Between Tradition and Modernization: Multifunctional Smallholder Agriculture and Sustainable Rural Development in the Mediterranean Region

Dissertation
zur Erlangung des Doktorgrades der Naturwissenschaften
an der Fakultät für Mathematik, Informatik und Naturwissenschaften
Fachbereich Erdsystemwissenschaften
der Universität Hamburg

vorgelegt von
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Hamburg, 2021

Fachbereich Erdsystemwissenschaften

Datum der Disputation: 01. April 2022

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Abstract

The adoption of conventional monoculture, mechanization, chemical inputs, and intensive irrigation has resulted in agriculture intensification and the massive short-term production of food. At the same time, in the medium and long terms, these practices generate numerous negative outcomes, such as increased greenhouse gas (GHG) emissions, biodiversity loss, degradation of land, water and ecosystems.

Hence, sustainable alternatives in agriculture are urgently needed. Diverse multifunctional agricultural systems provide numerous services to the environment, society and economy (e.g., biodiversity, recreation opportunities, tourism). One example is terraced smallholder agriculture in the Mediterranean region. It represents the outcome of the long-term convergence of human and environmental trajectories, resulting in a social-ecological system that has proven its stability and resilience over the past ten centuries or more. These farming systems have often maintained their multiple functions for the environment and society. Therefore, research has to investigate these systems, their challenges, and their potential to provide solutions for a social-ecological transformation in agriculture.

This leads to the following overarching research questions of this thesis: (1) What are the challenges and opportunities for sustainable Mediterranean smallholder agriculture, focusing on the Ricote Valley in southeastern Spain? (2) How to support multifunctional agriculture in the Mediterranean region? The Ricote Valley represents a historical agricultural landscape, which is still dominated by smallholders. My aim is to identify leverage points to increase the multifunctionality of agriculture, contribute to sustainable rural development in the Mediterranean region, and give a voice to the needs of smallholders. I use Geographic Information Systems (GIS) and mixed-method approaches, combining qualitative and quantitative data to gain a comprehensive understanding of the research topics and the specificities of the study area.

One of the major challenges identified by local stakeholders of the Ricote Valley is land fragmentation. The average farm in Ricote has an area of 3178 m², two to three water counters for drip irrigation and a standard distance of 240 m between plots. In the first article of my thesis, I developed the Fragmentation Index for Drip Irrigation and Distance Assessment (FIDIDA). FIDIDA quantifies the fragmentation of individual farms. The index is adapted to drip-irrigated agriculture of traditional field systems and aims at guiding strategies to reduce (a) water counters and (b) travelling distance between plots. These strategies have the potential to save costs, time and mitigate GHG emissions on the farm level.

Another challenge for smallholders is land abandonment. Land abandonment is a known phenomenon in remote European rural areas. However, specificities have to be investigated locally. In the second article, I aim to detect and quantify actively used and abandoned terraced fields in the Ricote Valley over the period of 2016–2019 while also exploring reasons for land abandonment over the longer period (i.e., the 1940s to present). I combined GIS-based methods with an expert survey. The results show that abandonment of agricultural terraces is frequent in the Ricote Valley but decreased from 56 % in 2016 to 40 % in 2019. At the same time, small parcels are identified as less vulnerable to land abandonment than larger parcels, and the most important reasons for land abandonment are related to the low income of farmers, land fragmentation, and a lack of farm succession.

Next, I focus on opportunities to reduce GHG emissions in Mediterranean agriculture. Traditional water wheels (spn. *norias*) lift irrigation water on multiple levels of agricultural terraces without producing direct emissions. In the third article, I explore the conservation state and potential for the deployment of *norias* in the Ricote Valley. The findings show that *norias* have been replaced mostly by motor pumps in the study area and that a reactivation of 16 *norias* for water lifting in the Ricote Valley could offset up to 148 t of GHG emissions each year based on a maximum of 8760 working hours/year and compared to the usage of diesel motor pumps. Therefore, rediscovering traditional technologies can contribute to achieving climate actions that reduce GHG emissions (Sustainable Development Goal 13 of the United Nations) while also providing multiple functions and services for sustainable life on land (Sustainable Development Goal 15).

Another opportunity to approach sustainable and multifunctional agriculture is agroecological management. It is based on traditional practices which farmers have used for millennia. These practices minimize external inputs and increase biodiversity compared to conventional practices. I conducted an online survey among farmers in Spain who aim for sustainable food production and promoting biodiversity. Based on their answers, I identify (1) the challenges and opportunities faced in the implementation of agroecological projects, (2) the perceived effects following the introduction of agroecological practices, (3) how farmers adapt to climate change, as well as (4) an Agroecology Index to assess farm agroecology in Spain, based on the management practices used. The results show that the consulted farmers apply on average 9 out of 14 agroecological practices, and 2/3 of the farmers consciously adapt to climate change. Most farmers have observed positive changes in soil, biodiversity and pests after applying agroecological practices. This study shows that agroecological management can avoid negative impacts on the environment and restore the multifunctionality of agriculture, contributing to achieving multiple Sustainable Development Goals.

In conclusion, this thesis identifies challenges for Mediterranean agriculture as well as multiple opportunities to increase the multifunctionality of agriculture by addressing land fragmentation, land abandonment, the reactivation of traditional technologies, as well as agroecological management. European, national and local policies should use these opportunities and focus on supporting multifunctional agriculture, which provides positive services for the environment, society and economy.

Zusammenfassung

Die Einführung konventioneller Praktiken wie der Anbau in Monokulturen, Mechanisierung, chemische Inputs und intensive Bewässerung hat zu einer Intensivierung der Landwirtschaft und einer kurzfristigen massiven Produktion von Nahrungsmitteln geführt. Gleichzeitig führen diese Praktiken mittel- und langfristig zu zahlreichen negativen Folgen wie erhöhten Treibhausgasemissionen, Verlust der biologischen Vielfalt, Degradation von Land, Wasser und Ökosystemen.

Daher werden nachhaltige Alternativen in der Landwirtschaft dringend benötigt. Vielfältige multifunktionale Agrarsysteme erbringen zahlreiche Leistungen für die Umwelt, Gesellschaft und Wirtschaft (z. B. Artenvielfalt, Erholungsmöglichkeiten, Tourismus). Ein Beispiel ist die kleinbäuerliche Terrassenlandwirtschaft im Mittelmeerraum. Sie repräsentiert das Ergebnis der langfristigen Konvergenz von menschlichen und ökologischen Pfaden zu einem sozial-ökologischen System. Die kleinbäuerliche Terrassenlandwirtschaft hat ihre Stabilität und Widerstandsfähigkeit in den letzten zehn Jahrhunderten bewiesen und ihre vielfältigen Funktionen für die Umwelt und Gesellschaft oft beibehalten. Deshalb müssen diese Art der Landwirtschaft, die Herausforderungen, die sich ihr stellen, und ihr Potenzial, Lösungsansätze für einen sozial-ökologischen Wandel in der modernen Landwirtschaft zu liefern, erforscht werden.

Das führt zu folgenden übergeordneten Forschungsfragen in dieser Arbeit: (1) Was sind die Herausforderungen und Chancen für eine nachhaltige kleinbäuerliche Landwirtschaft im Mittelmeerraum mit Fokus auf das Ricote-Tal im Südosten Spaniens? (2) Wie kann multifunktionale Landwirtschaft im Mittelmeerraum unterstützt werden? Das Ricote-Tal stellt eine multifunktionale Agrarlandschaft dar, die noch immer von kleinräumiger Landwirtschaft dominiert wird. Mein Ziel ist es, Ansatzpunkte zu identifizieren, um die Multifunktionalität der Landwirtschaft zu erhöhen und zu einer nachhaltigen ländlichen Entwicklung im Mittelmeerraum beizutragen. Außerdem möchte ich die Bedürfnisse von Kleinbäuerinnen und Kleinbauern aufzeigen. Ich habe Geographische Informationssysteme (GIS) sowie Mixed-Method-Ansätze verwendet, die qualitative und quantitative Daten kombinieren, um ein umfassendes Verständnis der Forschungsthemen und der Besonderheiten des Untersuchungsgebiets zu erlangen.

Eine der größten Herausforderungen, die von lokalen Akteurinnen und Akteuren in Ricote identifiziert wurde, ist Landfragmentierung. Die durchschnittliche Parzellengröße in Ricote misst 3178 m², enthält zwei bis drei Wasserzähler und hat eine Standarddistanz von 240 m zwischen den einzelnen Feldern. Im ersten Artikel meiner Dissertation habe ich den „Fragmentation Index for Drip Irrigation and Distance Assessment“ (FIDIDA) entwickelt. FIDIDA quantifiziert die Fragmentierung auf Betriebsebene. Der Index ist an traditionelle Landwirtschaft mit Tröpfchenbewässerung angepasst und zielt darauf ab, Strategien zur Reduktion von Wasserzählern und Fahrstrecke anzustoßen. Diese Strategien haben das Potenzial, Kosten und Zeit zu sparen sowie die Treibhausgasemissionen auf Betriebsebene zu verringern.

Eine weitere Herausforderung für Kleinbäuerinnen und Kleinbauern ist die Landaufgabe. Landaufgabe ist ein bekanntes Phänomen in den abgelegenen ländlichen Gebieten Europas.

Ortsspezifische Ausprägungen müssen jedoch lokal untersucht werden. Der zweite Artikel zielt darauf ab, aktiv genutzte und ungenutzte Terrassenfelder im Ricote-Tal im Zeitraum 2016–2019 zu erkennen und zu quantifizieren. Gleichzeitig werden die Gründe für die Landaufgabe über einen längeren Zeitraum (d.h. 1940er bis heute) untersucht. Ich habe GIS-basierte Methoden mit einer Befragung von Expertinnen und Experten kombiniert. Die Ergebnisse zeigen, dass der Anteil an Brache landwirtschaftlicher Terrassen im Ricote-Tal hoch ist, aber von 56 % im Jahr 2016 auf 40 % im Jahr 2019 zurückgegangen ist. Gleichzeitig werden kleine Parzellen als weniger anfällig für Landaufgabe identifiziert als größere Parzellen. Die wichtigsten Gründe für die Landaufgabe stehen im Zusammenhang mit dem geringen Einkommen der Landwirtinnen und Landwirte, der Landfragmentierung und einer fehlenden Hofnachfolge.

Als nächstes konzentriere ich mich auf Möglichkeiten zur Emissionsreduzierung in der mediterranen Landwirtschaft. Im dritten Artikel untersuche ich den Erhaltungszustand und das Potenzial für den Einsatz traditioneller Wasserräder (spn. *norias*) im Ricote-Tal. *Norias* transportieren Wasser zur Bewässerung auf die höheren Ebenen der landwirtschaftlichen Terrassen, ohne direkte Treibhausgasemissionen zu erzeugen. Meine Ergebnisse zeigen, dass die *Norias* im Untersuchungsgebiet größtenteils durch Motorpumpen ersetzt wurden. Eine Reaktivierung der 16 *Norias* für den Wassertransport im Ricote-Tal könnte bei maximal 8760 Arbeitsstunden/Jahr jährlich bis zu 148 t Emissionen einsparen im Vergleich zum Einsatz von Dieselmotorpumpen. Daher kann die Reaktivierung traditioneller Technologien durch eine Reduktion der Treibhausgasemissionen zum Klimaschutz beitragen (Ziel für nachhaltige Entwicklung der Vereinten Nationen Nummer 13) und gleichzeitig Leistungen für ein nachhaltiges Leben an Land bereitstellen (Ziel für nachhaltige Entwicklung 15).

Eine weitere Möglichkeit, um eine nachhaltige und multifunktionale Landwirtschaft zu fördern, ist agrarökologisches Management. Es basiert auf traditionellen Praktiken, die von Landwirtinnen und Landwirten seit Jahrtausenden angewendet werden. Diese Praktiken minimieren externe Inputs und erhöhen die Artenvielfalt im Vergleich zu konventionellen Praktiken. Im vierten Artikel führte ich eine Online-Umfrage unter Landwirtinnen und Landwirten in Spanien durch, die sich für eine nachhaltige Nahrungsmittelproduktion und die Artenvielfalt einsetzen. Basierend auf ihren Antworten identifiziere ich (1) die Herausforderungen und Chancen für agrarökologische Projekte, (2) welche Auswirkungen nach der Einführung von agrarökologischen Praktiken wahrgenommen wurden, und (3) wie Landwirtinnen und Landwirte sich an den Klimawandel anpassen. Außerdem entwickelte ich (4) einen Agrarökologieindex, der die Agrarökologie von landwirtschaftlichen Betrieben in Spanien basierend auf den verwendeten Praktiken bewertet. Die Ergebnisse zeigen, dass die befragten Landwirtinnen und Landwirte im Durchschnitt 9 von 14 agrarökologischen Praktiken anwenden und 2/3 der Befragten ihre Praktiken bewusst an den Klimawandel anpassen. Die meisten Landwirtinnen und Landwirte beobachten positive Veränderungen im Boden, in der Artenvielfalt und im Schädlingsbefall, nachdem sie agrarökologische Praktiken angewendet haben. Diese Studie zeigt, dass agrarökologisches Management negative Auswirkungen auf die Umwelt vermeiden, die Multifunktionalität der Landwirtschaft wiederherstellen und zur Erreichung mehrerer Ziele für nachhaltige Entwicklung beitragen kann.

Um Ansatzpunkte für eine nachhaltige ländliche Entwicklung im Mittelmeerraum zu identifizieren, untersucht diese Dissertation die Themen Landfragmentierung, Landaufgabe, Reaktivierung traditioneller Technologien sowie agrarökologisches Management. Dabei werden Herausforderungen sowie zahlreiche Chancen identifiziert, um die Multifunktionalität der mediterranen Landwirtschaft zu erhöhen. Die europäische, nationale und lokale Politik sollte diese Chancen nutzen und sich auf die Förderung einer multifunktionalen Landwirtschaft konzentrieren, die positive Leistungen für die Umwelt, Gesellschaft und Wirtschaft erbringt.

Contents

List of Publications

1. Heider, K.; Rodriguez Lopez, J. M.; García Avilés, J. M.; Balbo, A. L. (2018): Land fragmentation index for drip-irrigated field systems in the Mediterranean: A case study from Ricote (Murcia, SE Spain). In Agricultural Systems 166, 48–56. DOI: 10.1016/j.agsy.2018.07.006

As the lead author, Katharina Heider contributed approx. 80 % of the article's content. In collaboration with her co-authors, she developed the research idea. She conducted the literature review, GIS-analysis, prepared the first draft and led the review process.

2. Heider, K.; Rodriguez Lopez, J. M.; Balbo, A. L.; Scheffran, J. (2021): The state of agricultural landscapes in the Mediterranean: smallholder agriculture and land abandonment in terraced landscapes of the Ricote Valley, southeast Spain. In Regional Environmental Change 21(1), 23. DOI: 10.1007/s10113-020-01739-x

As the lead author, Katharina Heider contributed approx. 80 % of the article's content. Her contribution consisted in the development of the research idea, literature review, GIS-analysis, data validation and field research, preparation of the first draft, and leading the review process.

3. Heider, K.; Quaranta, E.; García Avilés, J. M.; Rodriguez Lopez, J. M.; Balbo, A. L.; Scheffran, J. (2021): Reinventing the wheel - The preservation and potential of traditional water wheels in the terraced irrigated landscapes of the Ricote Valley, southeast Spain. In Agricultural Water Management 259, 107240. DOI: 10.1016/j.agwat.2021.107240

As lead author, Katharina Heider contributed approx. 65 % of the article's content. In collaboration with her co-authors, she developed the research idea. She conducted the literature review and data collection, prepared the first draft, and led the review process. Emanuele Quaranta calculated the *noria* dimensions, mitigation of GHG emissions and power production potential of *norias*.

4. Heider, K.; Rodriguez Lopez, J. M.; Bischoff, A.; Balbo, A. L.; Scheffran, J. (2022): Towards climate-resilient and biodiverse agriculture: Experiences and potentials in agroecological management in Spain (to be submitted)

As lead author, Katharina Heider contributed approx. 80 % of the article's content. She developed the research idea and conducted the literature review. Moreover, she developed the theoretical and empirical research. The survey was co-designed by the authors and farmers' associations. Katharina Heider conducted the online survey and prepared the first draft.

Additional publications as first author or co-author

This list shows additional articles or chapters, which were published or submitted during the doctoral thesis.

- Balbo, A. L.; García Avilés, J. M.; Hunink, J.; Alcón, F.; Palenzuela Cruz, J. E.; Martinez-Fernández, J.; Puy, A.; Rodriguez Lopez, J. M.; Heider, K.; García Abenza, R.; Scheffran, J. (2020): Challenges and opportunities for historical irrigated agricultural systems in Mediterranean regions: Technical, cultural, and environmental assets for sustainable rural development in Ricote (Murcia, Spain). In Michael Brzoska, Jürgen Scheffran (Eds.): Climate Change, Security Risks, and Violent Conflicts. Essays from Integrated Climate Research in Hamburg: Hamburg University Press, 143-161

- Rodriguez Lopez, J. M.; Heider, K.; Balbo, A. L.; Scheffran, J. (2020): Sustainable access to rural and urban land by integrating local perspectives. The potential of using Information and Communication Technologies. In Michael Brzoska, Jürgen Scheffran (Eds.): Climate Change, Security Risks, and Violent Conflicts. Essays from Integrated Climate Research in Hamburg: Hamburg University Press, 163-173

- Heider, K.; Weinzierl, T.; Schwab, N.; Bobrowski, M.; Schickhoff, U. (2018): Future agricultural conditions in the Nepal Himalaya-A fuzzy logic approach using high resolution climate scenarios. In Die Erde 149 (4), 227-240. DOI: 10.12854/erde-2018-382

- Santos, A.; Colombo, V.; Heider, K; Rodriguez Lopez, J.M. (2022): A VGI comparison framework based on citizen participation. Comparing volunteered data acquisition methods on informal settlements for two large cities in Latin America. In Santiago Lopez (Ed.): Interdisciplinary Remote Sensing and GIS approaches to Socio-Environmental Research in Latin America: Springer Science (under review)

- Santos, A.; Rodriguez Lopez, J. M.; Heider, K.; Steinwärder, L.; Scheffran, J.; Vargas, J. C. (2022): One year of the COVID-19 pandemic in the Global South: Uneven vulnerabilities in Brazilian cities. In Erdkunde (under review)

List of Acronyms

AES	Agroecosystem service
AEDS	Agroecosystem disservice
BIC	Bien de interés cultural (engl. asset of cultural interest)
CAP	Common agricultural policy
DEM	Digital elevation model
EU	European Union
FIDIDA	Fragmentation index for drip irrigation and distance assessment
GHG	Greenhouse gas
GIS	Geographic information system
LiDAR	Light detection and ranging
NDVI	Normalized difference vegetation index
Rpm	Revolutions per minute
SAGA	System for Automated Geoscientific Analyses
SDG	Sustainable development goal
TEK	Traditional ecological knowledge

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1 Introduction

"To us [...] the land is more than a means of production. It is a space of life, culture, identity, an emotional and spiritual environment. Because of that, it's not a commodity, but a fundamental component of life" (Via Campesina 2013).

This citation shows the profound value of land for farmers. More than economic value, it represents emotional, cultural, ecological, and spiritual values. Therefore, agriculture provides more than food. Indeed, the functions of agriculture are numerous. It can contribute to protecting flora and fauna, water, air and soil. It can offset emissions and help to adapt to climate change. Furthermore, agriculture can create diverse and aesthetical landscapes. These landscapes can serve as space for recreation and physical activities. Moreover, agriculture can provide income and employment. Hence, it can create economic, social and ecological values. This is called the multifunctionality of agriculture, and the level of multifunctionality is strongly connected to the management practices used (Cairol et al. 2009; IAASTD 2009; OECD 2001).

During the last decades, many of these functions deteriorated in order to make agriculture more efficient and increase the provision of food. In consequence, production increased significantly (Foley et al. 2011). However, at the same time, the expansion of intensive agriculture based on monocultures and dependent on high inputs contributed to multiple global challenges: (1) climate change, (2) the loss of genetic and functional diversity, (3) land use and land cover changes, (4) depletion of freshwater resources especially in water-scarce regions as well as (5) nitrogen and phosphorus pollution (Campbell et al. 2017). Research has shown that we have left the safe operating spaces of the earth system for most of these challenges and entered the zones of increasing and high risk for abrupt, non-linear and often irreversible environmental changes. The thresholds between safe operating spaces and zones of risk are called planetary boundaries (Rockström et al. 2009; Steffen et al. 2015) and a major driver for the transgression of these boundaries is agriculture (Campbell et al. 2017).

One contribution to stop this transgression is to address agricultural management. Industrial agriculture produces large amounts of GHG emissions during food production, due to energy-intensive irrigation and large machinery, for the production of fertilizer, during transportation and due to deforestation for the expansion of the agricultural area (Campbell et al. 2017). To expand the agricultural area, many natural ecosystems have been converted to agriculture or pastureland (Foley et al. 2005; Habel et al. 2019). This agricultural expansion is responsible for land use, and land cover changes and biodiversity loss (Campbell et al. 2017). The cultivation of monocultures and the application of pesticides, herbicides, and fungicides under conventional management, further intensify the loss of biodiversity (German National Academy of Sciences Leopoldina, acatech – National Academy of Science and Engineering, Union of German Academies of Sciences and Humanities 2018). Moreover, water resources are exploited for the irrigation of agriculture, especially in water-scare regions like the Mediterranean (Cramer et al. 2018).

A redesign of agricultural and food systems based on sustainable management is needed (Eyhorn et al. 2019; Pretty 2018). Experiences from small-scale societies in traditional field systems can give valuable insights on maintaining the multiple positive services of agroecosystems for the environment, society and economy (Barthel et al. 2013; Gómez-Baggethun et al. 2013). These experiences and the traditional knowledge of small-scale societies can inspire sustainable management of agricultural and food systems.

Rediscovering traditional knowledge about sustainable management practices of agroecosystems can contribute to climate-resilience and emission mitigation (Balbo et al. 2016; Gómez-Baggethun et al. 2013; Gómez-Baggethun et al. 2012). Agroecological management practices are based on local traditional ecological knowledge (TEK) and aim for a sustainable farming system stabilizing and optimizing yields while also providing a wide range of other positive services. The main focus of research on agroecological management has been in the Global South (Altieri and Nicholls 2012, 2020; FAO 2018, 2019; Pretty 2018), but an increasing awareness for the negative impacts of industrial agriculture on the environment and society has promoted research on agroecology in the Global North (DeLeijster et al. 2019; DeLeijster et al. 2020; Dolci and Perrin 2018; Guerrero Lara et al. 2019; Silva and Moore 2017). Nevertheless, the implementation and effects of agroecological practices have to be investigated locally.

Furthermore, traditional technologies like water wheels, which were used in traditional field and food systems, can offer opportunities for emission mitigation and sustainable rural development. Often, these technologies are valued for promoting landscape aesthetics as well as the multifunctionality of rural areas by fostering recreation and rural tourism (Gil Meseguer, 2014). Nevertheless, water wheels are increasingly used for renewable power production at low head sites and old mill weirs. This opens up possibilities for re-using traditional water wheels, which have been abandoned during the past decades (Müller and Kaupert, 2004; Quaranta and Revelli, 2018; Quaranta, 2018; Quaranta et al., 2021). Yet, research has to assess the preservation state and the potential of traditional water wheels on specific sites.

