.1 Entendimiento de la sostenibilidad

4.1.1 ¿Qué entiendes por la palabra sostenibilidad? →*Si no conoce la palabra* : A nuestro entender, significa cuidar el medio ambiente al tiempo que se garantiza que las generaciones actuales y futuras tengan una vida justa.

4.2 Sostenibilidad de los sistemas de regadío

4.2.1 ¿Qué criterios debe cumplir un sistema de regadío agrícola para ser sostenible?

4.2.2 De los diferentes sistemas de regadío que has utilizado, ¿cuál es el más sostenible? ¿Por qué?

4.2.3 De los diferentes sistemas de regadío que has utilizado, ¿cuál es el menos sostenible? ¿Por qué?

4.2.4 ¿Qué medidas son necesarias para hacer más sostenible el actual sistema de regadío agrícola?

5 Cambios en el paisaje

5.1 Cambios generales en el paisaje

5.1.1 ¿Cómo ha cambiado el paisaje alrededor de sus tierras a lo largo del tiempo? ¿Cuándo se produjeron los cambios? ¿Por qué se produjeron los cambios?

Si no se ha mencionado ya: ¿Cuándo atolló los pozos de sus tierras? ¿Por qué ?

Si no se ha mencionado ya: ¿Cuándo eliminó las acequias de sus tierras? ¿Cómo cambió esto el paisaje?

5.1.2 ¿Cómo ha cambiado la humedad del paisaje? ¿Cuándo cambió? ¿Cómo le afectó a usted

5.2. Número / superficie de los árboles

5.2.1 ¿Cuántos árboles había/cuál era el tamaño de la zona cuando empezaste y cuando dejaste de trabajar en la granja?

5.2.2 *Si es relevante:* ¿Cuándo cambió el número de árboles / el tamaño de la zona con árboles? ¿Por qué?

Para SMP: Basándome en imágenes aéreas, he observado que hoy en día hay muchos menos árboles a lo largo de las carreteras y los campos en la zona norte de Santa

María del Páramo que en 1980. ¿Puede comentar esto? ¿Cuándo ha cambiado? ¿Por qué?

Para SMI: Basándome en las imágenes aéreas, he observado que apenas hay árboles a lo largo de las carreteras y los campos en la zona del norte de Santa María de la Isla ya en 1980. ¿Puede comentar esto? ¿Por qué y cuándo cambió a tan pocos árboles? Hoy en día, hay aún menos árboles a lo largo de las carreteras y los campos, pero hay más bosque a lo largo del río Órbigo. ¿Puede comentar esto? ¿Cuándo cambió? ¿Por qué?

5.3 Concentración parcelaria

5.3.1 ¿Cuántas veces se han concentró sus tierras?

5.3.2 ¿Cuándo se concentró su tierra por primera / segunda /... vez? ¿Cómo? ¿Por qué?

Si no se ha mencionado ya: ¿Cómo se relacionó la(s) concentración(s) parcelaria(s) con los cambios en el regadío? ¿Quién decidió la(s) concentración(es) parcelaria(s)?

5.3.3 ¿Cómo ha cambiado el paisaje después de cada concentración parcelaria?

6 Las consecuencias de la sostenibilidad: Dimensión medioambiental

6.3 Suelo y tierra

6.3.1 ¿Ha tenido problemas de salinidad del suelo?

En caso afirmativo: ¿Cuándo? ¿Por qué? ¿Qué parte de su terreno se vio / se ve afectada? ¿Cómo lo ha afrontado?

6.3.2 ¿Ha tenido problemas en algunas zonas de sus tierras a la hora de sembrar?

En caso afirmativo: ¿Cuándo? ¿Por qué? ¿Qué parte de su terreno se vio/se ve afectada? ¿Cómo lo ha afrontado?

6.3.3 ¿Ha pensado alguna vez en la agricultura ecológica? ¿Por qué (no)? ¿Qué papel ha desempeñado el regadío en esta decisión?

6.4 Biodiversidad

6.4.1 ¿Cómo ha cambiado la diversidad de aves, mariposas, ranas y flores silvestres desde que empezó a trabajar en la agricultura? ¿Cuándo ha cambiado?

6.4.2 ¿Qué otros cambios en la cantidad de especies (animales y plantas) ha notado en sus tierras? ¿Cuándo? ¿Y la diversidad de especies? ¿A qué crees que se debe este cambio?

6.5 Otras prácticas agrícolas

6.5.1 ¿Qué cantidad de abono mineral utilizabas cuando empezaste y cuando dejaste de trabajar en la explotación? ¿Empezaste a aplicarlo a través del sistema de regadío? *En caso afirmativo :* ¿Cuando ? ¿Cómo cambió esto la cantidad de fertilizante que utilizabas?

6.5.2 ¿Ha empezado a aplicar aditivos (herbicidas, fungicidas, insecticidas) a través del sistema de regadío? En caso afirmativo: ¿Cuáles y cómo ha cambiado la cantidad que utilizaba?

6.5.3 ¿Los cambios en la infraestructura de regadío han modificado alguna de sus otras prácticas agrícolas? (por ejemplo, el tipo y la frecuencia de laboreo)

7 Consecuencias de sostenibilidad: Dimensión económica

7.1 Ingresos y costes

7.1.1 ¿Cómo han cambiado los ingresos agricolas a lo largo de los años? ¿Por qué?

Si no lo han mencionado ya : ¿Cómo ha cambiado la cantidad producida del cultivo principal ? ¿Y ha cambiado el dinero recibido por dicho cultivo ?

7.1.2 ¿Qué cultivos eran más rentables desde el punto de vista económico cuando empezó y cuando dejó la explotación? ¿Por qué?

7.1.3 ¿Cómo han cambiado los gastos de agua de regadío a lo largo de los años? ¿Por qué?

7.1.4 ¿Cómo han cambiado a lo largo de los años los gastos de electricidad utilizados para el agua de regadío? ¿Por qué?

7.2 Mercado de venta

7.2.1 ¿Qué mercados de venta eran importantes para la(s) producción(es) principal(es) cuando empezó y cuando dejó de trabajar en la explotación?

7.2.2 ¿Cómo ha cambiado tu poder de negociación hacia los mercados a los que vendías durante estos años? ¿Cómo le afectó?