On a larger scale, land abandonment and agricultural intensification threaten the existence of smallholder agriculture all over Europe (Chemnitz 2019; Lomba et al. 2019). The effects, the extent, and the reasons for this development have to be explored locally (Lasanta et al. 2017a; Zagaria et al. 2018). One reason for the abandonment of smallholder agriculture might be the fragmentation of agricultural properties. Some of the disadvantages include inefficiencies such as the loss of productive land, hindering of mechanization and automatization processes, and loss of time. At the same time, positive effects of land fragmentation on biodiversity and risk diversification were proven, e.g., relative to soil erosion (Bentley 1987; Crecente et al. 2002; Tan et al. 2006; Tan et al. 2008). There are multiple fragmentation indices aiming to quantify land fragmentation (King and Burton 1982; Latruffe and Piet 2014; Tan et al. 2006; Tan et al. 2008; van Dijk 2003; Vijulie et al. 2012). However, none has been adapted to traditional field systems with drip irrigation.

The advantages of a diverse multifunctional production system have been confirmed by multiple international assessments of experts and many individual scientists (IAASTD 2009; IPES-FOOD 2016). Although smallholder agriculture is threatened in multiple ways, it also offers opportunities to explore TEK and traditional technologies, shedding light on pathways to sustainable rural development. Research needs to learn from the remaining sites using site-specific approaches.

1.1 Objectives and research questions

My overall aim is to identify leverage points to increase the multifunctionality of agriculture and contribute to sustainable rural development in the Mediterranean region, as well as to give a voice to the needs of smallholders. The multifunctionality of agriculture goes hand in hand with the sustainable development of rural areas following the definition of sustainable development as "[…] development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). This leads to the following overarching research questions of this thesis:

- How to support multifunctional agriculture in the Mediterranean region?
- What are the challenges and opportunities for Mediterranean smallholder agriculture, focusing on the Ricote Valley in southeastern Spain?

A major challenge identified for traditional agriculture by local stakeholders in the Ricote Valley is land fragmentation. There are multiple fragmentation indices for different purposes and contexts in the literature, but no fragmentation index is adapted to drip-irrigated agriculture in traditional field systems as it is practiced in the Ricote Valley. This leads to the following research question:

- How to assess agricultural land properties considering the influence of land fragmentation in traditional Mediterranean agroecosystems predominantly made of small farmers?

I aim to assess agricultural land properties and quantify land fragmentation considering transaction costs (i.e., travelling distance, number of water counters, and plot size), which make land management less efficient and less sustainable, in the first article of my thesis. As a result, a new fragmentation index, the Fragmentation Index for Drip Irrigation and Distance Assessment (FIDIDA), is developed which is adapted to the local conditions in the study area.

Besides land fragmentation, land abandonment is a known phenomenon in remote European rural areas (Lomba et al. 2019). Specificities concerning land abandonment have to be further investigated locally, though. Neither its progression nor the reasons have been explored and quantified for the Ricote Valley. This leads to the following research questions:

- What is the state of smallholder agriculture in the Ricote Valley?
- How much of the traditional terraced agriculture in the Ricote Valley was not cultivated between 2016 and 2019?
- What are the reasons for the observed land abandonment over the past decades?

In the second article, I therefore aim to detect and quantify actively used and abandoned terraced fields in the Ricote Valley over the period of 2016–2019[1] while also exploring reasons for land abandonment over the longer period (i.e., the 1940s to present).

The mitigation of GHG emissions is a major challenge to limit global warming and comply with the Paris Climate Agreement (IPCC 2021). While most research concentrates on emission mitigation through the development of new technologies, less effort is put into rediscovering traditional zero-emission technologies and traditional knowledge. In the third article, I bring together tradition and innovation by exploring the preservation state and potential for the deployment of traditional water wheels (*spn. norias*) in the Ricote Valley. Considering these historical elements of the traditional irrigation system in the valley, mitigation opportunities for energy-intensive irrigation might open up, accompanied by other positive services contributing to the multifunctionality of agriculture. This leads to the following research questions:

- What is the current preservation state of *norias* in the Ricote Valley?
- What are the reasons for the observed abandonment of *norias* during the past decades?
- What is the potential of *noria* renovation for a sustainable agricultural system?

Another opportunity to implement sustainable and multifunctional agriculture is agroecological management. Agroecological management is based on traditional practices, which farmers have used for millennia (Elevitch et al. 2018). These practices minimize external inputs like agrochemicals or fossil fuel and increase biodiversity compared to conventional agriculture (Altieri and Nicholls 2012). The fourth article aims to explore sustainable alternatives to conventional management of agroecosystems and provide a tool for the assessment of farm agroecology. Therefore, the potentials of agroecological management are explored theoretically and empirically, based on literature and the experiences of farmers in Spain. Moreover, I developed a framework to assess agroecosystem services in Spain dependent on the management practices used, answering the following research questions:

- What are the opportunities and challenges facing agroecological projects in Spain?
- What are the perceived effects on land degradation and regeneration using agroecological practices in Spain?
- How do farmers adapt agricultural land and water management to climate change in Spain?
- How to assess and explain farm agroecology considering agroecosystem services and disservices?

1.2 Study area

The main study region is the Ricote Valley, located in the Region of Murcia, southeast Spain. The Region of Murcia is known as "the orchard of Europe" because around 70 % of agricultural production of this area is exported to countries of the European Union (EU) (Martin-Gorriz et al. 2021). The climate in the Region of Murcia is semi-arid with strong seasonality. Hot and dry

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[1] The limited time period of 2016-2019 was chosen because of the limited availability of Sentinel data.

summers and mild winter temperatures are typical. In Ricote village, average summer temperatures of 25.5 °C and average winter temperatures of 10.2 °C were recorded between 1971 and 2000 (Garrido Abenza et al. 2013).

The Ricote Valley is located inland and stretches alongside the Segura River, comprising several villages. I include seven villages in my analyses: Abarán, Blanca, Ojós, Ricote, Ulea, Villanueva and Archena with a population of 44,742 in 2020 (Instituto Nacional de Estadística 2021). These villages are located at altitudes between 102 and 400 m (Fig. 1.1) and are surrounded by mountains. Each village contains traditional orchards which consist of agricultural terraces expanding agricultural land to ever higher grounds.

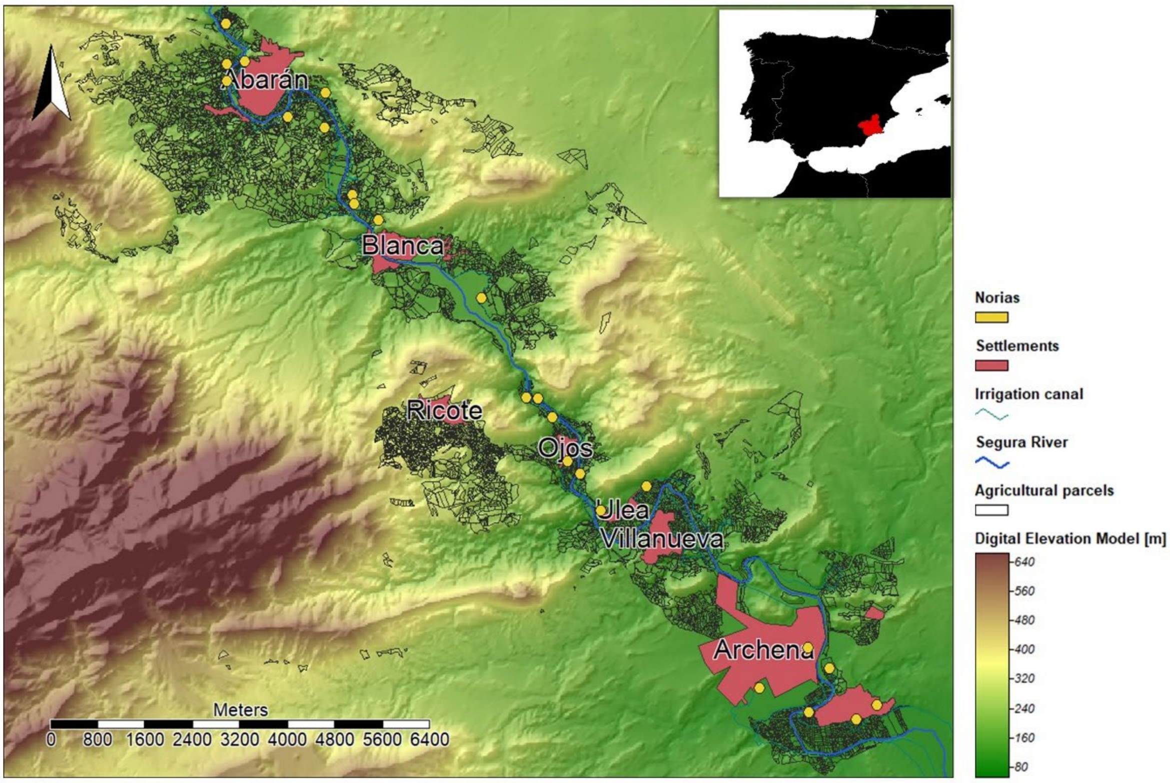

Figure 1.1 The Ricote Valley in the Region of Murcia, southeast Spain: settlements (light red), agricultural parcels, and *norias* (yellow)

The orchards in the Ricote Valley have been cultivated and irrigated with flood-irrigation for many centuries. The hydraulic system to irrigate the orchards of Ricote village was introduced by Amazigh-Berber populations more than 1000 years ago, which makes it one of the oldest known irrigation systems in Europe (Puy and Balbo 2013). Ricote is the only of the seven villages in the valley without direct access to the Segura river. The irrigation system incorporated carefully oriented terraces made of dry-stone walls and small canals. The water used to flow from a perennial spring through excavated channels on the agricultural terraces. In the villages with access to the river, *norias* were used to elevate irrigation water from the irrigation canals to the agricultural terraces. Flood irrigation has been a water-intensive and time-consuming option for farmers, and with technological innovations, the traditional irrigation has changed throughout the valley. Drip irrigation has progressively substituted the traditional irrigation system since 2007 (Puy et al. 2016).

Over time not only the irrigation system has changed but also the cultivated crops. Historical texts show that farmers cultivated various crops, e.g., plum, olive, apricot, orange, lemon, lime, figs, cherries, myrtle, grapes, pomegranates, cedar and alfalfa in Ricote village between the 15th and 16th century. At the beginning of the 17th century, the village already specialized in cash crops cultivating olives and mulberries. The latter is used for silk production (Puy 2014). Since the 1960s, lemon production as cash crops has increasingly substituted olive production (Balbo et al. 2020). Nowadays, the main crops in the study area are lemon, olive, almond and a variety of fruits. Many farmers produce mainly for export but also mixed cultivation for sale and self-supply as well as private gardens are part of the agricultural land in the Ricote Valley.

The agricultural land is highly fragmented. Almost 70 % of farms in Ricote village consist of more than one parcel. A single farm can consist of more than 30 parcels distributed around the orchard. The reason for the high land fragmentation is the traditional heritage system, which grants parts of the land to all siblings within a family. This fragmentation of land is perceived as one of the main challenges for agriculture by local stakeholders (Heider et al. 2018; Heider et al. 2021). An important reason for this perception are additional costs for drip irrigation devices which are needed for every parcel where drip irrigation is applied. Moreover, farm sizes in the study area are small. The landowners in Ricote village own, on average, 3.63 parcels, and the mean parcel size is 1073 m^2. The smallest parcel is 20 m^2, and the largest is 30,344 m^2 (i.e., c. 3ha) (Heider et al. 2018). Therefore, smallholder family farming (on less than 2 ha) remains the most widespread form of farming in the study area to the present day (Jouzi et al. 2017).

Figure 1.2 The orchards in the Ricote Valley shaped by irrigation canals and dry-stone walls (left and right), forming a terraced agricultural landscape (center, top) including *norias* to lift irrigation water, e.g., Noria de la Hoya in Abarán (center, bottom).

Nevertheless, agriculture in the Ricote Valley serves multiple functions for the environment, society and economy. First, smallholder agriculture is a source of food security, income, and employment in the Ricote Valley (García Avilés 2000, 2014). Agriculture often represents only an additional income source for families (pluriactivity) offering more resilience to the price volatility of crops. Furthermore, the cultural landscape shaped by smallholder agriculture attracts tourists, opening new income opportunities.

Second, traditional smallholder agriculture provides space for recreation and community interaction, such as knowledge and technology transfer and mutual support. At the same time, local heritage is preserved and maintained in multiple forms: traditional agricultural systems, traditional irrigation technologies (e.g., hydraulic systems and water wheels), traditional agricultural practices, and traditional ecological knowledge (Bravo Sánchez 2018; Gil Meseguer 2014; Puy and Balbo 2013).

Third, traditional smallholder agriculture involves greater biodiversity of species adapted to the human-made environment than industrial agriculture due to its small parcel sizes, diversity of microhabitats, and variety of cultivated crops. Additionally, a low degree of mechanization produces lower emissions and less air pollution (Heider et al. 2018). Nature and wildlife protection is supported in the study area due to its participation in the Natura 2000 network (Región de Murcia 2017).

But, the agricultural activity in the Ricote Valley, with its local social-ecological benefits, is threatened due to land abandonment or land-use intensification like in many other European rural areas (Heider et al. 2021; Lomba et al. 2019). Despite the importance of the multiple functions of smallholder agriculture, European statistics show that small-scale agriculture has deteriorated in recent years. In 2013, 3.1 % of agricultural companies cultivated more than 50 % of the agricultural area in Europe (Chemnitz 2019). In Spain, statistics show the same trend: 5.5 % of agricultural companies cultivated more than 55 % of the agricultural area, while 50 % of agricultural holdings cultivated only 4.2 % of the agricultural area in 2016 (Eurostat 2021).

I chose to investigate the challenges and opportunities for sustainable rural development and multifunctional agriculture, focusing on the Ricote Valley because it unites multiple challenges and opportunities in one location. First, smallholder agriculture is predominant in the Ricote Valley and preserves multiple traditional sites and functions of agriculture. Second, the Region of Murcia has one of the driest climates in Spain, and future warming, as well as droughts, are projected to increase in the Mediterranean region (IPCC 2021). Third, the broader Region of Murcia is severely affected by land abandonment (Alonso-Sarría et al. 2016). Terraced agricultural landscapes prevent soil erosion and are predominant in the Ricote Valley. However, these terraces could become a hazard if abandoned (Tarolli et al. 2014). Furthermore, *norias* are affected by abandonment. At the same time, they could represent an opportunity for sustainable rural development. Similar challenges and opportunities are widespread in the Mediterranean region, and they need detailed investigation on a local scale.

1.3 Data and methods

This thesis requires quantitative and qualitative data to answer the research questions mentioned earlier. It comprises interdisciplinary research and combines approaches from geography, economics, anthropology and hydraulic engineering. Therefore, a wide spectrum of methods is used in this thesis: GIS-based analysis, statistical analysis, surveys, participant observation, and a technological and socio-economic assessment. In most articles, I combine different data and methods using a mixed-method approach.

In mixed-method research, the researcher uses more than one methodological tradition in an empirical research project collecting, analyzing, and mixing quantitative and qualitative data and/or using quantitative and qualitative research methods. On the one hand, applying more than one methodological tradition can enhance the validity of results. On the other hand, mixed-method research can be used to gain a deeper understanding of the research subject (Kuckartz 2014). In this thesis, the focus lies on quantitative data and methods. However, qualitative data is used to enhance the understanding of the investigated phenomena. In the following, the methods and data applied in this thesis are presented.

All research has been conducted in collaboration with local stakeholders. During the research, science and stakeholder meetings took place in Ricote in 2017 and 2019. Another stakeholder meeting was planned for 2021, but due to the COVID-19 pandemic it has not taken place yet. The stakeholder meetings aim to exchange knowledge, integrate local perspectives and the needs of farmers, share research findings as well as create acceptance for place-based solutions.

The community in Ricote highlighted the urgent need to target land fragmentation to generate monetary savings and management simplification (i.e., number of water counters used for drip irrigation) during a stakeholder meeting. My motivation for the first article of this thesis was to address this need.

In the first article, I use spatial analysis to quantify and assess land fragmentation in Ricote village. I combine cadaster data and a land tenure database of the irrigators' community in Ricote. In the first step, I selected three variables that describe land fragmentation in Ricote: *degree of separation* (number of water counters), *degree of dispersion* (standard distance), and area (mean cultivated plot size) of agricultural properties. Each selected variable is analyzed statistically. Subsequently, they are combined in a fragmentation index (FIDIDA). FIDIDA is able to quantify overall land fragmentation considering the transaction costs. Spatial analysis was conducted using the System for Automated Geoscientific Analyses (SAGA-GIS, free and open source) and ArcGIS (commercialized by Esri).

In this context, the GIS platform was developed as a tool to (1) enable the visualization of data, (2) promote participative decision-making, (3) support the design of climate adaptation strategies and (4) facilitate the training of new staff. Furthermore, land swapping possibilities based on the results of FIDIDA can be assessed using the platform. The GIS platform as an interactive map for the community of Ricote is based on two datasets: the cadastral map of the Ministry of Agriculture in Spain and the land tenure database of the irrigators' community in Ricote. Both data sets were processed, connected and synchronized in SAGA-GIS. The GIS platform was installed on the computers of the irrigators community in 2017, and employees charged with the management of the irrigation system were trained to use the platform during two courses.

In the second article, I used remote sensing analysis to quantify the progression of land abandonment between 2016 and 2019 in the Ricote Valley. In the first step, I conducted a terrace detection using cadaster data and a Digital Elevation Model (DEM). I calculated the DEM based on Light detection and ranging (LiDAR) point clouds. In the next step, I conducted a land-use classification using Sentinel data. Remote sensing analyses were conducted in SAGA-GIS and ArcGIS. The validation of the land use classification in the Ricote Valley was conducted in May 2019, and the ArcGIS Collector App in combination with ArcGIS Online was used during fieldwork. The same software combination was used to collect geo data of *norias* in the Ricote Valley, which is further described in the third article.

In the second and third article, I used a combination of participant observation and expert surveys to explore the reasons for land abandonment and the reasons for the deterioration of *norias* in the Ricote Valley. In the first step, insights from participation in agricultural activities and communication with local stakeholders in combination with insights from literature were used to preselect the reasons used in the expert survey. In the next step, experts with scientific, economic and administrative backgrounds were selected on the basis of their expertise on the topic and the location, as well as their availability. In personal interviews, the experts were asked to evaluate the importance of preselected reasons and to add additional reasons, where appropriate.

Using an online survey, I explored agroecological farming practices and their effects in Spain, in the fourth article. The online survey among farmers committed to sustainable food production has been co-designed with collaborating agroecological associations to integrate their perspectives and knowledge of agricultural practices and on impacts on the environment. The software Lime Survey was used.

Approaches and methods from hydraulic engineering enabled to conduct a technological assessment of *norias* during a research collaboration. In the third article, (1) unknown geometric dimensions of *norias* in the Ricote Valley were estimated, (2) their irrigation potential, (3) their potential to mitigate GHG emissions compared to motor pumps, and (4) their potential to produce power were calculated.

Statistical analysis was used throughout the thesis. In the first article, basic statistics of the individual variables describing land fragmentation as well as FIDIDA were calculated. In the second, third, and fourth article, statistical analysis was used to evaluate the survey results. Moreover, in the fourth article, two regression models were developed. The first model estimates the relationship between the Agroecology Index as the dependent variable and a set of selected variables as independent variables. The second model estimates the relationship between changes in biodiversity as dependent variable and a set of selected variables as independent variables.

1.4 Thesis structure

This thesis is structured along four journal articles of which I am the first author. Three articles are published in peer-reviewed journals and one is in the process of submission. The study area of each article is adapted to the research question and extends from Ricote village over Ricote Valley to Spain. Each article is presented as one chapter, and the topic of each chapter is described below.

The second chapter deals with a major challenge for smallholders in Ricote: land fragmentation. In this chapter, I developed a new fragmentation index (FIDIDA) to quantify land fragmentation in Ricote village. Another challenge in the study area is land abandonment. In the third chapter, I investigate the progression of land abandonment in the Ricote Valley between 2016 and 2019 while also exploring its reasons over the past decades. The past can also show us opportunities for the future. Traditional technologies and traditional knowledge of small-scale communities might uncover alternatives to energy- and emission-intensive motor-based technologies. In chapter four, I explore the preservation state and potential for the deployment of *norias* in the Ricote Valley. Chapter five continues with valorizing traditional knowledge in the form of agricultural practices. This chapter investigates the experiences of farmers and the potential of agroecological management in Spain.

The final chapter synthesizes the findings of this thesis answering the research questions and addressing the objectives mentioned earlier. General conclusions are drawn to provide policy recommendations as well as recommendations for further research. All references are provided in one reference list at the end of this thesis, and survey questionnaires are provided in the appendices.

2 Land fragmentation index for drip-irrigated field systems in the Mediterranean: A case study from Ricote (Murcia, SE Spain)[2]

2.1 Abstract

Land fragmentation is widespread in traditional field systems of the Mediterranean region. A typical case for high fragmented properties is the Valley of Ricote. It is dominated by smallholder agriculture. To promote smart sustainable development in rural areas it is important to address the specific needs of these small agricultural producers; especially considering that agriculture is the most important consumer of water worldwide and that the great majority of farms are small production units extending over < 2 ha. Indeed, high land fragmentation, resulting from traditional land inheritance and transmission systems, may cause loss of water and productive land, entropic governance and superfluous emissions. In particular, drip-irrigated systems suffer from higher costs for irrigation due to high land fragmentation.

In this study, we develop a Fragmentation Index for Drip Irrigation and Distance Assessment (FIDIDA) using Geographic Information Systems. FIDIDA quantifies farms considering their transaction costs. Based on these costs, FIDIDA brings together mean plot size, *degree of separation* and *degree of dispersion* of land parcels on farm level. The index can be used to compare the individual fragmentation of farms or the land fragmentation between different study areas. The definition of FIDIDA aims at supporting the management of reasonable land fragmentation thresholds in the context of communities made of traditional small farms, while suggesting possible pathways for a gradual inversion of high land fragmentation trends through agreed plot fusion where necessary.

Keywords: agriculture, irrigation, transaction costs, GIS, mitigation, property

2.2 Introduction

Irrigated agriculture is fundamental to address current and future alimentary needs (Cárdenas et al. 2017) because it provides 40 % of the global food production using only 20 % of the global agricultural land (Anderies 5/9/2017). Irrigated agriculture obviously plays a key role for global food supply in times of increased population pressure. At the same time, within the global agro-alimentary industry, 90 % of farms can be defined as small producers, with < 2 ha, and often < 1 ha (Anderies 5/9/2017; Cárdenas et al. 2017). These small producers provide food to 40 % of the poorest population globally (Anderies 5/9/2017). In consequence, to promote smart sustainable agriculture on a global scale, it is important to address the needs of small producers.

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[2] This chapter has been published in the peer-reviewed journal Agricultural Systems as Heider, K.; Rodriguez Lopez, J. M.; García Avilés, J. M.; Balbo, A. L. (2018): Land fragmentation index for drip-irrigated field systems in the Mediterranean: A case study from Ricote (Murcia, SE Spain). In Agricultural Systems 166, 48–56. DOI: 10.1016/j.agsy.2018.07.006. The article has been reformatted as chapter of this thesis. The content is identical to the published version.

One of the major issues affecting efficiency in communities of small farmers is the high fragmentation of agricultural land properties, which has been observed in many parts of the world (Tan et al. 2006). The Valley of Ricote is a typical case for smallholder farming in highly fragmented traditional field systems in the Mediterranean region. Considering the need to assess land fragmentation in the specific context of drip-irrigated agriculture, our main research question is:

- How to assess agricultural land properties considering the influence of land fragmentation in traditional Mediterranean agro-ecosystems predominantly made of small farmers?

To answer this question, we developed a Fragmentation Index for Drip Irrigation and Distance Assessment (FIDIDA). We use Geographic Information Systems (GIS) to calculate FIDIDA on farm-level. FIDIDA quantifies farms considering transaction costs, i.e., costs for drip irrigation systems, plot size as well as emissions and travel time due to transportation. The quantification would then inform policies oriented to reduce land fragmentation, as well as highlight priority interventions for a gradual inversion of land fragmentation trends through agreed plot exchange and fusion among farmers with a high fragmentation index. The index can be used to compare the fragmentation of individual farms or, on a broader level, the land fragmentation between different study areas. FIDIDA aims at informing reasonable management of land fragmentation thresholds in traditional drip-irrigated field systems.

While several fragmentation indices can be found in the literature (Gónzalez et al. 2004; King and Burton 1982; Tan et al. 2006; van Dijk 2003; Vijulie et al. 2012), there is no land fragmentation index adapted to drip-irrigated agriculture of traditional field systems. Additionally, most of them fail to include the relative distance of plots in a combined index that also considers plot sizes and their *degree of separation*. When mentioned, distance is only considered as a separate and arbitrary (inconsistently used) parameter (Tan et al. 2008; Vijulie et al. 2012).

The fragmentation index we propose is adapted to drip-irrigated agriculture and uses a standardized measure for distance to include the costs of the irrigation system in terms of travel time and associated emissions. This measure for distance is integrated in the proposed fragmentation index, which has been conceived considering the need for mitigation strategies in agriculture within the context of climate change (IPCC 2012).

2.2.1 Land fragmentation, property rights and transaction costs

Some of the disadvantages associated with high land fragmentation include inefficiencies such as the loss of productive land due to the presence of fences, ditches or hedgerows, hindering of mechanization, higher production costs, incremental use of pipes and electrical wiring for automated drip irrigation, and the loss of time. Consequently, the net income per farm is affected. This can lead to the abandonment of farms and land use changes. Furthermore, land fragmentation fosters additional emissions due to the distance one has to travel between parcels (King and Burton 1982; Tan et al. 2006; Tan et al. 2008; van Dijk 2003).

Although the clear definition of property rights is one of the most prominent solutions to the tragedy of commons (Hardin 1968, 1989), high property partition is problematic for overall efficiency. Yet, it has to be mentioned that more recent studies of common properties on a local level suggest that self-management is a promising solution to prevent the tragedy of commons (Dietz et al. 2003; Ostrom et al. 1999; Ostrom 2009).

Higher fragmentation leads to increased transaction costs (Williamson 1981), e.g., in the form of needed infrastructure or distances to be travelled. In other words, if unchecked, the property rights solution for the tragedy of commons could generate a tragedy of property, also known as the "tragedy of the anticommons" (Heller 1998). Williamson (1981) argued that transaction costs are additional costs in mechanical production; for example, the transfer of a product between two machines produces the transaction cost of changing from one machine to another, and the longer and the more difficult the change is, the higher are the additional costs. For the decision process of small farmers, the cost of transactions between various fields is increased by high land fragmentation similarly to the additional costs in the industrial production. High transaction costs produce difficulties in decision-making. Assuming the existence of these difficulties, small farmers compare information to take rational decisions in a bounded form (Simon 1991) while assessing the possibility of making profits (opportunism). Hence, farmers should try to avoid fragmentation because of the high transaction costs and the associated difficulties indecision-making. Otherwise the net income per farm decreases contributing to the abandonment of food production activities.

2.2.2 Definition of terms

The term *parcel* is used here for cadastral land subdivisions. The term *plot* indicates a single parcel with drip irrigation or a cluster of neighboring parcels that belong to the same owner and are served by a single counter. A counter is a distribution point and measuring device for water used for one plot. i.e., the number of counters in Ricote equals the number of plots. Counters (and plots), rather than cadastral parcels, are therefore used as indicator for the *degree of separation* within farms. A farm describes all plots belonging to one owner or farmer. Distances between plots are used as indicator for the *degree of dispersion*.

2.2.3 Co-design in Ricote

This paper should be read as a result of co-design of researchers with local stakeholders in order to understand the needs of the community, exchange knowledge, integrate local expertise, cooperate, and create acceptance for place-based sustainable solutions (Levidow et al. 2014; Reynolds et al. 2014; Scheffran and Stoll-Kleemann 2003). A science and stakeholders meeting took place in June 2017 in Ricote as a part of the stakeholder dialogue on which we have relied on since the beginning of our research in this area in 2010. After defining the priorities and possible pathways for sustainable development with local stakeholders, we introduced a GIS platform as an interactive map for the community of Ricote (Murcia, Southeast Spain). The GIS platform was then used at community level as the basis to explore possible pathways to reach an efficient configuration in terms of land fragmentation. One of the needs highlighted by the local community was that of reducing land fragmentation, to minimize the *degree of separation* (i.e., number of counters used for drip irrigation), thus promoting monetary savings (deployment and maintenance) and management simplification (irrigation schedule complexity), without weakening the stability of the system.

2.3 Study area

The study area is the orchard (Spanish *huerta*) of Ricote, located in the region of Murcia in Southeast Spain (Fig. 2.1). Climate is semi-arid with strong seasonality. Total annual rainfall lies between 200 and 350 mm with more than twice the amount of evapotranspiration creating arid conditions. Average summer temperature is between 31and 34 °C and in winter between 1 and 5 °C (Lopéz Bermúdez 1973; Puy and Balbo 2013).

The *huerta* in Ricote was established by Amazigh-Berber populations > 1000 years ago (Puy and Balbo 2013; Puy et al. 2016) and as one of the oldest known irrigation systems in Europe, Ricote has a long history of water shortages and water conflicts (García Avilés 2000). Today, it counts about 1.330 inhabitants (Instituto Nacional de Estadística 2017). Its urban area is located to the north of the *huerta*, and both are surrounded by mountains. The orchard contains > 2000 parcels distributed among approx. 620 farmers. Most plots are cultivated on terraces, shaped by stonewalls. The primary crop is lemon, followed by olives and other fruits. An overview of the *huerta* is given in Figs. 2.1 and 2.2.

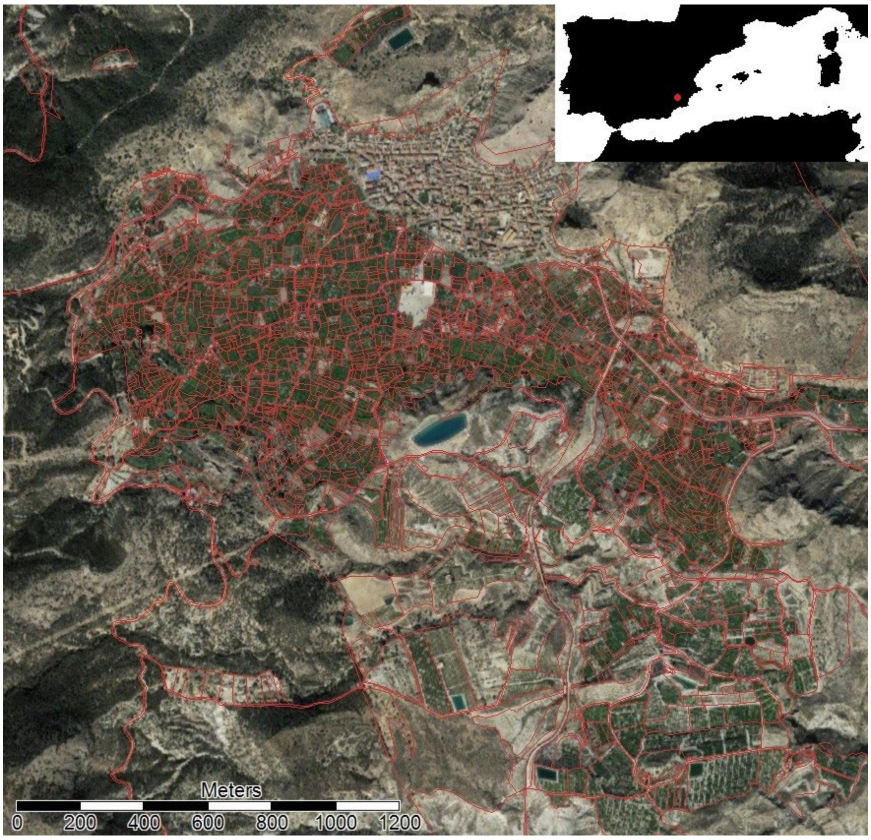

Figure 2.1 Overview of the study region of Ricote based on satellite imagery (GoogleSatellite, 2015) overlaid with a cadaster map (red)

Figure 2.2 The *huerta* of Ricote

Traditional irrigation techniques have mostly been substituted by drip irrigation in Ricote over the past 10 years, to make water management more efficient. Today, about 75 % of all parcels in the orchard rely on drip irrigation (Puy et al. 2016). Thus, the community is in a transition between traditional and modern irrigation. While significantly reducing farmers' workload, the drip irrigation system in Ricote suffers from high management and infrastructural costs relative to the overall land surface of the *huerta*, mostly due to high land fragmentation.

Specifically, due to the local traditional system of land heritage and transmission, by which land is split and inherited in equal parts among all siblings, land tenure is highly fragmented. Ricote's farmers own, on average, 3.63 parcels (standard deviation 3.92), and the mean size of a parcel is 1073 m^2 (standard deviation 1951 m^2), of which 884 m^2 (standard deviation 1317 m^2) is cultivated on average. The smallest parcel is as small as 20 m^2 and the largest is 30,344 m^2 (i.e., c. 3 ha). The mean land per farm is 3895 m^2, of which 3209 m^2 are cultivated on average. Thus, Ricote is characterized by small farm sizes. Almost 70 % of the farms in Ricote consist of more than one parcel. About one quarter of the farms comprise more than four parcels and a single farm can consist of > 30 parcels distributed around the *huerta*. A high number of electronic counters were deployed in Ricote for the drip irrigation system to adapt to the existing distribution of land; generally, one counter per parcel or cluster of contiguous parcels belonging to the same farmer. While allowing for the maintenance of pre-existing property patterns, the drip irrigation system in Ricote is associated with high deployment and maintenance costs, i.e., high transaction costs. Additionally, the high number of counters increases the execution time of the irrigation as well as the likelihood of technical problems.

2.4 Data and methods

2.4.1 The GIS platform

The GIS platform has been conceived as a tool to: (a) enable the visualization of data, (b) promote participative decision-making processes, (c) support the design of climate adaptation strategies and (d) facilitate the training of new staff (Fig. 2.3). The GIS platform consists of an interactive map based on the integration of two datasets: the land tenure database of the irrigators' community in Ricote and the cadastral map from the Ministry of Agriculture in Spain (FEGA). For each parcel contained in the cadastral map, the database of the irrigators' community in Ricote contains information relative to the cadastral number, farmer's identification number, type of crop, irrigation system used, affiliation to cooperatives, counter number, counter reading, traditional name of the area in which the parcel is located, size of parcels according to cadaster and size of parcel which is actually used for cultivation (the cultivated area is based on the irrigated surface authorized by the Confederación Hidrográfica del Segura). Both datasets were processed, connected and synchronized in SAGA-GIS, which is a free and opensource software (Conrad 2006). The GIS platform was then installed on the computers of the irrigators' community in Ricote in June 2017. Employees charged with the management of the irrigation system were trained to use the GIS platform during two courses, introducing its concept, applications and relevant functions. The community also uses the GIS platform to correct errors in the administration database.

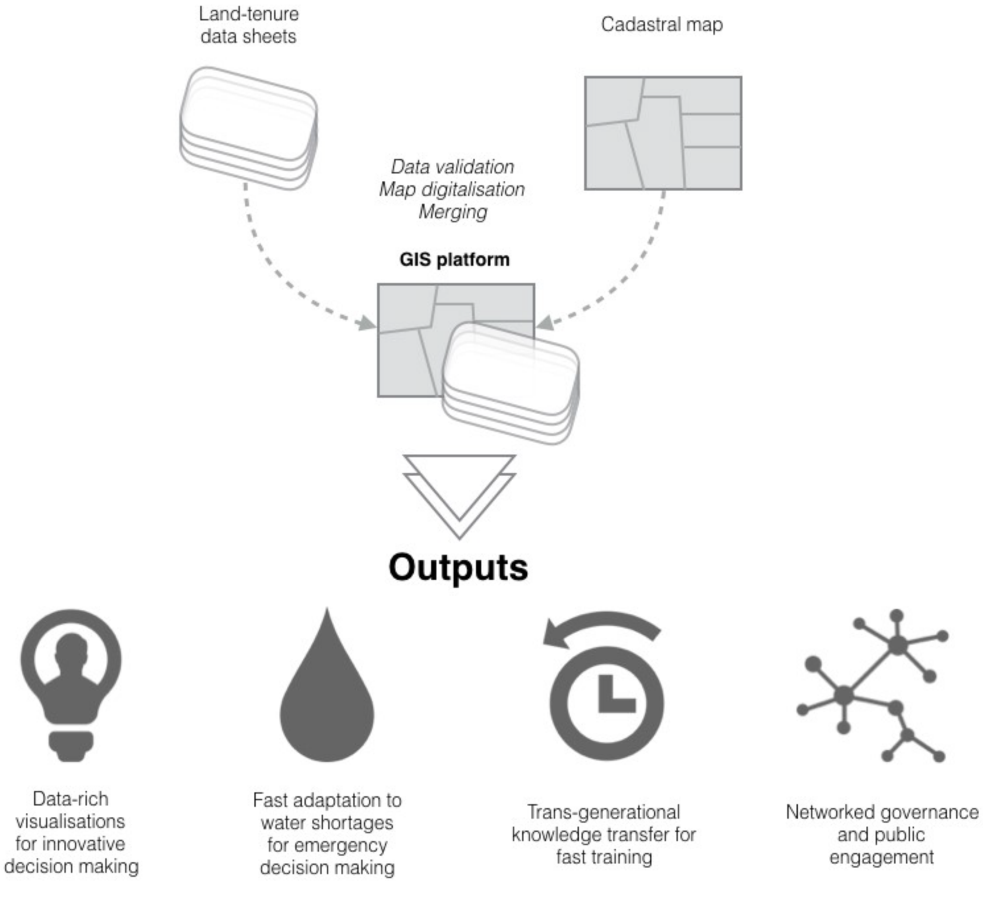

Figure 2.3 The concept of the GIS platform (icon credits: the noun project)

Overall, the database of the irrigators' community in Ricote includes 2105 parcels and 622 farmers. After an initial examination, parcels that have been urbanized as well as a number of parcels and farmers lacking updated information were identified, reducing the dataset to 1588 parcels and 437 farmers retained for analysis.

2.4.2 The assessment of land fragmentation

A fragmentation index is a widely used empirical tool to assess agricultural fragmentation (King and Burton 1982; Latruffe and Piet 2014; van Dijk 2003). Here, we aim at proposing a compact fragmentation index adapted to drip-irrigated agriculture that includes the number of plots of each farm, their location and relative distance, as well as their mean size (Latruffe and Piet 2014). A crucial factor while working on land fragmentation is the differentiation between owners and users (van Dijk 2003). However, this differentiation is not necessary in Ricote (and generally in small farm contexts), where owners cultivate their own land and subletting is virtually non-existent. Several fragmentation indices and measurement units can be found in the literature (King and Burton 1982; Latruffe and Piet 2014; van Dijk 2003; Vijulie et al. 2012). An extensively used measurement of fragmentation is based on area per landowner (van Dijk 2003). While providing an assessment of the farm size, this index fails to provide information on the *degree of separation* of parcels within one farm, i.e., the number of counters per farm. Another simple measurement of fragmentation is parcels per farm, but the *degree of dispersion*, i.e., the location and relative distance of the parcels, is still not considered (King and Burton 1982).

Other common fragmentation indices addressing farm size and *degree of separation* we referred to are Simmon's index, Januszewski's consolidation index, Simpson's index (King and Burton 1982; Tan et al. 2008; Vijulie et al. 2012) and the combined size and shape index (Gónzalez et al. 2004). Regarding the *degree of dispersion* of plots we referred to specific indices, mainly Igbozurike's index, Schmook's index, the average distance of a hectare index, the grouping index, the structural index (Janus and Markuszewska 2017; King and Burton 1982; Latruffe and Piet 2014). However, such indices were considered unsuitable for Ricote and other small traditional Mediterranean irrigated agro-ecosystems because either they did not take into account the *degree of dispersion* (Simmon's index, Januszewski's consolidation index, Simpson's index, combined size and shape index) or they did not consider the *degree of separation* (Igbozurike's index, Schmook's index, average distance of a hectare index, grouping index, structural index). To compensate for this, several studies applied in parallel more than one index to describe land fragmentation (Janus and Markuszewska 2017; Latruffe and Piet 2014).

The use of various units to represent distance, further reduces the possibility to use existing fragmentation indices systematically. For example, some authors represented distance as the walking time (in minutes) from homestead to plots (Tan et al. 2008), while others defined it as the linear “distance (in km) covered by farmers to visit their plots” (Vijulie et al. 2012, p. 413).

2.4.3 The Fragmentation Index for Drip Irrigation and Distance Assessment (FIDIDA)

Within the assessment of land fragmentation in Ricote, we create three rankings of the farms based on their size, *degree of separation* and *degree of dispersion*. The rankings are implemented by selecting the cases with the highest transaction costs concerning each indicator, i.e., the smallest farm size, the highest *degree of separation* (most counters) and the highest *degree of dispersion* (highest standard distance between plots of one farm). Subsequently, we present the results of our own index: the Fragmentation Index for Drip Irrigation and Distance Assessment (FIDIDA) for each one of the selected farms. FIDIDA combines the *degree of separation*, the *degree of dispersion* and a measure of size, i.e., mean plot size (see Fig. 2.4).

Finally, we conduct a rank correlation to assess the relationship between the results of FIDIDA and the *degree of separation*, *degree of dispersion*, mean plot size as well as farm size. We use the Spearman rank correlation because of its non-parametric character, which enables the usage of not normally distributed variables. The results of the correlation show the factors that are most decisive for the outcome of the index.

FIDIDA is calculated according to the following formula:

$$\text{FIDIDA} = \frac{C*SD}{A}$$

where C is the number of counters per farm, SD is the standard distance between the individual plots of a given farm and A is the mean cultivated area of plots belonging to one farm. While high values of C (*degree of separation*) and SD (*degree of dispersion*) result in a higher fragmentation and lead to a higher fragmentation index, high values of A (mean plot size) reduce the fragmentation index, implying a better mark for the estimation of the index value because of the higher productiveness of the farm.

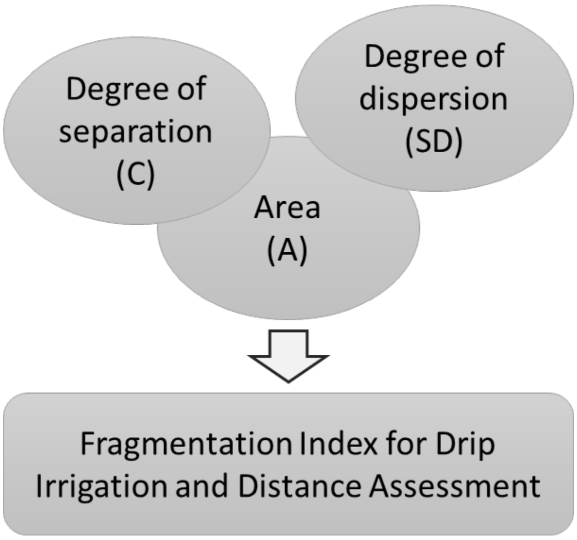

Figure 2.4 For the calculation of FIDIDA, the parameters *degree of separation* (C - number of counters), *degree of dispersion* (SD - standard distance) and area (A - mean cultivated plot size) are used

The number of counters per farm is used as a proxy of plot scattering, which best represents fragmentation in the context of drip irrigation in Spain (Gómez-Limón and Picazo-Tadeo 2012), where farmers can have several parcels irrigated by the same counter. Using counters per farm instead of parcels per farm in the fragmentation index is an adaptation to the increasing installation of drip irrigation in Spain (Gómez-Limón and Picazo-Tadeo 2012). Considering this recalculation and the exclusion of parcels without drip irrigation, the overall figures of 1588 parcels for 437 farmers are merged into 981 plots for 397 farmers, which constitute the basis for all further analyses. The observed reduction in the number of farmers is explained by the exclusion of parcels without drip irrigation.

In the next step, the *degree of dispersion* is included to count for distance, which plays a determinant role on transaction costs. We analyze each farm of the selected cases separately to assess the *degree of dispersion* between plots at the farm-level.

We propose a measure of distance, namely standard distance, representing the dispersion of a farm around the farm center. The standard distance (SD) is calculated according to the following formula:

$$\mathrm{SD} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - X)^2}{n} + \frac{\sum_{i=1}^{n}(y_i - Y)^2}{n}}$$

Where x_i and y_i are the coordinates for plots i, $\{\overline{X}, \overline{Y}\}$ represents the mean center of the plots, and n is equal to the total number of plots. Fig. 2.5 illustrates the standard distance as the radius of a circle. In this case, the standard distance is 900 m (see Table 2.2, farmer number 70).

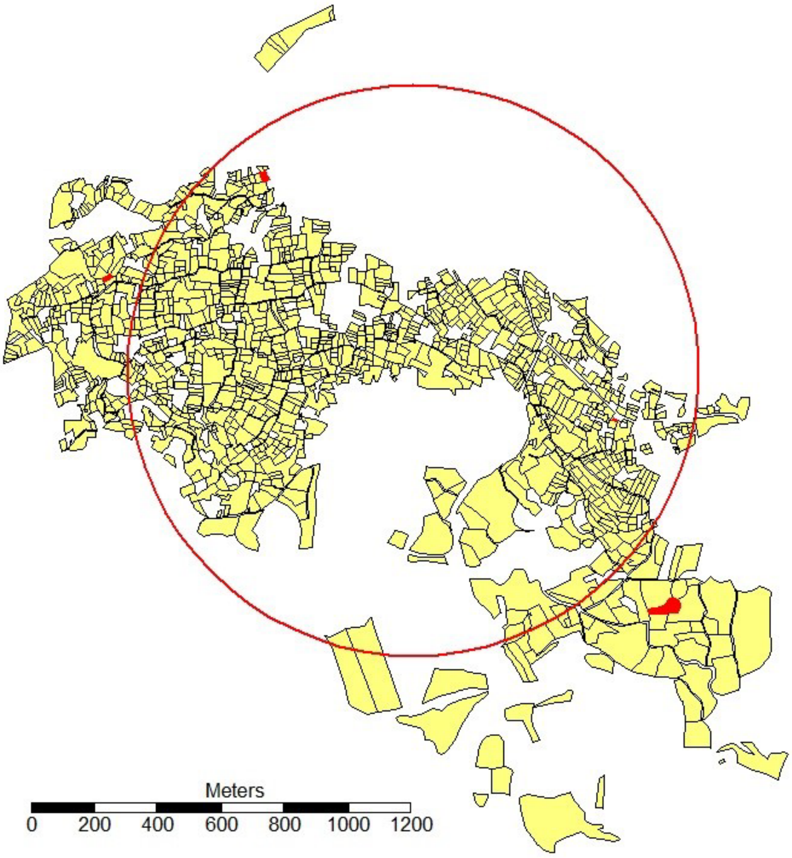

Figure 2.5 Illustration of standard distance. Standard distance equals the radius of the red circle. The result is based on the location of the mean center of each of the four red plots belonging to farmer number 70

For the calculation of standard distance, the polygon data of every farm is converted to point features, which is necessary to conduct a spatial point pattern analysis in SAGA-GIS. One output of the spatial point pattern analysis is standard distance, which we choose as an indicator to assess the *degree of dispersion*. The *degree of dispersion* is a proxy for traveling time and emission potential due to transportation between the plots of one farm. It is measured from the center of a plot.