7.3 Ingresos no agrícolas

7.3.1 *Para las explotaciones familiares:* ¿Cuánto [%] de los ingresos del hogar se generaba en actividades no agrícolas cuando empezó a trabajar y cuando dejó de hacerlo en la explotación?

7.3.2 *Si es relevante:* ¿Cuándo cambió esto? ¿Por qué?

7.5 Vulnerabilidad y minimización de riesgos

7.5.1 ¿En qué medida se siente o se sintió vulnerable a periodas de sequía en lo que respecta a las limitaciones de regadío? ¿Cómo ha cambiado esto a lo largo de los años?

7.5.2 ¿Cómo lo afronta o lo ha afrontado? ¿Ha tomado alguna medida para evitar posibles daños en la futura ?

8 Resultados de sostenibilidad: Dimensión social

8.1 Bienestar del agricultor

8.1.1 ¿Cómo ha cambiado su propio bienestar desde que empezó a trabajar en la agricultura? ¿Por qué?

8.1.2 ¿Cómo ha cambiado su satisfacción con sus condiciones de vida en estos años? ¿Por qué?

8.1.3 ¿Cómo ha cambiado su bienestar laboral en estos años? ¿Por qué?

8.1.4 ¿Cómo ha cambiado la media de horas de trabajo semanales a lo largo de los años? ¿Por qué? ¿Cómo le ha afectado?

8.1.5 ¿Ha podido tomarse vacaciones? En caso afirmativo, ¿desde cuándo, cómo ha cambiado?

8.1.6 ¿Cuáles fueron los momentos estresantes para usted en relación con el riego? ¿Qué le causó el estrés y cómo le afectó? ¿Cómo ha cambiado su nivel de estrés general a lo largo de los años? ¿Por qué?

8.2 Seguridad alimentaria

8.2.1 ¿Hubo algún momento en el que usted o su familia tuvieron dificultades para conseguir ganarse la vida? Si es así, ¿cuándo y por qué?

8.3 Equidad

8.3.1 ¿Ha cambiado el poder adquisitivo de los agricultores en comparación con los que no lo son ?¿Desde cuándo?

8.3.2 ¿Cómo se distribuían las tareas de la explotación en su familia cuando empezó y cuando dejó de trabajar? Si es relevante: ¿Por qué cambió esto*? Si ambos miembros de la pareja trabajan en la explotación:* ¿Quién está registrado como agricultor?

8.4 Compromiso social

8.4.1 ¿Hay union entre los agricultores aquí? ¿Ha cambiado a lo largo de los años? *En caso afirmativo:* ¿Cuándo? ¿Cómo? ¿Por qué?

8.4.2 ¿Como de importante son las relaciones entre los agricultores para el regadío? ¿Ha cambiado esto a lo largo de los años? *En caso afirmativo:* ¿Cuándo? ¿Cómo? ¿Por qué?

Preguntas finales

- ¿Hay algo que desee añadir a nuestra conversación de hoy?
- Si todavía tenemos alguna pregunta de seguimiento, ¿podemos ponernos en contacto con usted por teléfono?
- ¿Le interesaría ser informado de los resultados del estudio?

Desarrollo de sistemas de regadío: Preguntas de la entrevista (Irrigation communities)

Entrevistador:	
Código del entrevistado:	
Fecha y hora de la entrevista:	
Lugar de la entrevista:	
Tipo de entrevista:	□ Cara a cara □ Otro: ______________
Duración de la entrevista:	
Comentarios sobre la situación de la entrevista (ambiente, molestias, observaciones):	
Nombe de la comunidad de regantes:	
Sexo del entrevistado:	□ mujer □ hombre □ otro □ sin respuesta
Edad del entrevistado:	
Papel en la comunidad de regantes:	

1 Biografía y antecedentes

1.1 Para empezar, ¿podría hablarme de su papel en la comunidad de regantes?

Si no lo ha mencionado ya: ¿En qué año empezó a formar parte de la comunidad?

1.2 ¿Dónde creciste? *Si no es en la región del Páramo/ Vega del Tuerto:* ¿Cuándo se mudó aquí?

1.3 ¿Cuál es la función de la comunidad de regantes?

1.4 ¿Cuántos miembros tiene la comunidad de regantes?

1.5 ¿Cómo se hace uno socio? ¿Cuáles son las razones para hacerse socio?

1.6 ¿Qué zonas forman parte de esta comunidad de regantes (hay pueblos)?

2 Desarrollo de sistemas de regadío

2.1 Desarrollo tecnológico

La siguiente tabla puede rellenarse durante la entrevista, por lo que no es necesario transcribir esta parte. Las preguntas que figuran a continuación sirven para rellenar la tabla y para pasar rápidamente por esta parte.

Tipo	Periodo	Comparte en la zona	Fuente de energía

2.1.1 ¿Al principio se regaba por inundación en la zona de su comunidad de regantes, es verdad? ¿En qué periodo de tiempo se utilizó este tipo de regadío? ¿En qué parte de la superficie de su comunidad de regantes se utilizó?

2.1.2 ¿Cuándo se introdujeron las primeras tuberías aéreas? ¿Se siguen utilizando? ¿En qué parte de la superficie de su comunidad de regantes se utilizaron / utilizan? Qué fuente de energía es necesaria para su funcionamiento?

2.1.3 ¿Cuándo se introdujeron las primeras tuberías subterraneas? ¿En qué parte de la superficie de su comunidad de regantes se utilizó al principo y ahora? Qué fuente de energía se es necesaria para su funcionamiento?

2.1.4 ¿Qué porcentaje de pivots hay en SMP/ SMI? ¿Ventajas y desventajas de los pivots frente a los aspersores?

2.1.5 ¿Se ha usado algun tipo o alguna infraestructura de regadío que no se ha mencionado ?

2.1.6 ¿Qué procesos de drenaje estaban/están asociados al desarrollo del sistema de regadío de su comunidad? ¿Cuándo? ¿Por qué?

2.2 Impulsores de los cambios

2.2.1 ¿Todas las explotaciones pasaron por el mismo desarrollo al mismo tiempo?

Si no es así: ¿Cuáles fueron las diferencias? ¿Por qué?

2.2.2 Me gustaría repasar los cambios en el regadío con más detalle. Centrémonos ahora en la introducción de las tuberías aéreas. ¿Puede explicar por qué se han introducido estas?