Moreover, the mean cultivated plot size is included in FIDIDA as an indicator for productiveness. The analysis is based on the cultivated land area because it is the most precise information of agricultural land area and the most reliable information concerning the land area according to the local experts of the irrigators' community in Ricote.

2.5 Results

First, we assess land fragmentation in terms of size. The mean farm size in Ricote is 3178 m^2 (0.3178 ha); the largest being 54,927 m^2 and the smallest 70 m^2. The median farm size is 1698 m^2 (standard deviation 4883.96 m^2). The farm size alone is a poor indicator for value of land in a context of land fragmentation (van Dijk 2003; Vijulie et al. 2012).

Second, we investigate the *degree of separation*. The range varies between one, which is the minimum number of counters for a farm included in the analysis, and 16 counters, which is the farm with the highest number of counters. The mean number of counters is 2.47 and the median is 2 (standard deviation 2.12).

Table 2.1 Basic statistics of total drip irrigation farm data in Ricote: farm size, number of counters per farm (*degree of separation*), standard distance between plots of one farm (*degree of dispersion*) and the Fragmentation Index for Drip Irrigation and Distance Assessment (FIDIDA)

	Farm size [m^2]	No. of counters	Standard distance [m]	FIDIDA
Min	70	1	1	0
Max	54927	16	1062.17	13.97
Mean	3178.01	2.47	240.61	1.42
Median	1698	2	73.57	0.22
Std. Dev.	4883.96	2.12	284.12	2.22

Third, we use the *degree of dispersion*. It ranges in Ricote between 1 m, which is assigned to farms that consist of only one counter, and 1062.17 m representing the highest measured value of standard distance between plots of the same farm in Ricote. The mean standard distance of farms in Ricote is 240.61 m and the median is 73.57 m (standard deviation 284.12).

Finally, FIDIDA combines the *degree of separation*, the *degree of dispersion* and a size measure into one index describing the state of fragmentation of a farm. FIDIDA results in Ricote range between near zero and 13.97. An index result near zero is reached if e.g., the number of counters is one, as well as the SD. While low values represent a low fragmentation of the farm with small numbers of counters and small distances between plots, relative to the mean size of plots; higher values represent a higher fragmentation of the farm with a higher number of counters and longer distances between plots. The mean value of FIDIDA index results in Ricote is 1.42 and the median is 0.22 (standard deviation 2.22).

The histograms of farm size, number of counters, standard distance and FIDIDA are illustrated in Fig. 2.6. The determination of class numbers is based on the following formula:

$$k = 5 * \log n$$

where k is the number of class intervals and n is the number of plots (Pankowski and Brier 1958). The majority of the farms in Ricote are small, have one counter and small standard distances with a size of < 80 m. Despite the small farm sizes, most of the farms have a low fragmentation index < 1.

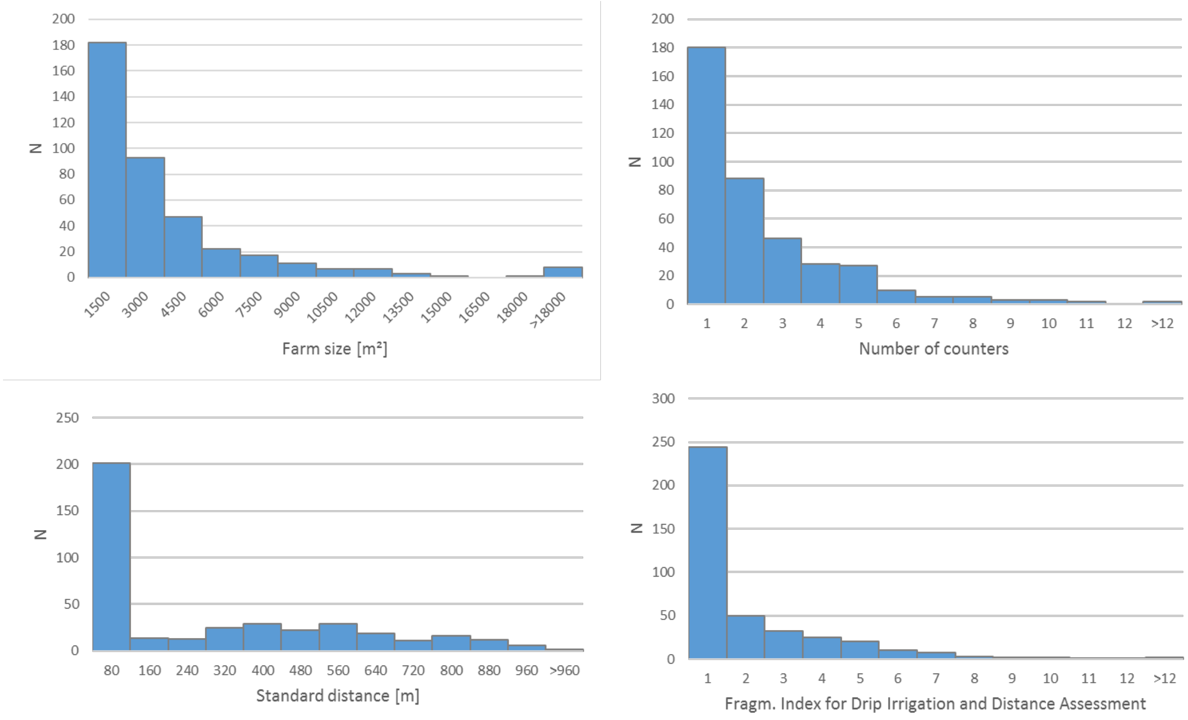

Figure 2.6 Histograms of farm size, number of counters (degree of separation), standard distance (*degree of dispersion*) and the results of FIDIDA in Ricote. N = number of farms

Table 2.2 shows that high values of FIDIDA often occur together with high values of standard distance and high counter numbers. For the construction of Table 2.2, we selected the 10 cases with the highest transaction costs according to three selected measures: farm size, *degree of separation* and *degree of dispersion*. In the last column, the Fragmentation Index for Drip Irrigation and Distance Assessment (FIDIDA) is shown. According to farm size, the smallest properties are selected. According to the *degree of separation*, the farms with the most counters are selected. According to the *degree of dispersion*, the farms with the highest standard distance between plots are selected. The results of FIDIDA represent how these parameters (*degree of separation*, *degree of dispersion* and mean plot size) are brought together into one value.

Table 2.2 Extract of the farm data in Ricote. The 10 cases with highest transaction costs according to farm size, number of counters (*degree of separation*), and standard distance (*degree of dispersion*) are selected and FIDIDA is calculated encompassing mean plot size, number of counters and standard distance. The farm (farmer number 248) with the highest fragmentation index (13.97) is not listed in Table 2.2 because it is considered an outlier based on our selection method

Farmer number	Farm size	No. of counters	Standard distance	FIDIDA
147	11,292	16	534.21	13.44
192	526	2	914.00	9.61
31	8186	9	435.62	8.92
3	11,425	10	703.21	7.49
99	490	2	871.79	7.12
219	7550	9	597.89	6.97
511	16,847	10	539.02	6.89
353	5498	9	438.99	6.47
205	13,273	10	555.71	4.77
151	20,100	11	551.34	4.45
70	3265	4	899.63	4.41
46	1615	2	871.20	4.32
209	21,768	11	598.23	4.31
370	54,927	14	514.59	2.99
478	2241	2	923.75	2.13
477	5898	3	896.92	1.81
203	2435	2	913.86	1.50
400	13,931	3	1014.45	1.27
58	5127	2	950.38	0.79
48	25,722	2	1062.17	0.49
15	70	1	1.00	0.01
461	150	1	1.00	0.01
623	150	1	1.00	0.01
372	180	1	1.00	0.01
593	180	1	1.00	0.01
622	186	1	1.00	0.01
167	190	1	1.00	0.01
652	209	1	1.00	0.00
691	210	1	1.00	0.00
287	220	1	1.00	0.00

Small farm sizes hardly have any effect on the results of FIDIDA because small farms often present low values of standard distance and counter number, representing low transaction costs leading to a good index result. Large farms do not necessarily have a good index result because of high transaction costs due to the high number of counters and high standard distances, which suggest lower efficiency compared to small farms. The high number of counters observed for large farms applies in particular to traditional irrigation systems like Ricote.

The Spearman correlation between the results of FIDIDA and the parameters of the index formula as well as the farm size are shown in Table 2.3. We find a high positive correlation between counter number (0.89) as well as standard distance (0.90) and the results of FIDIDA. In contrast, mean plot size has a negative correlation (−0.22) with FIDIDA. This stresses the focus on the *degree of dispersion* and the *degree of separation* within FIDIDA. Finally, farm size has a positive correlation (0.42) with the results of FIDIDA.

Table 2.3 Spearman rank correlation between farm size, counter number (*degree of separation*), standard distance (SD, *degree of dispersion*), mean plot size and the results of FIDIDA based on the total drip irrigation farm data set

Farm size; FIDIDA	Counter; FIDIDA	SD; FIDIDA	Mean plot size; FIDIDA
0.42	0.89	0.90	-0.22

2.6 Discussion

The estimation of fragmentation in the framework of FIDIDA (Tables 2.1 and 2.2) aims at an assessment of agricultural land properties that takes into account transaction costs, which make land management less efficient and less sustainable. This objective is reached by quantifying farms based on *degree of separation*, *degree of dispersion* and mean plot size. In contrast to other reviewed fragmentation indices (Gónzalez et al. 2004; Gónzalez et al. 2007; King and Burton 1982; Latruffe and Piet 2014; Vijulie et al. 2012), FIDIDA is adapted to the needs of drip-irrigated agriculture in traditional and historical contexts characterized by inherited high land fragmentation. FIDIDA combines the above-mentioned fragmentation descriptors into one index. The index aims at guiding strategies to (a) reduce counters and (b) reduce traveling distance between plots. These strategies have the potential to save time and mitigate emissions on farm-level. Thus, economic and mitigation aspects are considered.

An interesting result is the positive relationship between farm size and a high FIDIDA index. One explanation is that many farmers have only one counter, which serves a single plot, i.e., a single parcel or a cluster of contiguous parcels. This represents low transaction costs (low *degree of separation* and *dispersion*). In fact, > 40 % of farmers in Ricote own only one counter. The high number of small farms in Ricote relates to the high presence of farmers who do farming as a hobby or as a secondary supplement to household income. At the other end of the spectrum, most large farms in Ricote suffer from high transaction costs due to the high number of counters and high standard distances between plots, leading to a high FIDIDA index. Overall, the *degree of separation* in Ricote is high based on the number of counters used and the underlying "parcellisation" (King and Burton 1982).

As a measure for *degree of dispersion*, we propose standard distance. It has to be considered that standard distance is only used as a proxy for traveling distance and travel distances between plots are longer in reality. Thus, the potential to save emissions is higher than represented by standard distances.

Within this framework, the FIDIDA index fosters (a) a more accurate and holistic quantification of land properties, (b) increased transparency in the assessment of land fragmentation costs, (c) and the emergence of a clearer and more sustainable land market. Stakeholders have the possibility to address extreme cases of land fragmentation, enriching market evaluation of land with an integrated assessment of land use that includes efficiency and transaction costs.

While some northern European countries have already initiated land consolidation programs to address high land fragmentation (Tan et al. 2006; van Dijk 2003, 2007), Southern Europe seems to be lagging in this sense. This delay may be partially due to a stronger attachment to the land and continuity of traditional inheritance systems. With FIDIDA, we advocate for plot fusion with minimal changes to the physical and social structure of the traditional field system, to conserve the cultural values of these agricultural landscapes.

GIS mapping in Ricote highlights potential for further merging of contiguous plots under single counters, as a possible pathway towards reduction of land fragmentation. For instance, single-counter farms could be included in a fragmentation-reduction process based on voluntary land swapping, i.e., the targeted selling or purchasing of land. Farmers with a high fragmentation index could offer land-swapping to single-counter farmers located in the proximity of their larger plots.

Nevertheless, this process should consider farmers' attitudes (other than economic) towards inherited land, a paramount parameter for the feasibility of such land consolidation programs. Thus, a model that illustrates swapping possibilities should include a parameter mirroring the willingness of people to sell or swap plots, based on an evaluation of the emotional bonds of farmers to the land (van Dijk 2007).

Interventions on farms with a high *degree of separation* should be prioritized to the advantage of all farmers, given that the use of an excessive number of counters increases the cost of the irrigation system for the whole community. Stressing this aspect, one of the key insights emerging here is not on increasing mean plot size, often considered one of the most important aspects of land consolidation for higher lucrativeness by Janus and Markuszewska (2017), but rather on reducing the number of counters and related (and mutualized) transaction costs, individuated as a key impediment to land profitability by stakeholders in Ricote. In addition, the reduction of fragmentation implies an overall reduction of emissions and traveling time between plots within single farms, another key element of sustainable rural development.

Although not discussed in the present work, we acknowledge the proven potential positive effects of land fragmentation on biodiversity and risk diversification, e.g., relative to soil erosion (Bentley 1987; Crecente et al. 2002; Tan et al. 2006; Tan et al. 2008). Furthermore, research in the Mediterranean has shown that fragmented agro-ecosystems aim for stability rather than productivity (King and Burton 1982). The future challenge for land consolidation will be to adopt a pathway that considers economic, environmental and social aspects in a balanced way.

Here, Ricote has been selected as an open laboratory, a model community for the development and implementation of a new fragmentation index adapted to drip irrigation contexts. Nevertheless, the suggested fragmentation index could be implemented in other study areas with drip irrigation systems and similar issues of fragmentation, over-deployment of counters and high transaction costs.

The introduction of free and open source digital mapping technologies is suggested to alter efficiency in agriculture (Janssen et al. 2017; Wolfert et al. 2017). Data and software used in this paper have recently been introduced in the irrigators' community of Ricote, enabling in-house experimentation and implementation. Further applications of the GIS platform are planned in cooperation with local stakeholders. Digital technologies have the potential to produce jobs in the countryside and counter the loss of knowledge by the digitalization of information. Besides addressing land fragmentation, GIS opens new planning possibilities for emergency water management, collective actions for the control of parasites, planning of ecological agriculture and tourist activities as well as the conservation of local and traditional knowledge.

Following a pathway of information-driven innovation on a local level constitutes the basis for smart sustainable development in the future (Janssen et al. 2017; Naldi et al. 2015; Wolfert et al. 2017). Smart and sustainable development can help small agro-ecosystems to compete with intensive fruit and vegetable irrigation systems in littoral regions, which is important in the light of globalization and the integration within the broader economy (Cárdenas et al. 2017; Naldi et al. 2015). These intensive irrigation systems have a higher potential of pollution and water related problems caused by excessive water consumption, the use of fertilizers and pesticides (Gómez-Limón and Picazo-Tadeo 2012; Reynolds et al. 2014). Small fruit and vegetable irrigation systems in inland valleys like Ricote have less ecological and environmental impacts and can be regulated more easily (Campillo et al. 2013; Campillo et al. 2015; Gómez-Limón and Picazo-Tadeo 2012; Velasco et al. 2006). Moreover, smallholder agriculture needs to be supported in order to preserve cultural landscapes worldwide considering their ecological, cultural and historical values (Spanò et al. 2018). Thus, smallholder agriculture plays an important role for a sustainable and climate-compatible agriculture in the future (Leggewie and Messner 2012).

2.7 Conclusion

In this study, we assessed agricultural land properties considering the influence of land fragmentation in small Mediterranean agro-ecosystems. For this purpose, we developed a single combined fragmentation index, specific to drip-irrigated traditional field systems: the Index for Drip Irrigation and Distance Assessment (FIDIDA). FIDIDA is adapted to the needs of the study area. It quantifies farms considering their *degree of separation*, *degree of dispersion* and mean plot size.

The farms in Ricote show a high heterogeneity of FIDIDA values. Approx. 60 % of farms in Ricote have a FIDIDA value below 1 constituting a low degree of fragmentation. The highest FIDIDA value is 13.97 and the mean is 1.42 with a standard deviation of 2.22. FIDIDA values have a strong positive correlation with the number of counters (*degree of separation*) and the standard distance (*degree of dispersion*) of farms. Another positive correlation was found between farm size and FIDIDA values. This can be explained by the long history of land heritages and transmissions in Ricote, which led to land divisions and a high number of counters on large farms.

Researchers or authorities can use FIDIDA to compare the land fragmentation of individual farms or the land fragmentation between different study areas on a broader level. Moreover, FIDIDA aims at supporting the reasonable management of fragmentation thresholds in order to lower the main transaction costs of drip irrigation systems and to mitigate emissions by reducing the number of counters, maintenance costs and traveling distance between plots. To lower land fragmentation, we advocate for the exchange or sale of agricultural plots without changing the physical structure of the traditional field system with its terraces shaped by stone walls and ditches forming a landscape of high cultural, historical and ecological value.

Further research is needed for the implementation of the results. For example, the willingness of people to switch land needs to be assessed in the future. Furthermore, this assessment can be adapted to other areas in the Mediterranean region, with different socio-economic issues (e.g., water management, or soil degradation).

Smallholder agriculture plays a crucial role considering its importance for food security, especially in developing countries, and for the conservation of cultural landscapes worldwide. Hence, farmers need to participate in the research and implementation of sustainable agriculture from the beginning (Cárdenas et al. 2017). Further development of GIS applications and their implementation in the study area is a mutual process of co-creation pursued by researchers and stakeholders in Ricote at eye level. This process profits from the local and traditional knowledge of the community and the scientific expertise. To find sustainable solutions for land fragmentation, it is important to work on the local level and integrate local stakeholders (Zamora Acosta and Acosta Naranjo 2011) to prevent a tragedy of property.

3 The state of agricultural landscapes in the Mediterranean: smallholder agriculture and land abandonment in terraced landscapes of the Ricote Valley, southeast Spain[3]

3.1 Abstract

The fast and broad adoption of mechanization and chemical inputs in Mediterranean terraced agriculture, combined with warming climate trends, has led to the progressive degradation of environmental and social conditions. These factors have concurred with the increasing abandonment of smallholder agriculture. We aimed to detect and quantify the progression of cultivated and abandoned terraced fields in the Ricote Valley between 2016 and 2019, while also exploring reasons for land abandonment over the past decades. To quantify cultivated and abandoned agricultural terraces, we conducted 1) a terrace detection based on Lidar and cadaster data, 2) a land use classification based on Sentinel imagery, 3) an investigation of the reasons for land abandonment based on participant observation and an expert survey.

Our results show high rates of abandonment compared to the total available agricultural terraced area in the Ricote Valley. In 2016, 56 % of the detected terraced area was classified as not cultivated. In 2019, the percentage decreased to 40 %. Small parcels are cultivated to a higher percentage than large or medium-sized parcels. We identified five main reasons underlying land abandonment: 1) Low income of farmers; 2) Land fragmentation resulting in higher transaction costs; 3) Lack of interest in agricultural activities among young generations; 4) Lack of modernization; 5) Emotional bonds preventing the sale of abandoned parcels. We stressed the importance of a place-based mixed method approach to gain a comprehensive understanding of the specificities of a given research area.

Keywords: cultural landscapes, multifunctionality of agriculture, land fragmentation, Geographic Information System, mixed method, remote sensing

3.2 Introduction

Terraced smallholder agriculture is an important component of Mediterranean landscapes. It represents the outcome of the long-term convergence of human and environmental trajectories, resulting in a social-ecological system that has proven its stability and resilience over the past ten centuries or more (Balbo et al. 2016; Balbo et al. 2020; Blondel 2006; Lasanta et al. 2017b). However, since the 1940s, European agriculture has developed increasingly towards industrial, corporate, and globalized structures (Altieri and Nicholls 2012; Chemnitz 2019;

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[3] This chapter has been published in the peer-reviewed journal Regional Environmental Change as Heider, K.; Rodriguez Lopez, J. M.; Balbo, A. L.; Scheffran, J. (2021): The state of agricultural landscapes in the Mediterranean: smallholder agriculture and land abandonment in terraced landscapes of the Ricote Valley, southeast Spain. In Regional Environmental Change 21(1), 23. DOI: 10.1007/s10113-020-01739-x. The article has been reformatted as chapter of this thesis. The content is identical to the published version.

European Commission 2019; Reynolds et al. 2014). The expansion and common practices of industrial agriculture, such as the use of monocultures dependent on high inputs of chemical fertilizers and pesticides, combined with warming climate trends and increasing water scarcity, have led to deteriorating environmental and social conditions, and the homogenization of agricultural landscapes (Cramer et al. 2018; Endenburg et al. 2019; German National Academy of Sciences Leopoldina, acatech – National Academy of Science and Engineering, Union of German Academies of Sciences and Humanities 2018; IAASTD 2009; Kurz 2018; Lefebvre et al. 2015; Plieninger et al. 2006; Springmann et al. 2018; Vicente-Serrano et al. 2014). These factors have concurred with an increasing abandonment of smallholder agriculture over the past decades (Chemnitz 2019; European Commission 2019; Lasanta et al. 2017a; Lomba et al. 2019).

In the literature, different perspectives on land abandonment are presented. Some scholars described land abandonment as an opportunity while others understood it as a threat (Otero et al. 2015). Land abandonment often occurs in mountainous and remote areas and is generally associated with the loss of biodiversity (i.e., species adapted to human-made environments), increased risk of fires, soil erosion, loss of cultural, aesthetic, and historical values, as well as the loss of traditional ecological knowledge (Barthel et al. 2013; Gómez-Baggethun et al. 2013; van der Zanden, E. H. et al. 2018; Zagaria et al. 2018). However, benefits that may be gained from land abandonment include passive revegetation, active reforestation, water regulation, soil recovery, nutrient cycling, and increased biodiversity (Rey Benayas 2007; Zaragozí et al. 2011). Socio-economic factors have been described as the principal drivers of land abandonment, having a greater impact than environmental factors (Rey Benayas 2007). However, climate has been identified as the most important environmental driver in southeast Spain (Alonso-Sarría et al. 2016). Moreover, Lasanta et al. (2017a) identified the Common Agricultural Policy (CAP) of the European Union (EU) as one of the main drivers of land abandonment in the EU member states. In arid and semi-arid regions of southern Europe, decades of intensive cultivation and irrigation have led to soil degradation and further increased land abandonment (Lasanta et al. 2017a). Because of these and other negative externalities of current agricultural practices, an increasing number of authors are calling for changes in the current agricultural system, and challenging the productivity paradigm (Altieri and Nicholls 2012; Bernard and Lux 2017; Freibauer et al. 2011; Hathaway 2016; IAASTD 2009; IPES-FOOD 2016; Lomba et al. 2019; Reynolds et al. 2014; WBGU 2011).

Given this context, we explored recent trends of smallholder agriculture in the Ricote Valley. We examined cultivation and land abandonment in a study region still dominated by smallholder agriculture. This study aims to detect and quantify actively used and abandoned terraced fields in the Ricote Valley over the period of 2016–2019, while also exploring reasons for land abandonment over the longer period (i.e., 1940s to present). This aim led to the following research questions:

1. What is the state of smallholder agriculture in the Ricote Valley?
2. How much of the traditional terraced agriculture in the Ricote Valley was not cultivated between 2016 and 2019?
3. What are the reasons for the observed land abandonment over the past decades?

We used GIS-based analyses to detect agricultural terraces and quantify land cultivation and abandonment in the traditional orchards of the Ricote Valley. Using spatial analysis and place-based research methods, i.e., expert survey and participant observation, we explored the reasons for the abandonment of terraces combining quantitative and qualitative research methods.

The term ‘abandoned’ is used as equivalent to ‘not cultivated’. We define the ‘traditional’ agricultural area as the area that integrates local historic and cultural agricultural elements and has been established over decades to centuries. Examples for local historic and cultural agricultural elements are terraces, gravity-based flood irrigation, rainfed cultivation, stone walls, local crops, integration of livestock, and little mechanization. Nowadays, some of these elements have been substituted by conventional modern agricultural elements (e.g., monoculture, chemical inputs) in the study area.

3.3 The study area: smallholder agriculture in the Ricote Valley and its multiple functions

The study area includes the traditional orchards of the Ricote Valley and is part of the Segura river basin located in the region of Murcia in southeast Spain. The climate in the study area is semi-arid with strong seasonality. The studied orchards are spread across seven villages: Abarán, Blanca, Ojós, Ricote, Ulea, Villanueva, and Archena (Figure 3.1). This region contains a hydraulic system, which was introduced by Amazigh Berber populations more than 1000 years ago (Puy and Balbo 2013). Agricultural terraces are a central element of the hydraulic system. These terraces were constructed using stonewalls, and small canals between the terraces are used for flood irrigation. Drip irrigation has partially substituted traditional irrigation techniques over the past 12 years (García Avilés 2014; Puy et al. 2016). The primary crop planted on the terraces is lemon, followed by olive, almond and a variety of fruits. The agricultural land is highly fragmented due to the traditional heritage system in this region, which mandates that parts of land are granted to all siblings within a family. Smallholder family farming remains the most widespread form of farming in this area to the present day. Generally, farming activities on lands smaller than 2 ha are defined as small-scale farming (Jouzi et al. 2017), which is the case for most agricultural activities in the Ricote Valley.

Agriculture serves various functions for the environment, society, and economy of the Ricote Valley: Traditional smallholder agriculture involves greater biodiversity of species adapted to the human-made environment compared with industrial agriculture due to its small parcel sizes, diversity of microhabitats, and variety of cultivated crops such as lemon, olive, almond, peach, and vegetables. Additionally, a low degree of mechanization produces lower emissions and less air pollution. Furthermore, nature and wildlife protection is supported in the study area due its participation in the Natura 2000 network (Región de Murcia 2017).

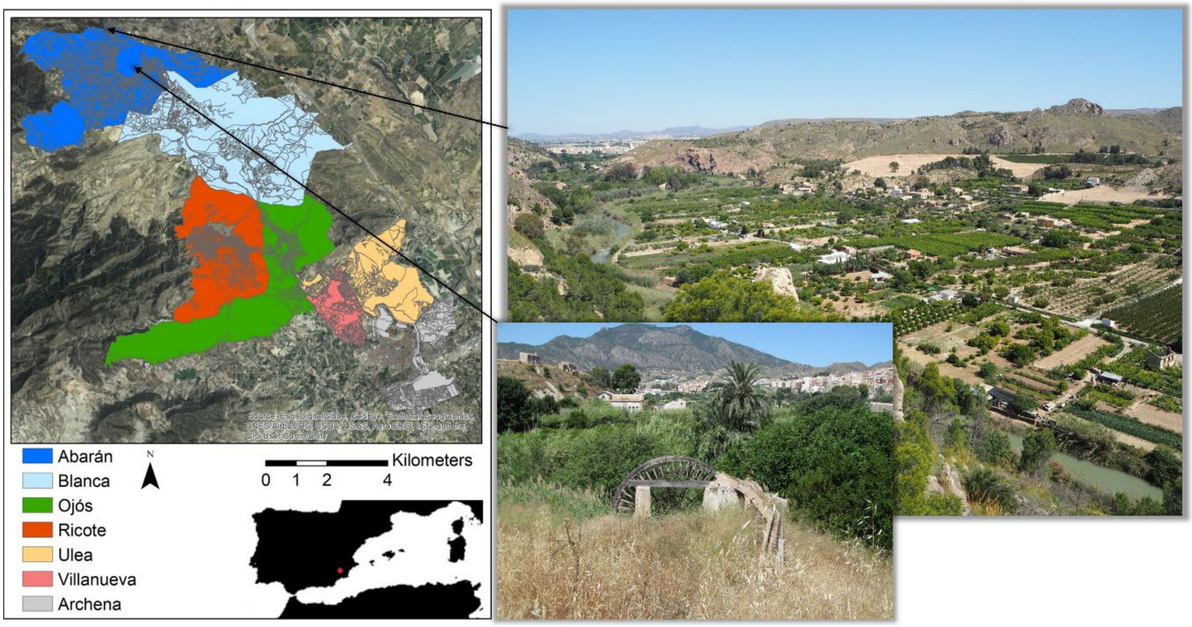

Figure 3.1 The study region: Ricote Valley, Murcia (map); traditional orchards, Abarán (above); parcel without cultivation for a long time, Abarán (below) (Photos: Heider)

From a social perspective, traditional smallholder agriculture provides space for recreation. Furthermore, local heritage is preserved in the forms of traditional agricultural systems, traditional irrigation technologies (e.g., hydraulic systems and *norias*), traditional agricultural practices, and traditional ecological knowledge (Bravo Sánchez 2018; Gil Meseguer 2014; Puy and Balbo 2013).

From an economic perspective, smallholder agriculture is a source of food, income, and employment in the Ricote Valley (García Avilés 2000, 2014). Often, agriculture represents an additional income source for families (pluriactivity), increasing their resilience to price volatility of the production. Moreover, the cultural landscape shaped by smallholder agriculture attracts tourists, opening new income opportunities.

We selected the study region because it is a multifunctional (agri)cultural landscape dominated by smallholder agriculture. Moreover, the study region is dominated by terraced agricultural landscapes, which could become a hazard if abandoned (Tarolli et al. 2014), and the broader Murcia region is severely affected by land abandonment (Alonso-Sarría et al. 2016). However, our study region represents one case of a broad range of European landscapes threatened by land abandonment or land-use intensification (Lomba et al. 2019).

Despite the high value of the various functions of smallholder agriculture, European statistics show that small-scale agriculture has deteriorated in recent years. Between 2003 and 2013, one-third of European farms were abandoned and smallholder farmers with family enterprises have been substituted by large companies (Alonso-Sarría et al. 2016; Chemnitz 2019). In the following sections, we discuss whether a similar trend can be identified in the study area.

3.4 Data and methods

To research the state of smallholder agriculture in the Ricote Valley, we used GIS-based analyses to detect agricultural terraces and quantify land cultivation and abandonment in the traditional orchards of the Ricote Valley. We implemented a three-step approach. First, we located traditional agricultural terraces and second, determined if they were cultivated. Third, we quantified cultivated and abandoned agricultural terraces in the years 2016 until 2019. Furthermore, we investigated the reasons for land abandonment using spatial analysis to include parcel sizes and place-based research methods (Reynolds et al. 2014), i.e., participant observation and an expert survey, to include local and expert knowledge.

The mixed method research design is shown in Figure 3.2. The sequential 3-phase design combines an explanatory design (Phase 1 and 2) to deepen the findings of the quantitative geo data analysis about land abandonment with an exploratory design (Phase 2 and 3) to identify reasons for land abandonment and quantify them. In the third phase, we integrated quantitative and qualitative data using the reasons identified during participant observation for the expert survey. The priority is given to quantitative research methods (Kuckartz 2014).

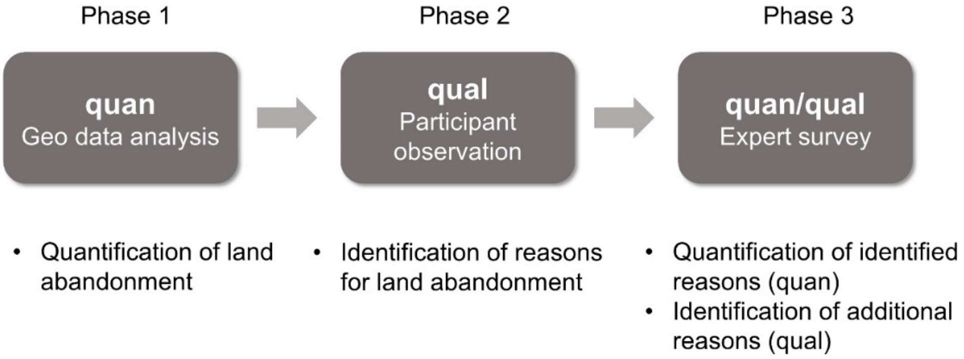

Figure 3.2 Mixed method research design combining quantitative methods (quan) and qualitative methods (qual)

3.4.1 Data and preprocessing

The GIS-analysis is based on cadaster data, a Digital Elevation Model (DEM, 2x2 m), which was calculated using laser point clouds (Lidar, 2016), and satellite imagery. As satellite images we used Sentinel data with a resolution of 10x10 m. For the analysis, we selected the months May and June for all available years, 2016 until 2019, of the Sentinel sensor. All data is freely available. We used SAGA-GIS and ArcGIS to conduct the analysis. For field validation, we used ArcGIS Online and the ArcGIS Collector App.

Cadaster data and Lidar point clouds need various steps of preprocessing. Cadaster data for the Ricote Valley is provided by the Spanish authorities (Ministerio de Hacienda 2020). Based on local expert knowledge, we included only the zones of traditional orchards in the cadaster data of every village for further analysis. Urban areas, as well as rivers and streets were excluded.

High resolution Lidar point clouds and Sentinel data can be downloaded free of charge (Instituto Geográfico Nacional 2019; USGS 2019). We conducted the preprocessing of point clouds in SAGA-GIS (Conrad et al. 2015). The point clouds have a mean point distance of 0.44 m. We merged and converted them to raster data with a grid size of 2x2 m. Gaps in data were filled using the tools "shrink and expand" and "spline interpolation". A Digital Surface Model (DSM) was created. In order to create a DEM, we excluded small structures like trees and bushes of the DSM using a morphological filter with a radius of 2. The DSM and DEM were cut to the extent of the study area using the selected zones of the cadaster data.

3.4.2 Terrace detection

The terrace detection is based on location (cadaster) and planarity of parcels (DEM). Spanó et al. 2018 tested different detection methods for terraces in Italy and their regional-scale approach using DEMs and cadastral maps represents a good fit to our data availability. We adapted the procedure to our study area. First, we transferred the elevation values (z-values) of the DEM to the polygon vertices of the cadaster data. Second, we calculated the standard deviation for the z-values per polygon in order to determine the planarity of a parcel. We set the threshold for the calculated planarity to 11.8. If polygons had a planarity value below or equivalent to 11.8, they were classified as terrace. If the value was larger, they were excluded. The planarity values and the usage as terrace are highly dependent on the study area and can vary from village to village. We set the threshold at 11.8 because it produced the best results excluding most of the rugged terrain and including almost all terraces in every village. As an additional parameter for terrace detection, Spanó et al. 2018 used the slope index. For our study area, the use of a slope index did not alter the results. One polygon in the cadaster data can consist of only one terrace containing almost no slope or various terraces containing very high slopes. This reduced the usability of the slope index for terrace detection in the study region. In consequence, we excluded it from the terrace detection procedure.

3.4.3 Land use classification

After the terrace detection, we classified the cultivation status of every parcel to cultivated or not cultivated. We used two different classification methods to determine if parcels were cultivated or not. The first method is based on Lidar data, calculating the plant height. The second method is based on Sentinel images using the Normalized Difference Vegetation Index (NDVI) to determine plant health.

To determine the plant height with Lidar data, we used the difference between the beforehand calculated DSM (including plants) and the DEM (excluding plants) to create a surface model of the plants in the study region. In the next step, we classified the plant height according to our needs. The main crops in the study area are lemons and olives. In consequence, we focused on tree heights of up to 3.5 m as this is the maximum height of trees in the study area, to facilitate the picking of fruits. Higher trees are mainly forests or parcels that are no longer in use. As minimum height we used 0.25 m including young trees. The classification of plants based on Lidar data can be seen in Figure 3.3 (left). The map shows a classification of plant heights in Ricote. Green parcels are cultivated, brown and blue parcels are not cultivated. In the following, the cultivation per parcel was calculated and quantified using the "zonal statistics" tool in ArcGIS. The results were cut to the extent of the detected terraces.

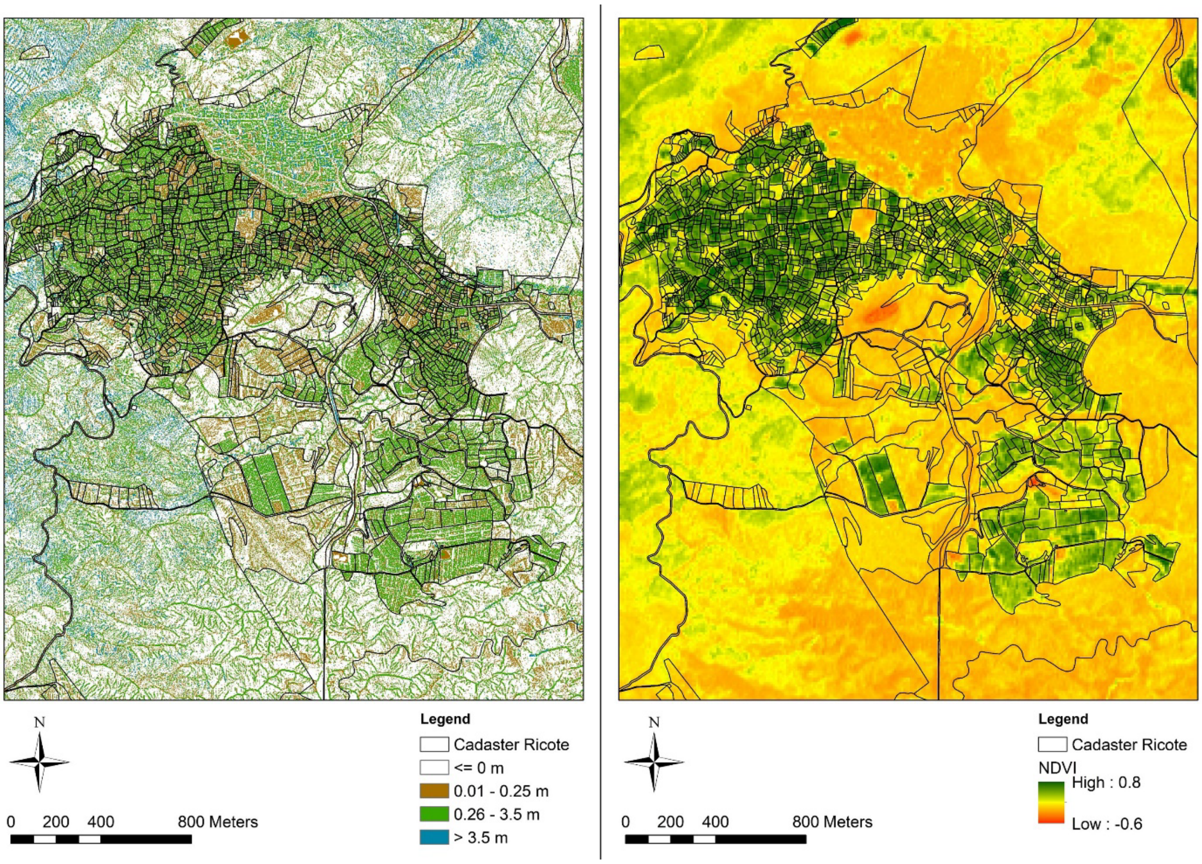

Figure 3.3 Land use classification based on Lidar data in Ricote village. The use of agricultural parcels is based on plant heights. Brown: heights lower than local tree plantations, green: possible tree plantation heights, blue: heights higher than local tree plantations (left). Normalized Difference Vegetation Index based on Sentinel data in Ricote village. Green: healthy vegetation (right)

As an alternative approach to the land use classification based on Lidar, we used the NDVI based on satellite data from Sentinel.

The NDVI is calculated using the following formula

$$\mathrm{NDVI} = \frac{NIR-red}{NIR+red}$$

where NDVI is the Normalized Difference Vegetation Index, NIR is near infrared (Sentinel: band 8), red is the red band (Sentinel: band 4).

The NDVI for Ricote can be seen in Figure 3.3 (right). In the following, we set a threshold for the differentiation between cultivated and not-cultivated parcels at 0.3 adapted to Mediterranean tree crops between April and August (Bendetti et al. 1994). We calculated and quantified the cultivation per parcel using "zonal statistics" in ArcGIS and cut the results to the extent of the detected terraces. We conducted the procedure for the years 2016 until 2019. The working steps of terrace detection and land use classification based on Sentinel data can be seen in Figure 3.4.

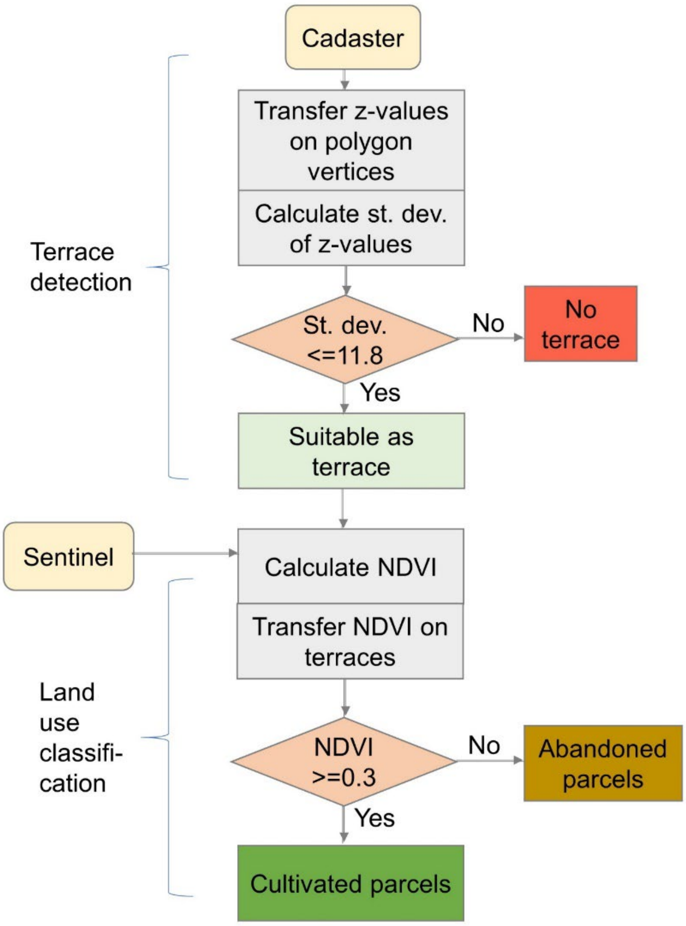

Figure 3.4 Workflow of GIS-analysis: Terrace detection (above) and land use classification (below) to identify cultivated and not-cultivated parcels

For the accuracy assessment, we conducted a preliminary assessment in the first step using high-resolution satellite imagery of Google Earth comparing Lidar (2016) and Sentinel classification results (2016-2019) (See et al. 2015). In the second step, we validated the results locally in the orchards of the seven villages in the Ricote Valley in summer 2019. For the validation, we created 100 random points according to our two classification classes (Lillesand et al. 2004). In the next step, we uploaded the validation points to ArcGIS Online and used the ArcGIS Collector App to validate and edit the data locally in the study region. Due to the construction of fences in the study region, we were not able to validate all points. The results of the validation are shown in a confusion matrix, based on which we calculated the producer's accuracy, the user's accuracy and the accuracy rate (Story and Congalton 1986).

$$\text{Producer's Accuracy} = \frac{CC}{CT}$$

where CC is the number of correctly classified samples of one category, CT is the column total, which represents the total number of reference samples of one category.

$$\text{User's Accuracy} = \frac{CC}{RT}$$

where CC is the number of correctly classified samples of one category, RT is the row total, which represents the total number of samples that were classified in one category.

Accuracy Rate = $\frac{TP+TN}{N}$

where TP is true positive (actual cultivated and classified cultivated), TN is true negative (actual not cultivated and classified not cultivated), N is the total number.

3.4.4 Exploring the reasons for land abandonment

In the next step, we explored the multivariate reasons for land abandonment in the study region. Using two separate approaches, we conducted a spatial analysis based on parcel sizes and we used participant observation and expert surveys in the study region to identify the most important reasons. To research the abandonment of parcels according to different parcel sizes, we classified parcels in three quantiles to determine small (<556 m²), medium-sized (556 – 1533 m²) and large parcels (>1533 m²). In the next step, we calculated the absolute and relative cultivated and not-cultivated area for every class and year of analysis. Moreover, we calculated how much of the total cultivated and not-cultivated land was covered by small, medium-sized, or large parcels.

Giving voice to the local people, participant observation and expert surveys enabled the integration of local perspectives to better understand the research results. During participant observation in the field, we participated in agricultural activities, communicating regularly with local stakeholders (Thomas 2019). Insights from participant observation supported by a literature review enabled the preselection of reasons for land abandonment used in the expert survey. We selected the experts on the basis of their expertise on the topic, location, and their availability. Eleven experts with scientific, economic, and administrative backgrounds participated in the survey. In personal interviews in June 2019, the experts were requested to evaluate the importance of preselected reasons for the abandonment of parcels in the Ricote Valley on a scale from 0 (not important) to 4 (very important), and they could also add other reasons. In the evaluation process, first, we created new categories that combined the preselected and added reasons; second, we calculated the weighted arithmetic mean of the new categories, considering the number of persons mentioning each added reason; finally, we only included reasons with a value higher than 2 (moderate importance).

3.5 Results

We found high rates of agricultural land abandonment within the terraced fields of the Ricote Valley. Figure 3.5 shows the dynamics of abandonment and cultivation of parcels between 2016 and 2019. Parcels are marked in red if they are classified as cultivated in 2016 and as not cultivated in 2019. Parcels are marked in green if they are classified as not cultivated in 2016 and as cultivated in 2019. Yellow parcels indicate no change. The map shows more green parcels than red parcels, which corresponds to the calculated increase of cultivated area in the Ricote Valley over the 2016-2019 period. Furthermore, the largest agglomerations of new cultivated areas are observed mainly in Abarán, Villanueva, and Archena. The mean percentage of abandonment of agricultural area between 2016 and 2019 is 51.35 %. In other words, more than half of the agricultural terraced land available in the Ricote Valley was not cultivated on average in the 2016-2019 period. The abandonment varies between years. While the percentage of abandonment in the first year of the analysis was 56.33 % (2016), the percentage decreased in the following years to 55.01 % in 2017, 54.12 % in 2018, and 39.94 % in 2019 (Table 3.1). Thus in 2019, with a difference of 14.18 % in comparison to 2018, much less abandoned area is detected. 2019 marks the year where the detected percentage of cultivated area (60.06 %) is higher than the abandoned area (39.94 %). After the description of the accuracy assessment, we will describe the detected reasons for abandonment including an analysis of parcel sizes.