2.2.3 ¿Cuál ha sido el papel de eso comunidad de regantes en el comienzo con la tubería aérea? ¿Qué le hizo introducir las tuberías aéreas? ¿Por qué (no) apoyaron ese cambio? ¿Qué otros personas, organizaciones y acontecimientos influyeron? ¿Cómo?

2.2.4 ¿ Qué partes de las tuberías aéreas pagó la comunidad de regantes ? ¿Quién más ayudó con la financiación?

Qué parte de las tuberías aéreas instaló la comunidad de regantes? ¿ Y el resto, quién lo instaló?

2.2.5 Centrémonos ahora en la introducción de las tuberías subterraneas. ¿Puede explicar por qué se han introducido estas?

2.2.6 ¿Cuál ha sido el papel de su comunidad de regantes en el cambio a las tuberías subterraneas? ¿Qué les llevó a impulsar las tuberías subterraneas? ¿Qué otros personas, organizaciones y acontecimientos influyeron? ¿Cómo? ¿Sabes quién tuvo por primera vez la idea de introducír tubería subterránea en el Páramo?

2.2.7 ¿ Qué partes de las tuberías subterraneas pagó la comunidad de regantes ? ¿Quién más ayudó con la financiación?

Qué parte de las tuberías subterraneas instaló la comunidad de regantes ? ¿ Y el resto, quién lo instaló?

2.2.8 ¿Por qué se (no) ha dejado de regar por inundación ?

Si otro tipo había sido usado, también pregunta 2.2.7 hasta aquí por este tipo.

2.2.9 ¿Cuáles fueron las leyes o medidas importantes que el gobierno implementó en relación con el desarrollo de los sistemas de regadío? ¿Cuándo se aplicaron? ¿Por qué eran importantes?

2.2.10 ¿Cómo influyeron en el desarrollo de los sistemas de regadío?

2.2.11 He leído que se han realizado votaciones sobre los cambios en los sistemas de regadío. ¿Cuándo fue la primera votación sobre la modernización? ¿Cuál fue el resultado? *Si no:* ¿Por qué la gente no quería? ¿Y cuándo han cambiado su opinión? ¿Por qué? ¿Quién las organizó?

Si no lo ha mencionado ya: ¿Cómo fue la resistencia de los agricultores al principio en cuanto a la modernización? ¿Cómo lo habéis afrontado?

2.2.14 ¿Está satisfecho con el tipo de regadío actual? ¿Por qué?

Si no es así: ¿Cómo le gustaría cambiarlo?

3 Cambios en el paisaje

3.1 Elementos del paisaje

3.1.1 ¿Cómo ha cambiado el paisaje en la zona de esta comunidad de regantes a lo largo del tiempo? ¿Cuándo se produjeron los cambios? ¿Por qué se produjeron los cambios?

3.1.2 ¿Hubo una época en la que se plantaron más árboles? ¿Cuándo? ¿Por qué? Y cuándo se quitaron? ¿Por qué?

3.2 Concentración parcelaria

3.2.1 ¿Cuántas veces se ha realizado una concentración parcelaria en esta comunidad de regantes?

3.2.2 ¿Cuándo se concentraron las tierras por primera / segunda /... vez? ¿Qué se hizo? ¿Por qué?

Si no se ha mencionado ya: ¿Cómo se relacionaron las concentraciones parcelarias con los cambios en el regadío? ¿Quién decidió la concentración parcelaria?

3.2.3 ¿El proceso fue simultáneo para toda la comunidad de regantes? ¿Por qué (no)?

4 Consecuencias de sostenibilidad: Dimensión medioambiental

4.1 Agua

4.1.1 ¿Cuánta agua se utiliza en su comunidad para el regadío al año?

¿Cómo ha cambiado esto con el tiempo? ¿Cuándo se produjeron los principales cambios? ¿Por qué?

4.1.2 ¿Cuál es la proporción de aguas sobrantes utilizadas para el regadío?

¿Ha cambiado esto con el tiempo? En caso afirmativo: ¿Cómo? ¿Cuándo? ¿Por qué?

4.1.3 ¿Adónde va a parar el agua utilizada para el regadío? ¿Cómo ha cambiado su calidad a lo largo de los años? ¿Cuándo se produjeron los principales cambios? ¿Por qué? *Si no se ha mencionado ya:* ¿Hay más / menos / la misma cantidad de residuos en el agua?

4.1.4 ¿Ha cambiado la calidad del agua de regadío que es usada a lo largo de los años? *En caso afirmativo:* ¿Cómo? ¿Cuándo? ¿Por qué?

4.1.5 ¿Hay problemas por nitritos/nitratos en esta zona? ¿Hay algún estudio con datos que nos puedas facilitar? Qué soluciones se han adoptado para resolver este problema?

4.1.6 ¿Qué usos se le da al agua procedente de la Estación Depuradora de Aguas Residuales de Santa María del Páramo?

4.2 Energía

4.2.1 ¿Cuánta energía [GigaJoules/año] se utiliza para el regadío en su comunidad al año?

4.2.2 ¿Cómo ha cambiado la cantidad de energía utilizada para el regadío desde el primer tipo de sistema de regadío? ¿Por qué?

4.2.3 ¿Se van a instalar placas solares para dar electricidad a las estaciones de bombeo en esta zona? Nos han hablado de un proyecto en la Milla, que de momento está parado.

5 Consecuencias de sostenibilidad: Dimensión económica

5.1 Ingresos y costes

5.1.1 ¿Cómo han cambiado los gastos de agua de regadío en su comunidad a lo largo de los años? ¿Por qué?

5.2 Tarifas e impuestos sobre el agua

5.2.1 ¿Cuál es el impuesto del agua en su comunidad de regantes? (Volumen / superficie / basada en volumen y superficie / tarifa plana / otra)

5.2.2 ¿Ha cambiado esto a lo largo de los años? En caso afirmativo: ¿Cuándo? ¿Cómo? ¿Por qué?

5.2.3 ¿Ha cambiado el valor de los impuestos del agua a lo largo de los años? *En caso afirmativo:* ¿Cuándo? ¿Cómo? ¿Por qué?

5.2.4 ¿Qué otros impuestos sobre el agua existen? ¿Han cambiado a lo largo de los años? *En caso afirmativo:* ¿Cuándo? ¿Cómo? ¿Por qué?

6 Consecuencias de sostenibilidad: Dimensión social

6.1 Compromiso social

6.1.1 ¿En qué medida están unidos los agricultores por aquí? ¿Cómo ha cambiado esto a lo largo de los años? ¿Por qué?

6.1.2 ¿Qué papel tienen las relaciones entre los agricultores en el regadío? ¿Cómo ha cambiado esto a lo largo de los años? ¿Por qué?

6.2 Papel de la administración

6.2.1 ¿Cuál es el grado de compromiso de las autoridades locales para responder a sus necesidades? ¿Ha cambiado esto a lo largo de los años? En caso afirmativo: ¿Cuándo? ¿Cómo? ¿Por qué?

6.2.2 ¿Existen instituciones formales o informales para la gestión de conflictos? En caso afirmativo, ¿cuáles y cuál es su función? ¿Ha cambiado esto a lo largo de los años? En caso afirmativo: ¿Cuándo? ¿Cómo? ¿Por qué?

6.2.3 ¿En qué medida cree que son justas las normas de asignación de agua? ¿Han cambiado a lo largo de los años? En caso afirmativo: ¿Cuándo? ¿Cómo? ¿Por qué?

6.2.4 ¿Qué grado de participación cree que tiene en la toma de decisiones sobre la gestión del agua en esta zona? ¿Ha cambiado esto a lo largo de los años? En caso afirmativo: ¿Cuándo? ¿Cómo? ¿Por qué?

6.2.5 ¿Cuál es su grado de satisfacción con respecto a la participación? ¿Ha cambiado a lo largo de los años? En caso afirmativo: ¿Cuándo? ¿Cómo? ¿Por qué? ¿Dónde le gustaría tener más voz?

7 Perspectivas de la comunidad de regantes sobre la sostenibilidad

7.1 Entendimiento de la sostenibilidad

7.1.1 ¿Qué significa por usted la palabra sostenibilidad?

7.2 Sostenibilidad de los sistemas de regadío

7.2.1 ¿Qué criterios debe cumplir un sistema de regadío agrícola para ser sostenible?

7.2.2 De los diferentes sistemas de regadío, ¿cuál es el más sostenible para la agricultura de su comunidad? ¿Por qué?

7.2.3 ¿Cuál es el menos sostenible? ¿Por qué?

7.2.4 ¿Cómo califica el desarrollo del sistema de regadío agrícola en la zona de su comunidad en cuanto a sostenibilidad? ¿Qué impactos negativos ha tenido? ¿Qué beneficios ha tenido?

7.2.5 ¿Qué medidas son necesarias para hacer más sostenible el actual sistema de regadío agrícola?

Preguntas finales

- ¿Hay algo que desee añadir a nuestra conversación de hoy?
- ¿Tiene algún mapa o documento sobre el desarrollo del sistema de regadío que pueda sernos útil? Incluso de los diferentes sectores de la modernización?
- Tenéis algún estudio socioeconómico / agroindustrial / medioambiental que se haya hecho en relación con la modernización en Santa María del Páramo?
- Si todavía tuviéramos alguna pregunta de seguimiento, ¿podríamos ponernos en contacto con usted por teléfono?
- ¿Le interesaría ser informado de los resultados del estudio?

Desarrollo de sistemas de regadío: Preguntas de la entrevista (Environmental experts)

Entrevistador:	
Código del entrevistado:	
Fecha y hora de la entrevista:	
Lugar de la entrevista:	
Tipo de entrevista::	□ Cara a cara □ Otro: ______________
Duración de la entrevista:	
Comentarios sobre la situación de la entrevista (ambiente, molestias, observaciones):	
Nombre de la organización medioambiental:	
Sexo del entrevistado:	□ mujer □ hombre □ otro □ sin respuesta
Edad del entrevistado:	
Papel en la organización medioambiental:	

1 Biografía y antecedentes

1.1 Para empezar, ¿podría hablarme de su función en la organización medioambiental?

Si no lo ha mencionado ya: ¿En qué año comenzó a formar parte de la organización?

1.2 ¿Cuántos miembros tiene la organización?

1.3 ¿Cuáles son las principales preocupaciones de la organización medioambiental?

Si no se han mencionado ya: ¿En qué regiones actúa?

1.4 ¿Cuál es la relación de la organización con el desarrollo de sistemas de regadío agrícola en el Páramo/ Vega del Tuerto?

2 Perspectivas de la organización medioambiental sobre la sostenibilidad

2.1 Entendimiento de la sostenibilidad

2.1.1 ¿Tiene su organización una declaración de objetivos en la que aparezca el término sostenibilidad? ¿Qué significa el término para usted?

En algunas preguntas vamos a utilizar consecuencias en cuanto a la sostenibilidad. Cuando usemos estas palabras puedes decir consecuencias positivas o negativas en función de lo que opines.

2.2 Sostenibilidad de los sistemas de regadío

2.2.1 ¿Qué criterios debe cumplir un sistema de regadío agrícola para ser sostenible?

2.2.2 De todos los sistemas de regadío que conoces, ¿cuál es el más sostenible para la agricultura? ¿Por qué?

2.2.3 ¿Cuál es el menos sostenible? ¿Por qué?

3 Consecuencias en cuanto a sostenibilidad

3.1 Santa María del Páramo

3.1.1 En mi investigación, me estoy centrando en los alrededores de Santa María del Páramo y Santa María de la Isla. Hablemos primero de Santa María del Páramo. ¿Tiene usted alguna relación con el desarrollo del sistema de regadío desde los años 60 en esta zona?

3.1.2 Desde el punto de vista de la sostenibilidad, ¿qué opina su organización sobre este desarrollo?

3.1.3 Hablemos ahora de las distintas etapas de desarrollo. ¿Qué consecuencias en cuanto a sostenibilidad se asociaron con la introducción de tuberías aéreas en torno a SMP?

Si el conocimiento no es lo suficientemente específico para la zona, la pregunta debería hacerse para la introducción de tuberías aéreas en general.

3.1.4 ¿Qué consecuencias en cuanto a la sostenibilidad se asociaron con el cambio de regadío a tuberías subterráneas en torno a SMP?