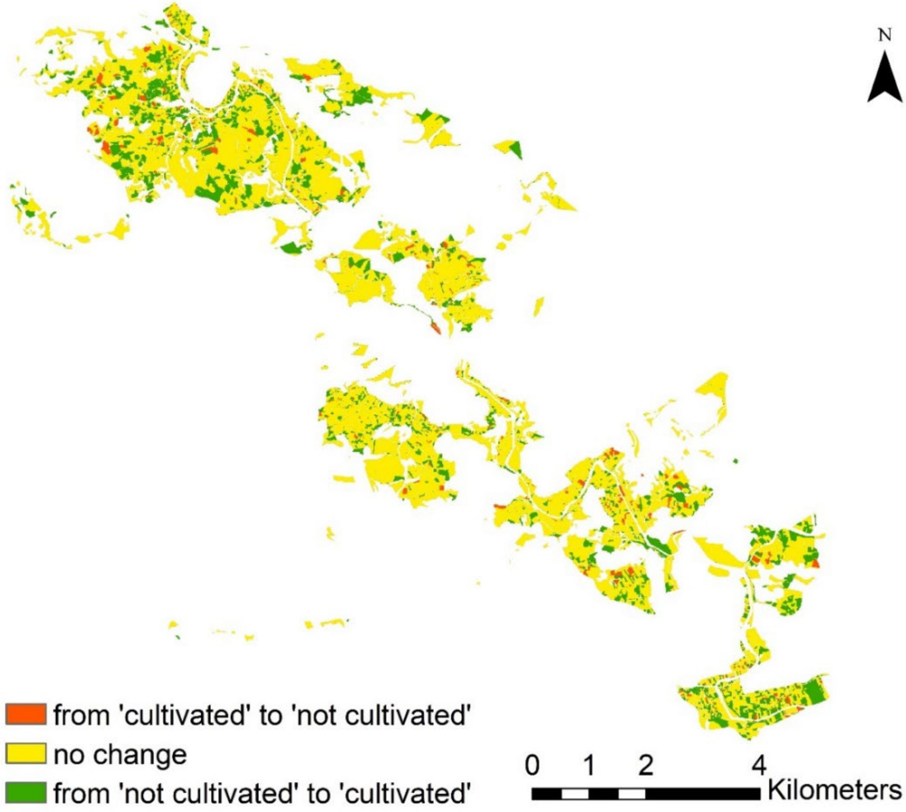

Figure 3.5 Cultivation and abandonment between 2016 and 2019; red parcels: change to not cultivated, green parcels: change to cultivated, yellow parcels: no change between 2016 and 2019

Table 3.1 Quantification of the cultivated (C) and not-cultivated (NC) area in the Ricote Valley between 2016 and 2019

Year	NC [m²]	NC [%]	C [m²]	C [%]
2016	12728791.06	56.33	9868456.88	43.67
2017	12430678.88	55.01	10166569.07	44.99
2018	12230382.72	54.12	10366865.23	45.88
2019	9024215.62	39.94	13573032.33	60.06

In the preliminary accuracy assessment using high resolution satellite imagery of GoogleEarth, we found a higher accuracy of land use classification based on Sentinel data than based on Lidar data. In the next step, we validated the classification results based on Sentinel imagery of 2019 locally. The field validation was conducted in summer 2019 and the results are shown in a confusion matrix. The confusion matrix illustrates the performance of the land use classification using predicted and actual classes of cultivated and not-cultivated parcels (Table 3.2). The producer's accuracy shows that 89 % of cultivated parcels are classified correctly, while only 44 % of not-cultivated parcels are classified correctly. The user's accuracy shows a probability of 78 % for a parcel classified as cultivated to be actually cultivated on the ground. The probability for not-cultivated parcels is 65 %. The overall accuracy rate is 0.753.

Table 3.2 Confusion matrix showing the validation of land use classification results for cultivated (C) and not-cultivated (NC) parcels based on Sentinel 2019. We conducted the validation for a total of 81 parcels in summer 2019

		Validated on the field			
		Actual "C"	Actual "NC"	Row total	User's accuracy
Classified	Predicted "C"	50	14	64	0.78
	Predicted "NC"	6	11	17	0.65
	Column total	56	25	81	
	Producer's accuracy	0.89	0.44		

In the following, we describe the reasons for land abandonment. The analysis of abandonment according to parcel size shows that the percentage of cultivated area decreases with an increasing parcel size (Figure 3.6). Parcels were categorized as small if they had an extent of up to 556 m^2, as medium with an expansion of 556 until 1533 m^2, and as large with more than 1533 m^2. Small parcels are cultivated to a higher percentage than large or medium-sized parcels. The mean cultivated area of small parcels between 2016 and 2019 was 66.20 %, while the mean cultivated area of large parcels was 45.68 %. The mean cultivated area of medium-sized parcels lied in between with a value of 58.83 %. In 2019, 76 % of the agricultural area of small parcels was cultivated, while only 57 % of the area of large parcels was cultivated. The percentage of cultivation increased between 2016 and 2019 for all parcel sizes and the largest increase in cultivation can be seen between the years 2018 and 2019 with an increase of over 10 % for all parcel size categories.

Based on a complementary calculation, Table 3.3 shows the percentage of total cultivated and not-cultivated land within small, medium-sized, and large parcels in 2016 and 2019 respectively. The cultivated area of large parcels covered c. 75 % of the total cultivated land in 2016, while the cultivated area of medium-sized parcels covered c. 18 % and the cultivated area of small parcels covered c. 7 % of total cultivated land. For not-cultivated land, we see a similar distribution. The not-cultivated area of large parcels covered c. 85 % of total not-cultivated land in 2016, while the not-cultivated area of medium-sized parcels covered c. 12 % and the not-cultivated area of small parcels covered c. 3 % of total not-cultivated land. Between 2016 and 2019, the percentage of cultivated and not-cultivated areas covered by small and medium-sized parcels decreased, while the percentage of cultivated and not-cultivated areas covered by large parcels expanded (Table 3.3).

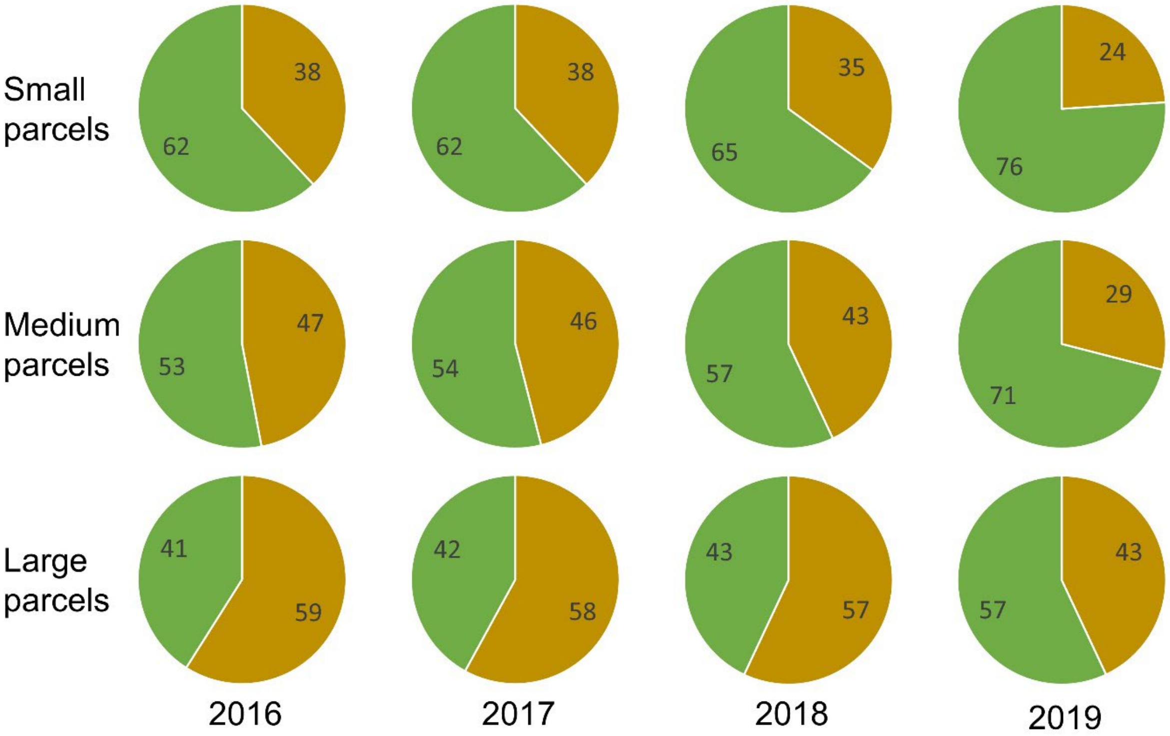

Figure 3.6 Percentage of cultivated (green) and not-cultivated (brown) agricultural area according to parcel sizes in the Ricote Valley between 2016 and 2019. Small parcels contain parcels up to 556 m², medium parcels 556-1533 m², and large parcels contain an area larger than 1533 m²

Table 3.3 Percentage of total cultivated (C) and not-cultivated (NC) land covered by small, medium-sized, and large parcels in 2016 and 2019

	2016		2019	
Parcel size category	C [%]	NC [%]	C [%]	NC [%]
Small	6.94	3.36	6.26	2.90
Medium	18.16	12.40	17.72	10.69
Large	74.91	84.24	76.02	86.40
Total [%]	100	100	100	100

According to the expert survey, the most important reasons for the abandonment of agricultural land in the Ricote Valley are socio-economic: 1) The low income of farmers, which is related to the current market situation and derived from competition with large-scale industrial agriculture in the surrounding area; 2) Land fragmentation, which causes higher transaction costs for farmers; 3) The lack of interest for agricultural activities among young generations. This is revealed in the high average age of farmers and the phenomenon of rural-urban migration, contributing to the depopulation of rural areas; 4) The lack of modernization is mentioned as a challenge that prevents agricultural farms in the Ricote Valley to compete with the industrial agriculture in the surrounding area; 5) Emotional bonds to agricultural land due to family farming history prevent the sale of abandoned parcels.

3.6 Discussion

The GIS-analysis has shown that a large percentage of the detected terraced area is not cultivated in the Ricote Valley. However, the cultivated area has increased during the last years, especially between 2018 and 2019. In particular, small parcels were found to be cultivated to a higher percentage than large or medium-sized parcels. In 2018, the percentage of cultivated area in small parcels was 22 % higher than the percentage of cultivated area in large parcels (Figure 3.6). Thus, smaller-scale agriculture seems to be more intact than larger-scale agriculture in the Ricote Valley. One explanation is the long tradition of family farming in the Ricote Valley. Most of the small agricultural parcels are cultivated by families, where the agricultural activity is not the main income source. In these cases, smallholder agriculture tends to be less vulnerable to price volatility and economic shocks. Nevertheless, like in most European regions (Chemnitz 2019), the agricultural area covered by small and medium-sized parcels decreased between 2016 and 2019, while the agricultural area covered by large parcels expanded.

The experts' perceptions captured by the questionnaire have revealed various reasons for the high percentage of abandonment of detected terraces in the Ricote Valley. Socio-economic dimensions emerged as the most important reasons for land abandonment. Most of the terraced fields in the study area are relatively small, with 2/3 of the detected terraces having an extension of less than 1533 m^2. Thus, the topography of the Ricote Valley, seems to have limited the uptake and expansion of industrial agriculture in the traditional orchards. However, the competition with industrial agriculture is omnipresent in the conversation with locals and experts. The Ricote Valley is surrounded by large-scale agriculture and crop prices are volatile, as they are determined by the European market and the large supply. Most EU subsidies are distributed according to the agricultural area under cultivation, which supports mainly large-scale farms (Chemnitz 2019; IPES-FOOD 2016). According to personal communications and explanations obtained from the questionnaire, many parcels in the Ricote Valley are too small to receive any helps from the European Common Agricultural Policy. This explains the low income of farmers and the current market situation as important reasons for land abandonment.

According to the experts, another important reason for abandonment was land fragmentation. The high land fragmentation in the study area is determined by geographical and cultural factors. On the one hand, the steep topography, in which agricultural parcels are located, limits the possibilities to merge smaller parcels into larger ones. On the other hand, the local heritage system based on Muslim traditions imposes the subdivision and inheritance of land among siblings. Land fragmentation was mentioned in the expert survey as an economic and management challenge that causes high transaction costs (Heider et al. 2018) and prevents further mechanization and industrialization of agriculture. However, land fragmentation is highly related to biodiversity, protection from winds and erosion, and to the cultural landscape that was shaped in the region over 1000 years or more (Bentley 1987; Blondel 2006; Crecente et al. 2002; Puy and Balbo 2013). Reducing land fragmentation by changing the physical structure of the agricultural area would possibly result in the deterioration of this cultural landscape, eroding the multiple values and functions of agriculture in the Ricote Valley. Furthermore, the spatial analysis showed that small parcels are cultivated at a higher percentage than large or medium-sized parcels and thus tend to be less vulnerable.

Importance was also given to the lack of interest shown by the next generation in continuing the agricultural activities of the family. Low farm income and high workload were mentioned as reasons for this lack of interest. Further related reasons for land abandonment were the high farmer age and migration to the cities. Nevertheless, emotional bonds of the local youth to the agricultural parcels cultivated by their ancestors are strong, often preventing the sale of not-cultivated parcels, as explained by local experts, which reinforces land abandonment.

Finally, we discuss limitations within our mixed method approach. The land use classification using Sentinel data produced better results than using Lidar data. The accuracy of Sentinel data is 75.3 %. However, in this analysis there are shortcomings in both detection methods, which produced classification errors during the detection of recently cultivated and recently abandoned parcels. Parcels, recently cultivated, were classified as not cultivated due to the high distance between small trees, and the high percentage of bare soil. Recently abandoned parcels were classified as cultivated, due to small changes only visible in the field or with very high-resolution images. Furthermore, there are various shortcomings using Lidar data. The most recent Lidar data is from 2016 (Instituto Geográfico Nacional 2019), thus we were not able to research the most recent changes based on this data source. Moreover, the analysis with Lidar data is based on vegetation heights. Thus, it is more suitable for the detection of the cultivation status in tree plantations than for the detection of vegetable or cereal cultivation. Although the study area is dominated by tree cultivation, there are areas dominated by vegetable cultivation where a classification based on heights might not work. In order to assess the accuracy, we validated the land use classification in-situ. Due to limited access to the agricultural parcels, we had to reduce the number of validation points to 81.

While in this study the priority was given to quantitative methods, qualitative methods helped to deepen the understanding of the reasons for land abandonment and integrate local perspectives into the expert survey. This would not have been possible conducting a monomethod approach.

3.7 Conclusion

In this article, we examined the most recent trends of smallholder agriculture in the Ricote Valley, quantified the cultivation and abandonment of traditional orchards between 2016 and 2019, and investigated the reasons for abandonment using a mixed method approach.

We observed a high percentage of agricultural land abandonment for terraces detected within the traditional orchards of the Ricote Valley. In 2016, 56.33 % of the detected terraces in this agricultural area were classified as not cultivated. This trend of abandonment has been decreasing recently, with only 39.94 % of the detected terraces in this agricultural area being classified as not cultivated in 2019.

In the study area, small parcels were cultivated to a higher percentage than large or medium-sized parcels. This could be related to small parcels being cultivated by family farms, and agriculture not representing their main income source. In fact, small parcels tend to be less vulnerable to price volatility. Nevertheless, like in most European regions, the agricultural area covered by small and medium-sized parcels decreased between 2016 and 2019, while the agricultural area covered by large parcels expanded.

In addition to a GIS-based top-down approach, we used participant observation and an expert survey as place-based research methods. This mixed method design contributed to a more complete picture of land abandonment in the study area. According to the experts, there are multiple important reasons for the abandonment of agriculture in the Ricote Valley: low income of farmers and market competition with large-scale industrial agriculture in the surrounding area; land fragmentation, which results in higher transaction costs for farmers; lack of interest in continuing agricultural activities among young generations; lack of modernization; and finally strong emotional bonds to the land, which have prevented the transfer of agricultural parcels and may further explain land abandonment.

We emphasize that a paradigm shift in agriculture is needed to identify alternative pathways for the recovery of abandoned and degraded lands. Alternative pathways should be based on integrating social, ecological and economic needs. Such an integrated approach should be supported by dedicated policies at the European, national and local levels. Agricultural subsidies should be distributed following the principle of public money for public services, promoting multifunctional agriculture. More support for young farmers, for innovative farms, and for a transition to organic agriculture is needed, addressing the low income of farmers and the lack of interest in farming activities among young generations. For example, promoting farms that use agroecological practices, sell directly to urban customers and process their products in-house, can contribute to the regeneration of degraded and abandoned lands, the reinforcement of local food chains, and the revival of local employment. A reformed agricultural policy can make one of the greatest contributions to protecting biodiversity, mitigating the effects of climate change, reducing rural exodus, and supporting social innovation.

We are going to continue our research in Spain, investigating the regeneration of abandoned and degraded lands. Therefore, we will explore the role of agroecological practices for a multifunctional agriculture. We will focus on alternative water and land management pathways, which integrate traditional agroecological knowledge, practices, and technologies from Mediterranean semi-arid regions.

4 Reinventing the wheel - The preservation and potential of traditional water wheels in the terraced irrigated landscapes of the Ricote Valley, southeast Spain[4]

4.1 Abstract

Lifting water is crucial to irrigate agricultural terraces in the Mediterranean region. But the energy demand and emissions of modern forms of water pumping have increased, while many traditional water wheels, which lift water at zero direct emissions, have been abandoned. We explored the state of preservation and the potential for the deployment of traditional water wheels known as *norias* in the Ricote Valley of southeast Spain, where some are still in function, while also investigating the reasons for their widespread abandonment. A mixed method approach is used here to combine GIS-based methods, an expert survey, and a technological and socio-economic assessment of noria renovation.

Our findings show that norias in the Ricote Valley have mostly been replaced by thermal-engine water-lifting technologies. The reactivation of traditional irrigation technologies, many of them lying dormant but still standing, could contribute to reducing the high energy demand and the resulting emissions of irrigation systems in the Mediterranean region and beyond. It was estimated by data extrapolation that 16 renovated norias included in our analysis can irrigate 140.3 hectares in the Ricote Valley, for a total achievable power of 23.8 kW. To irrigate a similar surface applying diesel motor pumps would produce up to 148 tons of emissions/year and cost up to approx. 70,000 €/year based on a price of 1.25 €/l diesel for a maximum of 8760 working hours/year. In the case of electric pumps, we estimate that up to 55 tons of emissions/year and costs up to approx. 48,000 €/year can be saved.

Therefore, we argue that rediscovering traditional technologies has potential to contribute to achieving climate actions that reduce GHG emissions (SDG 13). Moreover, these technologies provide multiple functions and services for a sustainable life on land (SDG 15), which needs to be considered within a holistic approach.

Keywords: irrigated agriculture, cultural landscape, multifunctionality of agriculture, water management, emission mitigation

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[4] This chapter has been published in the peer-reviewed journal Agricultural Water Management as Heider, K.; Quaranta, E.; García Avilés, J. M.; Rodriguez Lopez, J. M.; Balbo, A. L.; Scheffran, J. (2021): Reinventing the wheel - The preservation and potential of traditional water wheels in the terraced irrigated landscapes of the Ricote Valley, southeast Spain. In Agricultural Water Management 259, 107240. DOI: 10.1016/j.agwat.2021.107240. The article has been reformatted as chapter of this thesis. The content is identical to the published version.

4.2 Introduction

The expansion of agriculture globally is putting high pressure on resources and biodiversity (IPBES 2019). As much as 70 % of global freshwater withdrawal and 38 % of the Earth's terrestrial surface serves agricultural production (Foley et al. 2011). While crop yields per hectare have increased significantly within the last decades and irrigated agriculture provides 34 % of the global food production using 24 % of the global agricultural land (Foley et al. 2011; IAASTD 2009), decades of agricultural expansion, intensive cultivation, homogenization and irrigation have also led to environmental and social degradation (Bjornlund and Bjornlund 2019; IAASTD 2009; Lasanta et al. 2017a; Lomba et al. 2019). In the Mediterranean region, future warming is expected to exceed global warming rates by 25 %, with extreme summer temperatures and reduced precipitation. At the same time, Mediterranean agriculture is intensifying with increased irrigation and energetic use, and consequently with undesirable effects on water resources, biodiversity, climate and landscape functioning (Cramer et al. 2018; Martin-Gorriz et al. 2021).

In Spain, ongoing transformations in the irrigation systems can potentially reduce water consumption per hectare, but energy demand has increased by 657 % between 1950 and 2008, following the widespread introduction of thermal-engine pumping systems (Soto-García et al. 2013). Consequently, irrigation is responsible for 45 % of GHG emissions from agriculture in Spain, conflicting with the EU's emission targets (European Commission 2020; Martin-Gorriz et al. 2021).

Sustainable alternatives for intensive irrigation systems are urgently needed. The revival of pre-industrial technologies and traditional ecological knowledge may help finding new sustainable solutions, e.g., improved water efficiency based on agroecological practices like cover crops, contour farming, the use of agricultural terraces and locally adapted crops or, as we will explore in this study, the reintroduction of traditional water wheels, known as norias (Altieri and Nicholls 2012; Bernard and Lux 2017; IAASTD 2009; Lomba et al. 2019; Pretty 2018).

Traditional terraced smallholder agriculture is an important component of rural Mediterranean landscapes and remains a predominant farming model in the Ricote Valley (Heider et al. 2021). It represents the outcome of the long-term convergence of human and environmental trajectories, resulting in a social-ecological system that has proven its stability and resilience over the past ten centuries or more (Balbo et al. 2016; Blondel 2006; Lasanta et al. 2017b). The agricultural terraces of the Ricote Valley are part of a gravity-based irrigation system, which was introduced more than 1,000 years ago (Puy and Balbo 2013). Water wheels that lift irrigation water to higher agricultural terraced land, known as norias, have played a key role in the long-term sustainability of these irrigated landscapes, allowing the exponential extension of irrigated land based on a zero-emission technology.

The rural development policy within the second pillar of the common agricultural policy (CAP) of the EU aims to combine ecological and social needs with economic targets.

Unfortunately, the CAP has also, perhaps unwillingly, contributed to the homogenization of rural landscapes and to the deterioration of small-scale agriculture during the last decades (Chemnitz 2019; Heider et al. 2021; Lefebvre et al. 2015). A minimum area of 0.2 ha is needed to obtain subsidies in Spain. This, combined with the gradual withdrawal of small amounts of public aids, has further intensified these trends (BOE 2014), accelerating the abandonment of traditional technologies, often used and maintained by smallholders.

While ubiquitous in large human agglomerations, knowledge and innovations are fast eroding in rural areas, also due to rural-urban migration of the young population (Balbo et al. 2020; Tacoli and Mabala 2010). The resulting lack of access to existing knowledge is another major limitation for smart and sustainable development in rural areas (Copus et al. 2011), where traditional knowledge is a key dimension of sustainability. By focusing on the appreciation of regional endowments, such as biophysical, economic, cultural, social, historic and technological strengths, our paper explores smart and green specialization strategies in rural areas (Asheim et al. 2011; Thissen et al. 2013).

In the literature, norias are mostly investigated from a historic perspective (Glick 1977; Headworth 2004), stressing their cultural heritage values (Bravo Sánchez 2018; Gil Meseguer 2014), technological values (Banegas Ortiz and Gómez Espín 1992; Gómez Espín 2014; Yannopoulos et al. 2015), as well as evaluating their performance (Stillwater and Awad 1991). Indeed, water wheel sites (both mills and pumping sites) can be considered among the main drivers of economic, industrial and social development of rural agricultural spaces before the industrial revolution (Hassan 2011; Quaranta and Wolter 2021). It is estimated that over 350,000 of such hydro sites may have existed in Europe at one time or another. In Japan water wheels comprised 56 % of total power generation until 1886 (Punys et al. 2019; Quaranta and Wolter 2021).

The abandonment of most norias in Spain started with the generalized introduction of motor pumps over the past decades (Bravo Sánchez 2018; Closas 2014). The following increase of intensive groundwater extraction technologies promoted over-extraction in Spain (Closas 2014). Indeed, water wheels have been replaced by motors or hydro plants all over Europe (Quaranta et al. 2021).