Si los conocimientos no son lo suficientemente específicos para la zona, la pregunta debería formularse para el cambio de regadío a tuberías subterráneas en general.

3.1.5 ¿Cómo ha cambiado la diversidad de especies vegetales y animales desde la década de 1960 en torno a Santa María del Páramo? ¿Por qué? ¿Qué especies aumentaron/disminuyeron en número? ¿Cuándo? ¿Por qué?

3.1.6 ¿Cómo ha cambiado la cantidad y la calidad de los humedales desde la década de 1960 en torno a Santa María del Páramo? ¿Cuándo se produjeron los principales cambios? ¿Por qué?

3.1.7 ¿Cuál es la postura de su organización sobre los embalses y canales que se construyeron para llevar el agua a las explotaciones agrícolas de los alrededores de Santa María del Páramo?

3.1.8 ¿Cómo es el estado actual de la canalización en la zona? ¿Qué papel desempeña la pérdida de agua?

3.1.9 ¿Qué otros problemas de sostenibilidad de los que no hemos hablado todavía se le ocurren en relación con el regadío agrícola en Santa María del Páramo? ¿Y los beneficios en cuanto a la sostenibilidad?

3.1.10 ¿Qué desarrollo futuro es importante para hacer más sostenible el regadío agrícola en esta zona? ¿Quién tiene que tomar qué medidas?

3.2 Santa María de la Isla

3.2.1 Ahora hablemos de Santa María de la Isla. ¿Tiene usted alguna relación con el desarrollo del sistema de regadío desde los años 60 en esta zona?

3.2.2 Desde el punto de vista de la sostenibilidad, ¿qué opina su organización sobre este desarrollo?

3.2.3 ¿Qué consecuencias en cuanto a la sostenibilidad se asociaron con la introducción de tuberías aéreas en los alrededores de Santa María de la Isla?

Si los conocimientos no son lo suficientemente específicos para la zona, omita la pregunta.

3.2.4 ¿Cómo ha cambiado la diversidad de especies vegetales y animales desde la década de 1960 en torno a Santa María de la Isla? ¿Por qué? ¿Qué especies han aumentado o disminuido en número? ¿Cuándo? ¿Por qué?

3.2.5 ¿Cómo ha cambiado la cantidad y la calidad de los humedales desde la década de 1960 en torno a Santa María de la Isla? ¿Cuándo? ¿Por qué?

3.2.6 ¿Cuál es la postura de su organización sobre los embalses y canales que se construyeron para llevar el agua a las explotaciones agrícolas de los alrededores de Santa María de la Isla?

3.2.7 ¿Cómo es el estado actual de la canalización en la zona? ¿Qué papel desempeña la pérdida de agua?

3.2.8 ¿Qué otros problemas de sostenibilidad de los que no hemos hablado todavía se le ocurren en relación con el regadío agrícola en Santa María de la Isla? ¿Y los beneficios de la sostenibilidad?

3.2.9 ¿Qué desarrollo futuro es importante para hacer más sostenible el regadío agrícola en esta zona? ¿Quién tiene que tomar qué medidas?

3.3 Ambos sitios

3.3.1 Si comparamos los dos lugares de estudio, ¿dónde fue más sostenible el desarrollo del sistema de regadío? ¿Por qué?

3.3.2 ¿La cantidad de agua utilizada para el regadío, cómo es diferente con inundación, tuberías aéreas y tuberías subterráneas? ¿Y puede decir algo sobre la calidad del agua utilizada para el regadío? ¿Tenéis algunas estadísticas sobre los cambios en la cantidad y la calidad del agua?

3.3.3 ¿En qué se diferencian los sistemas de regadío superficial y subterráneo en cuanto a su impacto en la calidad del suelo? ¿Y en comparación con la inundación? ¿Y la degradación del suelo?

3.3.4 ¿En qué se diferencian los sistemas de regadío superficial y subterráneo en cuanto a su impacto en la biodiversidad? ¿Y en comparación con la inundación?

3.3.5 ¿Qué retos de sostenibilidad ve para el futuro en relación con el regadío agrícola en los dos lugares de estudio?

3.3.6 ¿Qué soluciones ve para estos retos?

Preguntas finales

- ¿Hay algo que desee añadir a nuestra conversación de hoy?
- Tenéis algún documento o algunas estadísticas en cuenta al desarrollo de sistemas de regadio en estas zonas que podrían ser útil para nosotros? Por ejemplo sobre los especies, o sobre la evolución de la aplicación de fertilizantes y productos fitosanitarios?
- Si todavía tuviéramos alguna pregunta de seguimiento, ¿podríamos ponernos en contacto con usted por teléfono?
- ¿Le interesaría ser informado de los resultados del estudio?

Desarrollo de sistemas de regadío: Preguntas de la entrevista (Regional government)

Entrevistador:	
Código del entrevistado:	
Fecha y hora de la entrevista:	
Lugar de la entrevista:	
Tipo de entrevista::	□ Cara a cara □ Otro: ______________
Duración de la entrevista:	
Comentarios sobre la situación de la entrevista (ambiente, molestias, observaciones):	
Sexo del entrevistado:	□ mujer □ hombre □ otro □ sin respuesta
Edad del entrevistado:	
Papel en el gobierno:	

Papel de la persona / función del gobierno regional

- Para empezar, ¿podría hablarme de su papel en el desarrollo de los sistemas de regadío?
  Si no lo ha mencionado ya: ¿Cuáles son tus tareas? ¿Desde cuándo las realizas?

- ¿Y cuál es el papel del gobierno regional en el desarrollo de los sistemas de regadío? ¿Qué tareas hacéis exactamente?
  Si no lo ha mencionado ya: ¿Dónde actuáis?

- *Si no lo ha mencionado ya:* ¿Cuál ha sido el papel en el desarrollo de los sistemas de regadío en Santa María del Páramo? ¿Y en el desarrollo de los sistemas de regadío en Santa María de la Isla?
- También tuviste/ tuvisteis un papel en la introducción de tuberías aéreas en estas regiones?

Cambios de regadío

- ¿Cuáles fueron las leyes o medidas importantes que el gobierno implementó en relación con el desarrollo de los sistemas de regadío? ¿Cuándo se aplicaron? ¿Por qué eran importantes? ¿Cómo influyeron en el desarrollo de los sistemas de regadío?
- Sabes por qué la tubería aérea ha sido introducida más tarde en SMI que en SMP? Sabes de donde vino la idea de instalar las primeras tuberías aéreas?
- ¿Qué criterios tienen que ser cumplidos para que una zona se pueda modernizar?
- ¿Cuáles son los pasos de la transformación a tubería subterránea?
- Si lo sabes: ¿Dónde se hizo la primera modernización? ¿Por qué se hizo? ¿Cómo surgió la idea?
- ¿Cómo funciona la financiación para la modernización? ¿Ha cambiado esto a lo largo de los años?
- Con quién colaboráis/ trabajáis juntos en cuanto a las modernizaciones? ¿Como es la colaboración?
- ¿Qué comunidades todavía no han dicho “si” a la modernización? ¿Por qué crees que no están interesados?
- ¿Por qué la modernización en SMI es mucho mas tarde que en SMP? ¿Cuándo se aprobó? ¿Por qué la modernización en Villarnera se va a realizar 8 años después de que el pueblo la haya aprobado?
- ¿Qué instalaciones técnicas son necesarias para la modernización?¿Es lo mismo con pivot y pajaritos?
- ¿Cuál es la proporción de agricultores que compran un pivot después de la modernización? Qué ventajas / desventajas tiene un pivot en comparación con los pajaritos/aspersores?
- ¿Qué subvenciones pueden recibir los agricultores en relación con el riego? ¿Cómo han cambiado las subvenciones a lo largo de los años?
- ¿Podrías contarnos cómo funcionan las subvenciones para la instalación de placas solares que proporcionen electricidad a las estaciones de bombeo asociadas al sistema de regadío modernizado? ¿Se podrá utilizar toda la energía generada en ellas? ¿Qué se hará con la energía sobrante? ¿Hay proyectadas nuevas instalaciones de placas solares en otras zonas? ¿En el Páramo?
- ¿Por qué la rentabilidad de la remolacha ha bajado tanto en los últimos años?
- ¿Cómo esperáis que los cultivos vayan a cambiar con la modernización?
- En el análisis del sector agroindustrial se dice que la concentración parcelaria y la modernización mejoran la conservación del suelo y del paisaje. ¿Cómo exactamente?

- ¿Hay lugares donde se aumenta la superficie utilizada por la agricultura debido a la modernización?
- Los agricultores cuentan que un 5% de sus tierras dejan de ser suyas debido a la modernización y pasan a ser del Estado. ¿Por qué? ¿Cuál es el uso que se da a esas tierras?

Preguntas finales

- Tienes alguna información / planes / mapas / documentos que podrías darnos, en cuanto a:
  - ¿Planos de las obras de la modernización?
  - Cuando se hicieron las diferentes votaciones, concentraciones parcelarias y modernizaciones del riego (en las comunidades / los pueblos de SMI/ SMP)?
  - ¿Desarrollo de números de pivots utilizados?
  - Desarrollo de calidad de agua/ suelo (concentraciones de fertilizantes/ nitrógenos etc. en el agua / en el suelo)
  - Desarrollo de cantidad de agua utilizada para el riego
  - Desarrollo de cantidad de energía utilizada para el riego
- Si todavía tuviéramos alguna pregunta de seguimiento, ¿podríamos ponernos en contacto con usted por teléfono?
- ¿Le interesaría ser informado de los resultados del estudio?

Desarrollo de sistemas de regadío: Preguntas de la entrevista (Irrigation union)

Entrevistador:	
Código del entrevistado:	
Fecha y hora de la entrevista:	
Lugar de la entrevista:	
Tipo de entrevista::	□ Cara a cara □ Otro: ______________
Duración de la entrevista:	
Comentarios sobre la situación de la entrevista (ambiente, molestias, observaciones):	
Nombre del sindicato:	
Sexo del entrevistado:	□ mujer □ hombre □ otro □ sin respuesta
Edad del entrevistado:	
Papel en el sindicato:	

Papel de la persona / función del sindicato

- Para empezar, ¿podría hablarme de su papel en el desarrollo de los sistemas de regadío?
  Si no lo ha mencionado ya: ¿Cuáles son tus tareas? ¿Desde cuándo las realizas?

- ¿Y cuál es el papel del sindicato en el desarrollo de los sistemas de regadío? ¿Qué tareas hacéis exactamente?
  Si no lo ha mencionado ya: ¿Dónde actuáis?

- *Si no lo ha mencionado ya:* ¿Cuál ha sido el papel en el desarrollo de los sistemas de regadío en Santa María del Páramo? ¿Y en el desarrollo de los sistemas de regadío en Santa María de la Isla?
- También tuviste/ tuvisteis un papel en la introducción de tuberías aéreas en estas regiones?

- ¿Cuáles han sido los problemas, en relación al regadío, a los que te has tenido que enfrentar durante todos estos años? ¿Cuáles son las diferentes posturas de los agricultores frente a la modernización? ¿Cómo se ha conseguido que aquellos agricultores reacios al cambio al final estén de acuerdo con el?

Cambios de regadío

- ¿Cuáles fueron las leyes o medidas importantes que el gobierno implementó en relación con el desarrollo de los sistemas de regadío? ¿Cuándo se aplicaron? ¿Por qué eran importantes? ¿Cómo influyeron en el desarrollo de los sistemas de regadío?

- *Si no se han mencionado todavía:* ¿Qué papel ha desempeñado/desempeña la ley de aguas en el desarrollo de los sistemas de regadío?
- Sabes por qué la tubería aérea ha sido introducida más tarde en SMI que en SMP? Sabes de donde vino la idea de instalar las primeras tuberías aéreas?
- ¿Qué criterios tienen que ser cumplidos para que una zona se pueda modernizar?
- ¿Cuáles son los pasos de la transformación a tubería subterránea?
- Con quién colaboráis/ trabajáis juntos en cuanto a las modernizaciones? ¿Como es la colaboración?
- Si lo sabes: ¿Dónde se hizo la primera modernización? ¿Por qué se hizo? ¿Cómo surgió la idea?
- ¿Cuándo ha cambiado la votación sobre la concentración parcelaria de mayoría absoluta a mayoría simple? ¿Por qué?
- ¿También se convierten algunas tierras de secano al regadío en los procesos de modernización?
- ¿Cómo funciona la financiación para la modernización? ¿Ha cambiado esto a lo largo de los años?
- ¿Qué comunidades todavía no han dicho “si” a la modernización? ¿Por qué crees que no están interesados?
- Podrías explicarnos la evolución de las comunidades de regantes en la zona de Santa María de la Isla…
    - ¿siguen actuando de forma individual o ahora a través de la única comunidad de regantes del Bajo Tuerto?
    - Todas las comunidades han aprobado la modernización?
    - Sabes si alguna otra comunidad de la región no ha aprobado la modernización?
    - Cuando fue la votación en la comunidad de regantes de Canal Alto de Villares? Están modernizando ahora en esa zona?