From a current perspective, norias are valued for promoting landscape aesthetics as well as the multifunctionality of rural areas by fostering recreation and rural tourism (Gil Meseguer 2014). Furthermore, water wheels are increasingly valued for renewable power production at low head sites and at old mill weirs. This opens up possibilities for the re-use of traditional water wheels (installed power typically below 50 kW), which have been abandoned during the past decades (Müller and Kaupert 2004; Quaranta and Revelli 2018; Quaranta 2018; Quaranta et al. 2021).

This study analyses the state of norias in the Ricote Valley, while also exploring the reasons for their deterioration. Furthermore, we investigate the potential for their renovation and their potential contribution to the multifunctionality of agriculture. This leads to the following research questions:

1. What is the current state of preservation of norias in the Ricote Valley?
2. What are the reasons for the observed abandonment of norias during the past decades?
3. What is the potential of noria renovation for a sustainable agricultural system?

To address these questions, we used a mixed method approach combining GIS-based methods, an expert survey, and an assessment of the potentials of noria renovation. First, we collected available geo data to explore the state of preservation and location of norias in the Ricote Valley. Second, we combined participant observation with the inquiry of experts to identify the reasons for the deterioration of norias. Finally, we investigated the norias under a hydraulic and geometric perspective with the aim of calculating their irrigation potential (i.e., the pumped flow rate, irrigated area) as well as emission mitigation and saved costs, compared to electric and diesel pumps. We also elaborated their geometric dimensions in order to find easy and expeditious tools that can be used in future research to re-construct and estimate unknown dimensions and performance of norias. The estimation of such dimensions is important to better understand their historical deployment for irrigation in the past, but also their potential as an integral component of future pathways for sustainable agricultural systems. The results will be then discussed with focus on the Ricote Valley and could be extrapolated to other traditional agricultural landscapes in the Mediterranean region.

4.3 Study area

The study area is the Ricote Valley in the region of Murcia, southeast Spain (Fig. 4.1). The climate in the study area is semi-arid with strong seasonality. We include in our analysis seven villages, which stretch alongside the Segura River: Abarán, Blanca, Ricote, Ojos, Ulea, Villanueva, and Archena with a population of 44,742 in 2020 (Instituto Nacional de Estadística 2021). Part of the villages are the traditional orchards (Fig. 4.2). Lemon is the current primary crop cultivated in the valley, followed by olive, almond, multiple fruits, and vegetables. Many farmers cultivate their primary products for export, which leads to challenges due to price volatility and competition with modern industrial agriculture in the neighboring regions (Heider et al. 2021). Furthermore, the agricultural properties are highly fragmented due to the traditional heritage system in the study area. Most of the agricultural properties are smaller than 1 hectare (Heider et al. 2018). Thus, smallholder farming dominates agriculture in the study area until today.

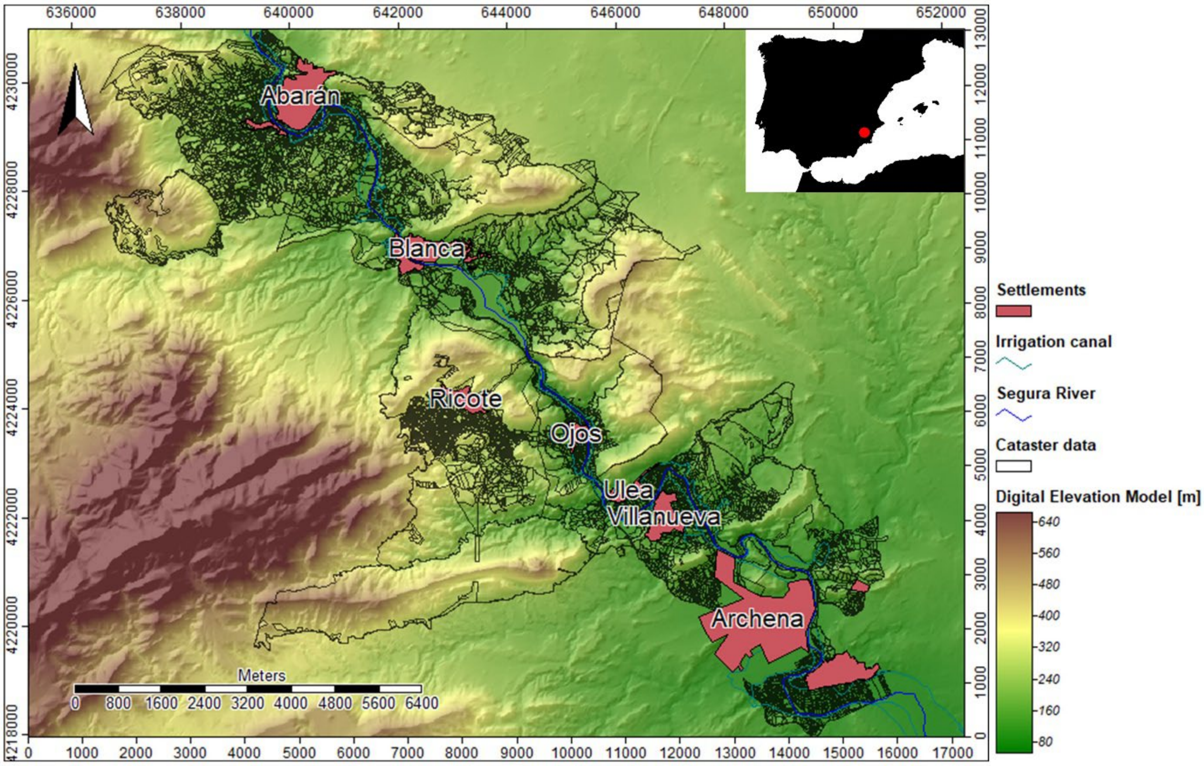

Figure 4.1 The Ricote Valley, Murcia, southeast Spain, and the seven villages included in our study

Figure 4.2 Terraces alongside the Segura River in the Ricote Valley (Photo: Andreas Bischoff)

The traditional orchards contain multiple levels of agricultural terraces in different sizes and shapes divided by stonewalls and crossed by small irrigation canals. These terraces are part of a hydraulic system, which was introduced by Amazigh Berber populations over 1,000 years ago for flood irrigation (Puy and Balbo 2013). Norias were added at a later stage of expansion of these agricultural systems, lifting water and expanding agricultural land to ever higher grounds. They are distributed along irrigation canals outbranched from the Segura river, which is characterized by strong seasonal differences and high flood risk (Ministerio para la Transición Ecológica y el Reto Demográfico 2021).

Technically, the norias in the Ricote Valley originate from the "Egyptian water wheel" with buckets attached and powered by the water flow. It was originally invented by the Romans approx. between 600 and 700 BCE (Yannopoulos et al. 2015). During the Middle Ages, the expansion of Arab civilizations contributed to the broad diffusion and progressive modification of norias across the Islamic world (Martínez Soler and Banegas Ortiz 1994). In the Ricote Valley, they probably existed prior to the 16th century, as they were well-known and widespread in Al-Andalus. However, their installation in the valley coincided with a population increase and therefore the need to increase irrigated cropland from the 16th century onwards (García Avilés 2000; Puy 2012). With an increasing production, the transport of locally produced crops became also important, with large numbers of muleteers in the valley deployed to export cash crops (García Avilés 2007). The current norias are a result of the adaptation to the cultivation of new crops, rising production and rising irrigation needs for an increasing agricultural area. Therefore, they increased in size with the increasing needs for water uplift (García Avilés 2007; Pérez Picazo and Lemeunier 1990).

The traditional irrigation system, made of historic elements such as norias, irrigation canals, and agricultural terraces, shapes a cultural and multifunctional landscape, which represents the local water culture of the region (García Avilés 2014, 2000; Gil Meseguer 2010). At the same time, it illustrates pre-industrial ingenuity and creativity for water use prior to the introduction of thermal-engine machines. Therefore, such systems do not represent only tangible heritage, but also the intangible heritage and technological knowledge needed for their design and maintenance. This knowledge has been transmitted over centuries. Today, a touristic route with information panels follows the Segura River along the norias of Abarán, which have been declared of cultural interest (spn. Bien de Interés Cultural, BIC) (Ayuntamiento de Abarán 2021; García Avilés 2014, 2000; Gil Meseguer 2010, 2014). On the other hand, the irrigation system has been modernized and drip irrigation has largely substituted traditional irrigation techniques to minimize water consumption and to improve farmers' working conditions (Puy et al. 2016).

4.4 Data and methods

To answer our research questions, we implemented a mixed method approach that integrates two strands of analysis (Fig. 4.3). In the first strand, we (a) explored the state and location of norias in the Ricote Valley using GIS technologies including in-situ correction, (b) identified reasons for the deterioration of norias using participant observation supported by a literature review and (c) conducted an expert survey to identify additional reasons for deterioration and quantify the importance of each reason. In the second strand, we (a) calculated the irrigation potential of the norias in the Ricote Valley, estimated the unknown geometric dimensions, (b) their potential to mitigate emissions, and (c) their potential to produce power. Figure 4.3 shows the mixed method research design with two strands. The first strand combines an explanatory design (phase 1 and 2a) to deepen the findings of the quantitative geo data analysis about the current state and location of norias with an exploratory design (phase 2a and 3) to identify reasons for the deterioration and quantify them. In the third phase, we integrated quantitative and qualitative data using the reasons identified during participant observation in the expert survey. In phase 2b in the second strand, we explored the future potential of the traditional technologies integrating our collected geo data (phase 1) and focusing on traditional and innovative usages. We integrated both strands in the discussion (phase 2b and phase 3). The priority is given to quantitative research methods (Kuckartz 2014).

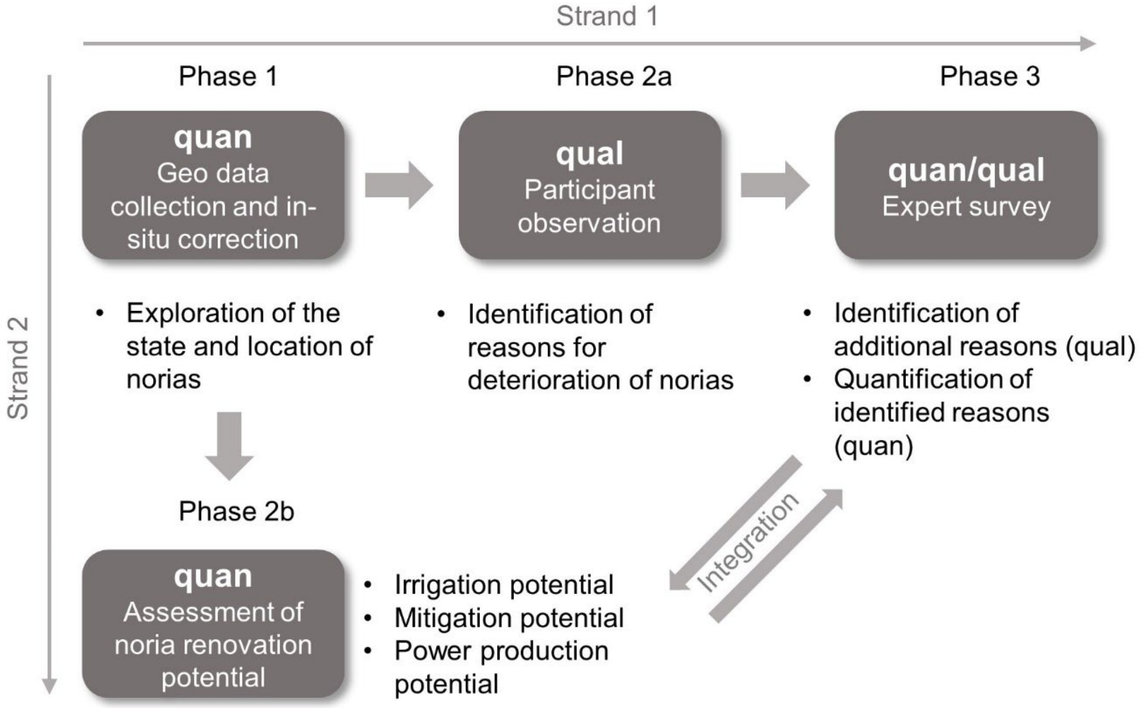

Figure 4.3 Mixed method research design combining quantitative (quan) and qualitative (qual) methods

4.4.1 Data and data collection

To identify the location of the norias in the Ricote Valley, we used an official list provided by the region of Murcia (i.e., Consejería de Turismo, Cultura y Medio Ambiente). Based on this list, we created a geo-database of norias. In this database, we collected available data about the characteristics of the norias (i.e., diameter, width, number of paddles, irrigated area, lifted water volume) combining information from research (Bravo Sánchez 2018), local working groups (Martínez Soler and Banegas Ortiz 1994) and on-site information from the region of Murcia (i.e., information panels).

We validated each location in-situ in the orchards of the Ricote Valley in summer 2019. For the validation, we uploaded our database to ArcGIS Online and used the ArcGIS Collector App to validate and edit data. During this process, we aggregated the condition of each noria and created four categories to describe it. The category In use describes a noria that is still working and lifts irrigation water to an irrigation canal on a higher elevation; Conserved describes a site, where the base and the wheel of the noria are still existing; Destroyed describes a site, where the wheel of the noria is non-existent but the base is still present; Disappeared describes a site, where wheel and base are non-existent. Data visualization was conducted in SAGA-GIS (Conrad et al. 2015).

4.4.2 Exploring reasons for the deterioration of norias

In the next step, we explored the reasons for the deterioration of the norias in the Ricote Valley. To integrate local perspectives, we used participant observation and a survey of eleven experts. During participant observation in the study area, we communicated regularly with local stakeholders and participated in agricultural activities (Thomas 2019). We combined insights from participant observation with a literature review. Based on this, we selected possible reasons for the deterioration of norias, which were included in the expert survey. Experts were selected based on their expertise on the topic, location, and their availability. Eleven experts with administrative, scientific, legal, and economic backgrounds participated in the survey (see Table 4.1). In June 2019, we requested the experts to evaluate the importance of preselected reasons for the deterioration of norias in the Ricote Valley on a scale from 0 (not important) to 4 (very important), and they could also add other reasons. For the evaluation, we (a) created new categories that combined the preselected and added reasons; (b) calculated the weighted arithmetic mean of the new categories, considering the number of persons mentioning each added reason; and (c) included only reasons with a value higher than 2 (moderate importance).

Table 4.1 Characteristics of eleven experts

Attribute	Frequency
Gender	
Female	2
Male	9
Age	
Average	58
Education	
University degree	10
Professional formation	0
A-levels	1
Occupational sector	
Academia	5
Civil servant	1
Law	2
Agriculture	3

4.4.3 Exploring the potentials of noria renovation in the Ricote Valley

In this section the procedure to estimate the power developed by a noria, its lifted flow rate, and the saved emissions compared to an electric or diesel pump, is explained. In order to estimate these quantities, some geometric and hydraulic characteristics of the norias had to be estimated by analyzing and elaborating the known dimensions (Fig. 4.4).

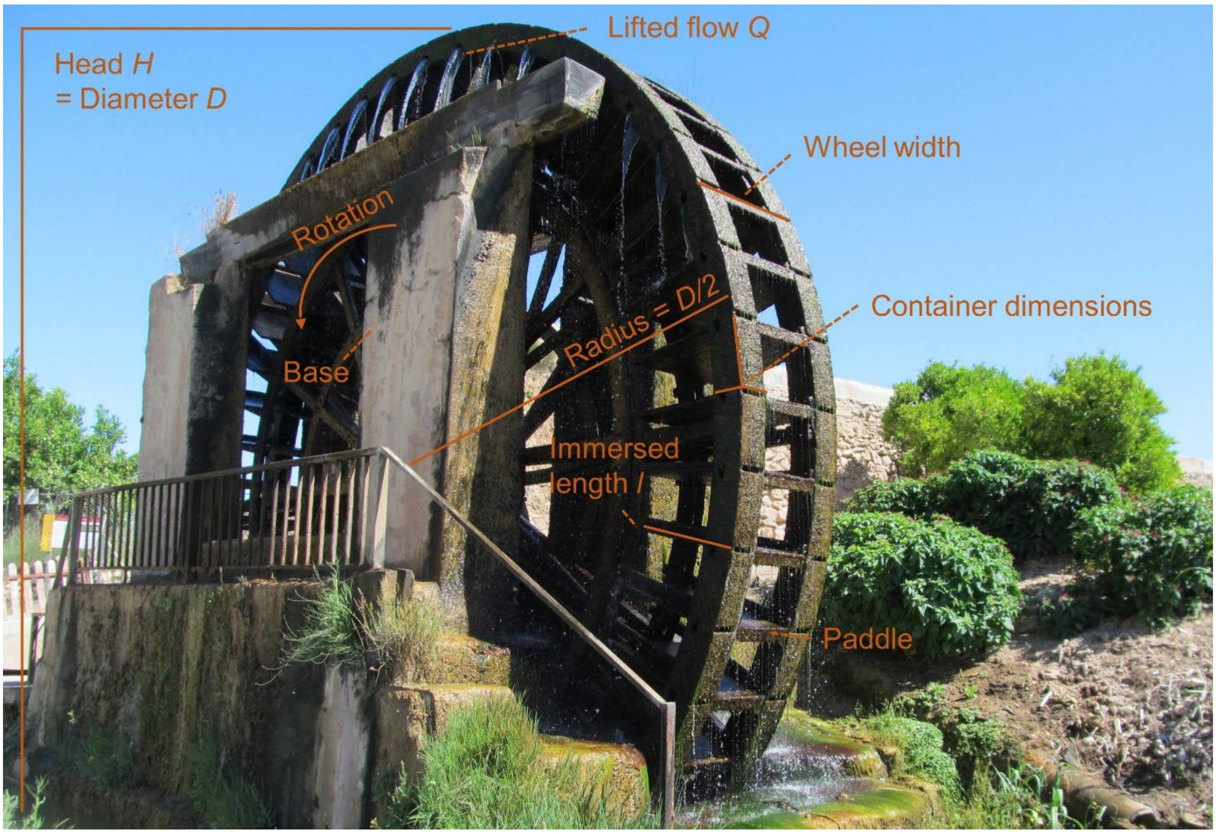

Figure 4.4 Geometric and hydraulic characteristics of norias (here: Noria de la Hoya, Abarán)

The first step consisted of finding the mathematical relation between diameter and number of blades, also called paddles. The number of paddles is known for 11 norias. By plotting the number of paddles versus the diameter (Fig. 4.5), the following equation was found:

$$n = 3.42D + 24.87 \qquad \text{(Eq.1)}$$

where n is the number of paddles and D is the diameter (m). Equation 1 (Eq.1) exhibits a coefficient of determination $R^2 = 0.76$, that means that the number of blades and the diameter are highly correlated. By Eq.1 the number of paddles can be estimated as a function of the wheel diameter, and then choosing a multiple of 4 (common practice both for norias and also for water wheels). By knowing diameter and number of paddles, the circumferential distance between two adjacent paddles can be calculated. Eq.1 is an expeditious equation that can be generalized and used to estimate the number of blades of any noria. Eq.1 is in line with some equations to estimate the number of paddles (as a function of diameter) commonly used for water wheels designed to power mills or generate electricity (Quaranta and Revelli 2018). The slope of Eq.1 (slope = 3.42), that expresses a change in the number of blades with the diameter, is smaller than the analogous equations for water wheels because the diameter of norias is generally much larger than that of the other water wheel types. Examining the equations summarized in Quaranta and Revelli (2018), the paddle number that is closest to Eq.1 is that proposed by Weisbach (Weisbach and Johnson 1849).

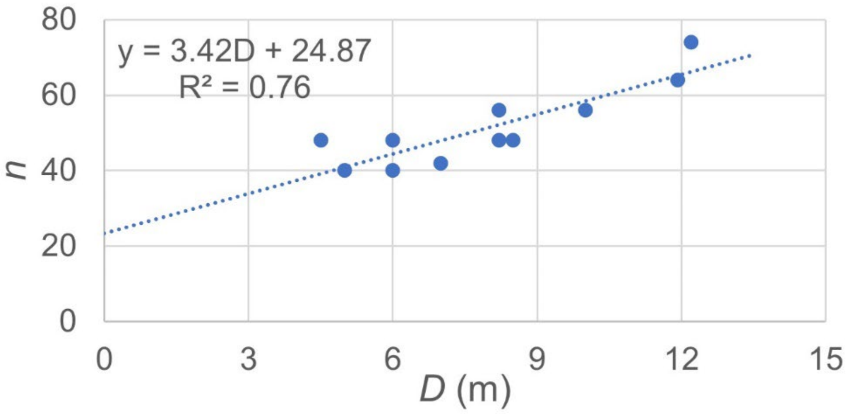

Figure 4.5 Number of paddles versus the diameter based on 11 norias

The second design dimension that was analyzed is the immersed length l of the paddle. Based on the Noria de la Hoya (Fig. 4.4), where pictures and videos are available, l = D/8 was estimated. This dimension was considered valid for all the other norias. This value is in line with the commonly suggested dimension of l = D/5 for floating water wheels (Quaranta 2018). For the norias, the length is smaller (D/8 instead of D/5) because of the very large diameters (> 5 m).

The rotational speed was instead estimated by considering the known diameter and speed of the Noria de la Hoya, and the equation proposed in Quaranta and Revelli (2015) for overshot water wheels (Quaranta and Revelli 2015):

$$N = \frac{c}{\sqrt{D}} \qquad \text{(Eq.2)}$$

with N the rotational speed (revolution per minute, rpm) and c a coefficient that is 30 $m^{1/2}$ for overshot water wheels (see Quaranta and Revelli 2018). In our case, the coefficient c for the Noria de la Hoya was estimated to be c = 4.3 $m^{1/2}$ min^{-1}. By Eq.2, the rotational speed N of each noria can be estimated from the diameter. Eq.2 practically expresses the Froude hydraulic similarity concept, where velocities scale as the square root of linear dimensions. With such estimated N, the tangential speeds range between 0.5 and 0.7 m/s, which is consistent with the fact that, in general, the optimal tangential speed of stream water wheels (i.e., water wheels driven by the kinetic energy of flowing streams) is one half of the river velocity. In our case, this would correspond to 1-1.4 m/s, a common flow velocity in rivers and canals (Quaranta 2018).

The other analyzed dimension was the container dimension. For the Noria de la Hoya, the container equals the distance between two paddles, which is intuitive. Width and depth of the container are one quarter of the wheel width. These proportions can be applied to all the norias whose container dimensions are not known.

By knowing the container dimensions and the rotational speed, the lifted flow rate Q could be estimated, considering that it is known for two norias (Noria de la Hoya and Noria Grande). The estimation of the lifted flow allows to calculate the power developed by the wheel (Eq.3)

$$P = \rho g Q H \qquad \text{(Eq.3)}$$

where P (W) is the power, g is the gravity acceleration (9.81 m/s^2), ρ = 1000 kg/m^3 is the density of water, Q is the lifted flow rate (m^3/s) and H (m) is the pumping head (in the case of norias, H = D).

From Eq.3, it can be seen that, for a certain power, the higher the pumped head H is, the lower must be the lifted flow Q. Therefore, Q is inversely proportional to the head H (i.e., the diameter). Furthermore, the lifted flow Q is proportional to the cross-section area A (m^2) of the container that catches the water from the river below the noria. Therefore, it is possible to define the coefficient q expressed in Eq.4:

$$Q = q\frac{A}{H} \qquad \text{(Eq.4)}$$

From Eq.4, q = 5.83 m^2/s for the Noria de la Hoya and q = 5.02 m^2/s for the Noria Grande, so that an average value of q = 5.4 m^2/s can be taken as reference. The fact that the values of q for the two norias are similar, confirms the method is reasonably generalizable. Therefore, the value of Q for the other norias was estimated as $Q = 5.4\frac{A}{H}$, and implemented in Eq.3 to estimate the power developed by the norias.