- ¿Por qué la modernización en SMI es mucho mas tarde que en SMP? ¿Por qué la modernización en Villarnera se realiza años después de que el pueblo la haya aprobado?
- ¿Cuál es la proporción de agricultores que compran un pivot después de la modernización? Qué ventajas / desventajas tiene un pivot en comparación con los pajaritos/aspersores?
- ¿Cómo esperáis que los cultivos vayan a cambiar con la modernización?
- ¿Por qué la rentabilidad de la remolacha ha bajado tanto en los últimos años?
- ¿Hay lugares donde se aumenta la superficie utilizada por la agricultura debido a la modernización?
- ¿Dónde exactamente/ qué comunidades han tenido que acabar con el riego este año el 20 de agosto? ¿Desde cuándo lo sabían los agricultores? Quién lo decidió / por qué en otros sitios no?
- ¿Podrías contarnos cómo funcionan las subvenciones para la instalación de placas solares que proporcionen electricidad a las estaciones de bombeo asociadas al sistema de regadío modernizado? ¿Se podrá utilizar toda la energía generada en ellas? ¿Qué se hará con la energía sobrante? ¿Hay proyectadas nuevas instalaciones de placas solares en otras zonas?
- ¿Por qué hay problemas de nitratos y nitritos en la margen derecha del río Órbigo? ¿Hay algún informe con resultados de analíticas? ¿Podrías proporcionárnoslos o decirnos dónde conseguirlos? ¿Se están tomando medidas para evitar que estos problemas se sigan produciendo?

Preguntas finales

- Tienes alguna información / planes / mapas / documentos que podrías darnos, en cuanto a:
    - Planos de las obras de la modernización?
    - Cuando se hicieron las diferentes votaciones, concentraciones parcelarias y modernizaciones del riego (en las comunidades / los pueblos de SMI/ SMP)?
- Si todavía tuviéramos alguna pregunta de seguimiento, ¿podríamos ponernos en contacto con usted por teléfono?
- ¿Le interesaría ser informado de los resultados del estudio?

Desarrollo del sistema de regadío: Declaración de conformidad

Las investigaciones realizadas en el marco del proyecto internacional e interdisciplinario SIPATH (Sustainable Agricultural Intensification Pathways in Europe) indicaron un cambio importante en el regadío agrícola en torno a Santa María del Páramo desde la década de 1960. En el marco de mi tesis de máster, sigo investigando el desarrollo de los sistemas de regadío agrícola y los cambios resultantes en torno a Santa María del Páramo, así como en la zona de Santa María de la Isla. Para ello, mi compañera Virginia me ayuda a realizar entrevistas con diferentes actores. Entre ellos hay 10 agricultores de los dos lugares.

En la entrevista, hacemos preguntas sobre el desarrollo del regadío agrícola, las características de las explotaciones, los cambios en el paisaje y los resultados de la sostenibilidad. Las respuestas que nos proporcione ayudarán a comprender la evolución del regadío agrícola en el pasado y sus repercusiones.

La participación en este estudio no entraña ningún riesgo. Las respuestas que dé en la entrevista serán anónimas y sólo se utilizarán para mi tesis de máster y las actividades relacionadas con el proyecto SIPATH.

La participación en este estudio es voluntaria: No tiene que responder a ninguna pregunta que no quiera y puede interrumpir la entrevista en cualquier momento.

Para poder evaluar sus respuestas, es importante que grabemos la entrevista.

☐ Sí, se puede grabar la entrevista.

Con mi firma, confirmo que he comprendido la información anterior y acepto voluntariamente participar en esta encuesta.

Nombre del participante: ____

Firma ______________________________ Fecha ____________________________________

Si tiene alguna pregunta sobre este estudio, no dude en ponerse en contacto conmigo:

Fabienne Frey (University of Bern)
Hallerstrasse 12
3012 Bern
fabienne.frey@students.unibe.ch

D: SIPATH Land Use Classification

SIPATH NAME	DESCRIPTION	LAND USE CLASS	SHAPE	MINIMUM SIZE AND DELIMINATION (FROM GREENVEINS)	CODE
WATER	includes all types of running and standing water bodies	semi-natural	polygon	5x5 m. streams/ditches must be > 0.5 m wide.	1
WETLANDS	Wetlands, with the water table at or above ground level for at least half of the year, dominated by herbaceous or ericoid vegetation.	semi-natural	polygon	5x5 m	2
EXTENSIVE GRASSLAND	extensive grassland that is used (cut or grazed) ≤3x per year. This may include dry grassland, seasonally wet grassland, or wood-land fringes.	semi-natural	polygon	5x5 m	3
INTENSIVE GRASSLAND	intensively used grassland that has > 3 uses (cuts or grazings) per year. This is usually mesic grassland (E2). Or the grassland is sown for fodder on pur-pose and therefore has a typical and reduced spe-cies mixture.	agricultural	polygon	5x5 m	4
HEATHLAND, SCRUB AND TUNDRA	Non-coastal land which is dry or only seasonally inundated (with the water table at or above ground level for less than half of the year) with greater than 30% vegetation cov-er. Tundra is characterized by the presence of perma-frost. Heathland and scrub are defined as vegetation dominated by shrubs or dwarf shrubs of species that typically do not ex-ceed 5 m maximum height.	semi-natural	polygon	5x5 m	11
SHRUB PLANTATIONS	Plantations of dwarf trees for non-food purpose	agricultural	polygon	5x5 m	5
FOREST	Woodland and recently cleared or burnt land where the dominant vege-tation is, or was until very recently, trees with a can-opy cover of at least 10%.	semi-natural	polygon	10x10 m	6

BAREN LAND	Rocky or otherwise baren soil areas with less than 30% vegetation cover	semi-natural	polygon	5x5 m	10
CROPS	annual crop production fields such as cereals that are not covered by grass	agricultural	polygon	5x5 m	9
SETTLEMENT & ROADS	Primarily human settle-ments, buildings, industri-al developments, the transport network, waste dump sites. Include roads and railroads.	settlement	polygon	5x5 m	8
INTENSIVE ORCHARDS & FRUIT PRODUCTION	Stands of trees cultivated for fruit or flower produc-tion, providing permanent tree cover once mature. Only map as orchard if the trees are too small to be identified individually (< 2 m diameter).	agricultural	polygon	10x10 m	7
FOREST PLANTATION	Area where dominant vegetation is plantation of trees	Semi-natural	polygon	10x10 m	15
FIELD TREES	trees (more than 5 m high) in agricultural land. Does not include tree rows. Since this is a point fea-ture, this may overlay with polygon land classes. May be subdivided into size classes: >5m and <5m	semi-natural	point	> 2 m diameter	1(big) & 2(small)
HEDGEROWS	Woody vegetation forming strips within a matrix of grassy or cultivated land or along roads, typically used for controlling live-stock, marking boundaries or providing shelter. Hedgerows differ from lines of trees (G5.1) in being composed of shrub species, or if composed of tree species then being regularly cut to a height less than 5 m.	semi-natural	line	40 m hedge length, gaps < 25 m (inde-pendent of field boundaries); solitary trees which are not further than 50 m from hedge end to be included as part of the hedgerow. Hedgerows wider than 10 m to be at-tributed as woodland or scrubland.	2
LINES OF TREES	More or less continuous lines of trees forming strips within a matrix of grassy or cultivated land or along roads, typically used for shelter or shad-ing. Lines of trees differ from hedgerows (FA) in being composed of species that can grow to at least 5 m in height and are not regularly cut down to a height below 5 m.	semi-natural	line	should be comprised of a minimum of 3 trees which are less than 50 m apart	1
FIELD WALLS	stone piles in lines, usually as borders to fields or pastures or along roads	semi-natural	line	> 1 m wide and an area > 25 m2	-

OTHER LANDSCAPE ELEMENTS	Stone piles, cultural landscape elements such as rock terraces or special trees that are iconic to a landscape but not captured by any of the above habitat types	anthropogenic	polygons	>5m	14
FIELD MARGIN VEGETATION	<5m around fields, no afforestation, not used actively for agriculture	Semi-natural	Polygon	<5m	12
ABANDONED LAND	Unused land, no more use visible	Semi-natural	Polygon	>5m	13

E: Remote Sensing Codes

SMP Study Site 1985-2012

```
//calculating ndvi
function addNDVI(image) {
    var ndvi = image.normalizedDifference(['B4', 'B3']);
    return image.addBands(ndvi);
        }
//filter for dates and study perimeters
var filtered = L5.filterDate('1985-01-01', '2012-12-31')
               .filterBounds(SMP)
               .map(function(L5){return L5.clip(SMP)});
//mapping function across image collection, filter clouds and create chart
var with_ndvi = filtered.map(addNDVI);
var greenest = with_ndvi.qualityMosaic('nd');
var rgb_vis = {min: 0, max: 0.3, bands: ['B4', 'B3', 'B2']};
Map.addLayer(filtered.median(), rgb_vis, 'RGB (median)');
Map.addLayer(greenest, rgb_vis, 'RGB (greenest pixel)');
print(ui.Chart.image.series(with_ndvi.select('nd'), SMP));
```

SMP study site 2013-2022

```
//calculating ndvi
function addNDVI(image) {
    var ndvi = image.normalizedDifference(['B5', 'B4']);
    return image.addBands(ndvi);
        }
//filter for dates and study perimeters
var filtered = L8.filterDate('2013-11-02', '2022-12-31')
               .filterBounds(SMP)
               .map(function(L8){return L8.clip(SMP)});
//mapping function across image collection, filter clouds and create chart
var with_ndvi = filtered.map(addNDVI);
var greenest = with_ndvi.qualityMosaic('nd');
var rgb_vis = {min: 0, max: 0.3, bands: ['B4', 'B3', 'B2']};
Map.addLayer(filtered.median(), rgb_vis, 'RGB (median)');
Map.addLayer(greenest, rgb_vis, 'RGB (greenest pixel)');
print(ui.Chart.image.series(with_ndvi.select('nd'), SMP));
```

SMI study site 1985-2012

```
//calculating ndvi
function addNDVI(image) {
    var ndvi = image.normalizedDifference(['B4', 'B3']);
    return image.addBands(ndvi);
        }
//filter for dates and study perimeters
var filtered = L5.filterDate('1985-01-01', '2012-12-31')
               .filterBounds(SMI)
               .map(function(L5){return L5.clip(SMI)});
//mapping function across image collection, filter clouds and create chart
var with_ndvi = filtered.map(addNDVI);
var greenest = with_ndvi.qualityMosaic('nd');
var rgb_vis = {min: 0, max: 0.3, bands: ['B4', 'B3', 'B2']};
Map.addLayer(filtered.median(), rgb_vis, 'RGB (median)');
Map.addLayer(greenest, rgb_vis, 'RGB (greenest pixel)');
print(ui.Chart.image.series(with_ndvi.select('nd'), SMI));
```

SMI study site 2013 to 2022

```
//calculating ndvi
function addNDVI(image) {
    var ndvi = image.normalizedDifference(['B5', 'B4']);
    return image.addBands(ndvi);
        }
//filter for dates and study perimeters
var filtered = L8.filterDate('2013-01-01', '2022-12-31')
               .filterBounds(SMI)
               .map(function(L8){return L8.clip(SMI)});
//mapping function across image collection, filter clouds and create chart
var with_ndvi = filtered.map(addNDVI);
var greenest = with_ndvi.qualityMosaic('nd');
var rgb_vis = {min: 0, max: 0.3, bands: ['B4', 'B3', 'B2']};
Map.addLayer(filtered.median(), rgb_vis, 'RGB (median)');
Map.addLayer(greenest, rgb_vis, 'RGB (greenest pixel)');
print(ui.Chart.image.series(with_ndvi.select('nd'), SMP));
```