4.5 Results

4.5.1 Current state and location of norias in the Ricote Valley

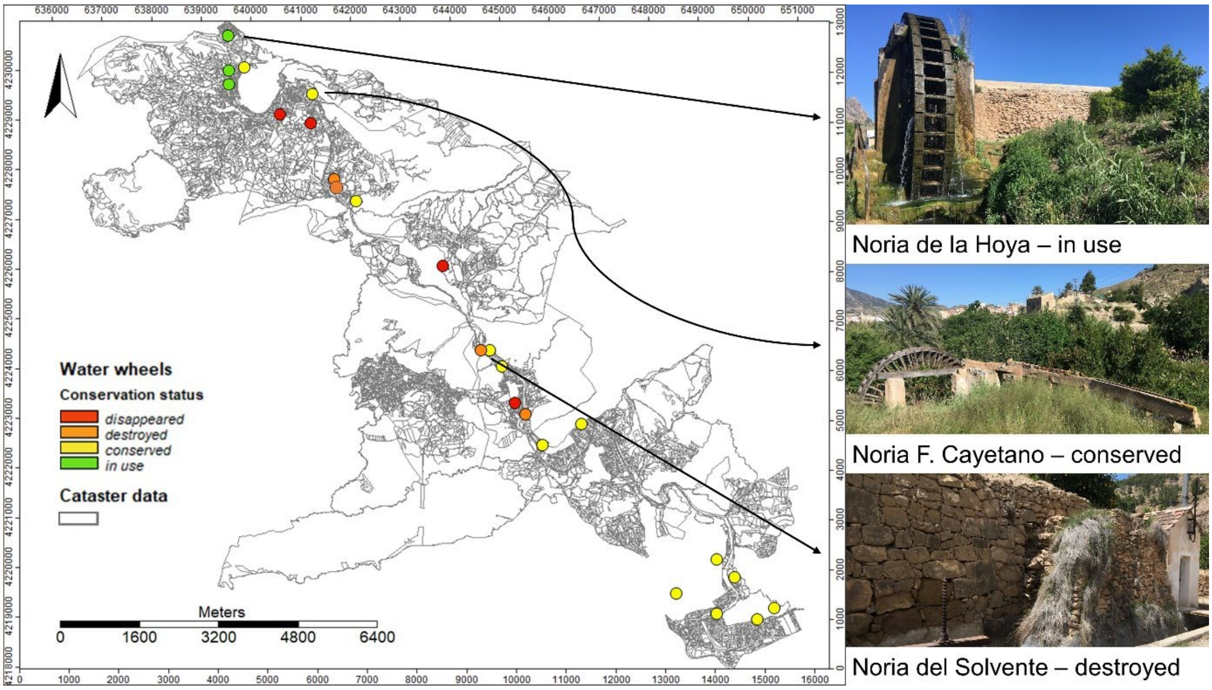

Figure 4.6 Preservation state of 24 norias in the Ricote Valley, Murcia. Green points represent norias in use, yellow points represent conserved norias, orange points represent destroyed norias, and red points represent norias that have disappeared totally. Examples are illustrated on the right

We identified the location of 24 norias in the Ricote Valley as well as their current condition (phase 1). The condition and location of each noria in the Ricote Valley is shown in figure 4.6. Three norias (12 %) are still in use to lift irrigation water. All of them are located in Abarán (green). 13 norias (54 %), classified as conserved, are distributed across the valley. Four norias are destroyed (17 %) and four have disappeared (17 %). Examples for each category are given in figure 4.6.

4.5.2 Reasons for the observed deterioration of norias during the past decades

As expected, most of the norias (88 %) in the Ricote Valley are no longer in use. The eleven consulted experts identified multiple reasons for their deterioration in the Ricote Valley. The most important reasons are 1) use of new technologies; 2) lack of valorization of traditional technologies; 3) high maintenance costs; 4) expansion of infrastructures and urbanization.

Most norias have been replaced by motor pumps during the past decades, contributing to the high energy demand and related emissions of Spanish irrigation systems. According to experts, the lack of valorization of traditional technologies plays an important role and can be explained by an increasing loss of the relationship between local populations and agriculture. In particular, the young generation is less interested in continuing the agricultural activities. This leads to a lack of transmission of traditional knowledge between generations and loss of interest in heritage conservation. The noria as an instrument of production and a material heritage, which is passed down from parents to children along with the land, suffers the same neglect as the land it irrigates. In the words of a local farmer: "Today's traditional agriculture in the valley survives because of small technical improvements and sentimental value, but the generation after mine no longer understands this sentimentality".

Furthermore, the high maintenance costs had a large effect on the deterioration of the norias. Many norias have been financed by their users. Often users are organized in local users' communities (i.e., irrigators communities). These communities are responsible for the maintenance of norias, and reparation costs are usually distributed between users. But the local irrigators communities are facing increasing economic challenges. Most users have a low income from agricultural activities without price premiums or subsidies. For example, the common agricultural policy (CAP) does not grant aid to owners of small plots. A minimum area is required to qualify for subsidies and in the Ricote Valley, only a few farmers fulfill this requirement. Additionally, the number of users decreases due to land abandonment. As a local farmer describes: "Small farms with traditional agricultural or livestock production systems are disappearing, absorbed by agribusiness, they have been preserved where their products are valued and the farmers can earn an appropriate income with their production".

Finally, the expansion of infrastructure and urbanization led to the displacement of agricultural activities. While norias in the Ricote Valley were originally constructed within the traditional orchards, several of them are now located next to main roads or within urban areas. This is the case for the Noria Grande de Abarán and the Noria "La Tía Vicenta" surrounded by sealed surfaces in small urban recreational areas.

All consulted experts considered the preservation of norias important, arguing for their high historical, cultural, touristic, and technological value and they agreed that the conservation of norias should not be sustained by the users alone. Eight out of eleven experts think that renovation and maintenance should be co-financed between users, local and regional authorities.

Based on our findings, we have identified three main management patterns for norias in the Ricote Valley. In the first pattern, norias are still in use and irrigate the surrounding agricultural area. However, due to land abandonment or urbanization, the agricultural area has been reduced, and the irrigators community is confronted with higher costs per farmer for maintenance. In the case of the Noria de la Hoya in Abarán (Fig. 4.4) and to solve the difficulties in the irrigators community, a single landowner, who owns much of the land irrigated by the noria, agreed to maintaining it. Furthermore, Noria de la Hoya has been declared of cultural interest (BIC), and benefits from support by the regional administration.

In the second pattern, norias are no longer used for irrigation, but are maintained for reasons of heritage conservation. This is the case of Noria Grande de Abarán, maintained in function although the irrigated land is lost to urbanization. It has been declared as asset of cultural interest (BIC) and the regional administration became responsible for maintenance. However, the change of responsibilities can represent an additional challenge, hampering the transmission of local traditional knowledge, necessary for cost-effective maintenance (Asociación Cultural La Carraila 2019).

In the third pattern, the noria is surrounded mostly by abandoned land or has been substituted by motor pumps and is neither used, nor renovated or maintained. In these cases, responsibilities for maintenance and preservation are weakly defined. In the following section, we will describe our results about the potential of noria renovation, also exploring whether power production might be a sustainable fourth usage pattern of norias in the Ricote Valley.

4.5.3 Assessment of the potentials of noria renovation for a sustainable agricultural system

By means of the procedure explained in the method section, it was possible to re-construct the geometric dimensions and the pumping characteristics of norias (number of blades, container dimensions, speed, pumped flow and developed power). The Noria de la Hoya and the Noria Grande de Abarán were the reference ones, because most of their dimensions are known. The proposed methodology can be used in general to estimate preliminary dimensions of any noria, as long as diameter and width are known. This is the case for 15 norias (see Tab. 4.2). In our calculations, if width and diameter of a given noria were not known, the noria was not considered. Therefore, the following dimensions can be estimated, in general, knowing diameter and width:

- number of paddles
- immersed length of the paddles (m)
- rotational speed (revolutions per minute, rpm)
- dimensions of the container (width, depth, length, assuming to be a cylinder with square cross section)
- pumped flow rate (liters per second)

- developed power (W)

Potential power production, emission mitigation, irrigated area, and economic savings for noria renovation

In this section, we describe the procedures to estimate the power production potential, emission mitigation, economic saving and irrigated area.

Power production: Table 4.2 shows that the power developed by the norias is generally limited below 3 kW, with an average power of 1.5 kW (in Table 4.2, the power is expressed in W instead of kW). The energy is expressed in Wh (product of Watt and hours) or kWh dividing by 1,000. Based on this calculation, we estimate that 23.8 kW could be produced with 16 renovated norias. Knowing the number of operating hours in one year, the annual energy developed by the norias was estimated by multiplying the power by the number of hours. We propose four scenarios to estimate the potential of norias. The assumed maximum potential is 8760 h/year representing 24 working hours per day (100 %). But as more realistic numbers we propose 6570 h/year (75 %), 4380 h/year (50 %), 2190 h/year (25 %).

Table 4.2 Characteristics, potential irrigated area and power production for each noria. Those with unknown width and diameter could not be entirely elaborated

Name	Estimated construction year	Height (diameter) (m)	Width (m)	No. of paddles	Irrigated area (hectares)	Lifted flow (l/s)	Rotational speed (rpm)	No. of containers	Power (W)
Noria de la Hoya (de D. García)	1818	8.2	1.1	48	26.0	42.2	1.5	96	3397
Noria Grande de Abarán	1807	11.9	1.2	64	17.3	25.0	1.2	128	2923
Noria de Candelón	1850	6.0	0.5	40	1.0	12.4	1.8	80	728
Noria La Ñorica	1850	5.0	0.4	40	0.9	9.3	1.9	80	458
Noria y acueducto de Félix Cayetano		6.0	0.7	48	3.4	22.7	1.8	96	1335
Noria de la "Viuda de Don Juan de Teodoro"		8.2	0.4	56	1.8	6.3	1.5	112	505
Noria de Miguelico Núñez		8.2	0.4	56	0.4	6.3	1.5	112	505
Noria de Ribera		7.0	0.5	42	0.3	9.3	1.6	84	640
Noria del Olivar		8.5	0.7	48	3.4	20.2	1.5	96	1684
Noria de Dª Elisa Carrillo		4.8	0.3	44		5.9	2.0	88	276
Noria del Conde de Villa-Felices		9.0	0.6	56	0.4	12.9	1.4	112	1138
Noria de los Semolicas		10.0	0.6	60	5.3	11.6	1.4	120	1138
Noria del Otro Lao o Noria de D. Matías Martínez		4.5	0.8	48	16.8	35.5	2.0	96	1566
Noria de "Los Chirrinches"	1910	7.5	0.8	52	20.7	27.5	1.6	104	2023
Noria "La Tía Vicenta"		10.0	0.8	56	14.0	20.6	1.4	112	2023
Noria del Acebuche		12.2		74	14.5	29.0			3481

Emission mitigation: We estimated emissions potentially avoided by using norias instead of diesel or electric pumps. A pump driven by a diesel engine consumes 0.27 liters for each developed kWh, and emits 2635 g of polluting substances (CO, CO_2 and $PM_{2.5}$) per liter (Adhikari et al. 2019). In Figure 4.7, the tons of the above-mentioned polluting emissions saved each year were expressed as a function of the pumped flow rate. Considering the saved emissions of 16 norias, the annual saved emissions were estimated between 37 and 148 tons, depending on the working hours (see Tab. 4.3). In case of different numbers of working hours, the obtained results from figure 4.7 scale proportionally. It must be noted that the mitigated pollution estimated here must be interpreted considering the additional benefits that the use of a renovated noria can generate, rather than a motivation to build a noria instead of using a motor pump, since the choice of technology should also consider the practical aspects of flexibility, maintenance, installation and fabrication.

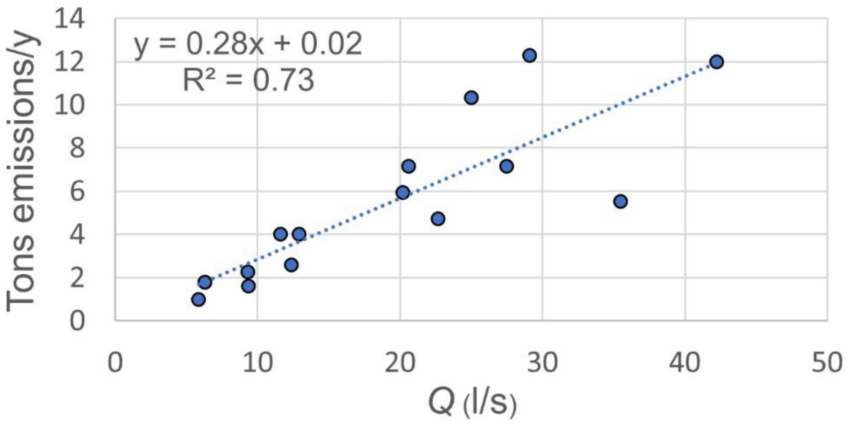

Figure 4.7 Saved emissions per year versus the pumped flow based on 15 norias

If electric pumps would be considered, the saved emissions would be between 14 and 55 tons/year (Tab. 4.3), assuming that the electric pump emissions are 265.5 gCO_2/kWh (European Environment Agency 2018). The saved emissions of Noria Acebuche could not be estimated with the methodology proposed in the method section, due to its unknown width. Indeed, the width of the noria is used to estimate the container dimensions, as well as the pumped flow, and it has to be known. Therefore, in case of unknown width, the pumped flow can be estimated by inverting the equation proposed in Figure 4.8 as a function of the irrigated area.

Table 4.3 Estimated potential benefits summed up for 16 norias with known dimensions in the case of noria renovation in the Ricote Valley for four scenarios. The scenarios represent seasonal variabilities of working hours

Scenario (hours)	Working hours	Energy (kWh)	Saved emissions diesel (t/year)	Saved emissions electr. pump (t/year)	Saved cost diesel (€/year)	Saved cost electricity (€/year)
100%	8760	208,663	148	55	70,424	47,993
75%	6570	156,497	111	42	52,818	35,994
50%	4380	104,332	74	28	35,212	23,996
25%	2190	52,166	37	14	17,606	11,998

For each noria, the irrigated area was known from official data, so that Figure 4.8 shows the irrigated area versus the pumped flow. The higher the pumped flow, the higher is the area that can be irrigated. We calculated that 16 renovated norias could irrigate a minimum of 140.3 hectares saving between 14 and 148 tons of CO_2 per year compared to the usage of motor pumps covering the same surface (see Tab. 4.3). The 140.3 hectares represent 6.21 % of the agricultural terraced land in the Ricote Valley (2259.72 hectares) based on an estimation from a previous study (Heider et al. 2021). It has to be considered that approx. 40 % of agricultural terraced land was abandoned in 2019.

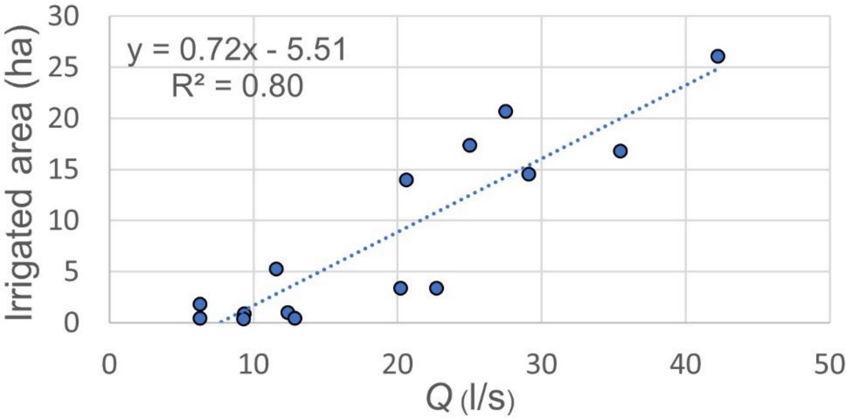

Figure 4.8 Irrigated area versus pumped flow based on 15 norias

Economic savings and benefits: The use of norias would offset the cost of diesel by between 17,606 and 70,424 €/year for the production of 23.8 kW (16 norias) of power for between 2,190 and 8,760 working hours/year, based on the estimated need of 0.27 liters of diesel per kWh and on an estimated cost for diesel of 1.25 €/l. In the case of electric pumps, the use of norias would offset the cost of electricity by between 11,998 and 47,993 €/year for the same production and working hours mentioned above based on an estimated electricity cost of 0.23 €/kWh (Eurostat 2021). Alternatively, if the norias would be deployed for power production instead of water pumping and the produced electricity would be sold, we estimate a benefit of between 2,608 and 10,433 €/year. This was calculated by multiplying the total power of 16 norias by working hours by the energy price. The result is based on an estimated price of 0.05 €/ kWh paid by Spanish electricity companies to private producers (Guijarro Ruiz 2021). Such savings should be factored in towards the maintenance of norias.

However, an initial investment is needed to obtain these services. After this investment, a noria is likely able to sustain more than half of its maintenance costs, only considering economic savings from diesel consumption compared to engine-based technologies. Maintenance costs of a noria add up to c. 5000 €/year. Considering the average diesel savings of 2,750 €/year, a noria could offset 55 % of these costs. If a noria is alternatively used to produce electricity instead of water pumping, gains from selling energy could offset approx. 8 % of its maintenance costs. We estimate that these calculations will change in favor of norias in the near future with increasing CO_2 prices.

Renovation costs depend on the individual preservation state of each noria and have to be assessed by an expert individually. Therefore, we discuss construction costs. The construction cost of a noria without irrigation canals lies between 8,000 and 15,000 € per meter of diameter. According to this, a noria with a height of 8 meters costs between 64,000 and 120,000 €, depending on the materials used. (The described construction and maintenance costs are based on personal communications with Miguel Ángel Molina Espinosa, technical engineer specialized in hydraulic machines and norias).

4.5.4 Renovated norias as drivers of the multifunctionality of agriculture

Above, we have shown the potential of noria renovation. Renovating norias can promote sustainable rural development and the multifunctionality of agriculture (Cairol et al. 2009; IAASTD 2009; Renting et al. 2009) (Fig. 4.9). An increasing renovation of traditional irrigation technologies like norias would contribute to lower the high energy demand for pumping and mitigate emissions, helping to further approach the EU emission targets. However, the potential of the norias in the Ricote Valley for electricity production is limited due to their high diameter and low rotational speed compared to modern water wheels used for electricity generation. Nevertheless, we stress the multifunctional character of the norias and the multiple positive services they can provide if maintained.

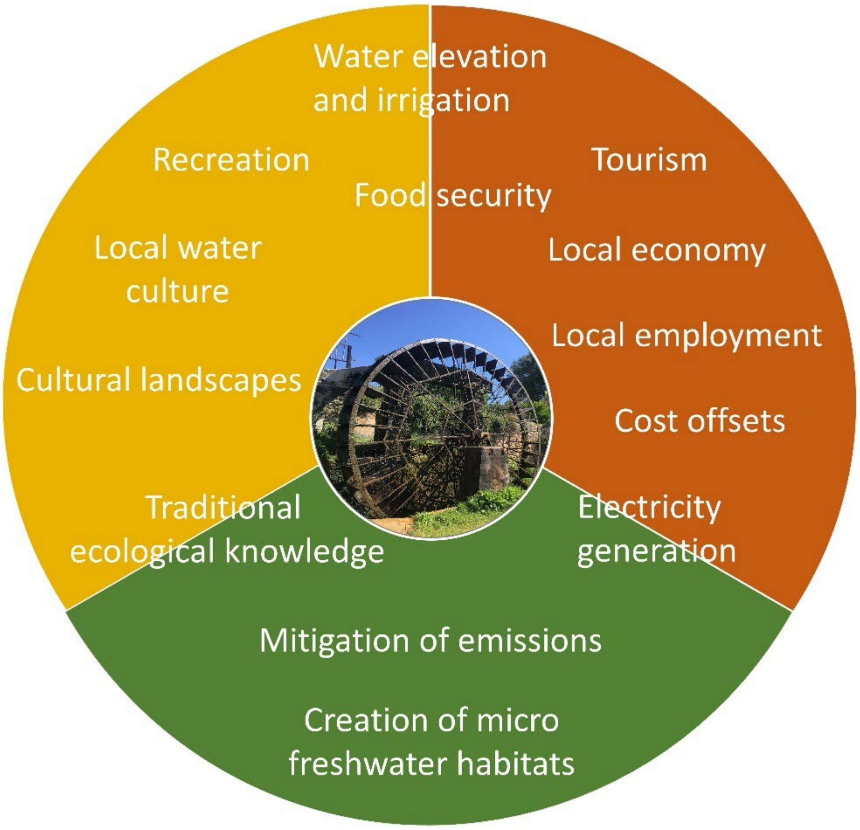

Figure 4.9 Norias as drivers for the multifunctionality of agriculture combining social (yellow), economic (orange), and ecological (green) needs

The norias in the Ricote Valley have been used to lift irrigation water on the multiple levels of agricultural terraces, contributing to food security. Some of them are still in use while also being part of a popular touristic route (Ayuntamiento de Abarán 2021). Thus, norias contribute to recreation and tourism, to the aesthetics of a cultural landscape, and represent a part of the local water culture. They help to preserve traditional knowledge and create local employment. Moreover, norias contribute to biodiversity by creating micro-habitats for flora and fauna, e.g., water pools attracting birds, insects and promoting plant growth (Freshwater Habitats Trust 2021).

4.6 Discussion

Our analysis has shown that 88 % of the norias in the Ricote Valley are currently not used and one of the most important reasons for the deterioration mentioned by the experts was the introduction of new technologies, especially motor pumps. Generally, motor pumps (diesel or electric pumps) can be easily bought, are cheaper, handier, of easy transport and easy adaptation on different sites, while high diameter water wheels are more complex in requirements, construction, and maintenance. Nevertheless, the renovation of norias provides important social, ecological, and economic services like irrigation without using fuel or electricity (emission mitigation), valorization of cultural heritage and social attractiveness.

In the Ricote Valley, mainly surface water (Segura River, El Molino spring, etc.) is used for irrigation representing relatively low energy consumption for water acquisition compared to groundwater extraction, external water transfer or desalination (Soto-García et al. 2013). However, energy is needed for water elevation on the different levels of the agricultural sectors within the valley. Since the 1970s boreholes substituted traditional norias using mostly diesel pumps (Closas 2014). Until today diesel pumps and electric engines are mainly used for the provision of irrigation water including extraction and transport on different elevations (Espinosa-Tasón et al. 2020).

A similar trajectory of abandonment to that described for the norias in the Ricote Valley, has been observed for water mills across Europe and beyond. This trend is alarming, considering the high cultural and historical value of norias and water mills. Exploring their history and potential seems fundamental not only for better understanding the past, but also in defining innovative sustainable strategies for the future of agriculture, tourism and rural communities worldwide. The trend seems set, but needs to be consolidated, as many water wheel sites are experiencing a revival, both for electricity generation and thanks to a deeper understanding of their cultural value (Quaranta and Revelli 2018).

The expert survey has shown that all experts considered the preservation of norias in the Ricote Valley important, including experts from the local irrigators communities. Furthermore, local associations, like the cultural association la Carraila, are active in the protection and recuperation of the cultural heritage in the Ricote Valley (i.e., norias). However, the maintenance of several norias poses some challenge, due for example to different ownership regimes. Some of them are owned by irrigators communities, others by a group of private individuals, and others by a single owner. Therefore, flexible coordination, cooperation and financial support is needed.

Based on our assessment, we estimate that 16 renovated norias included in our analysis can irrigate 140.3 hectares in the Ricote Valley. To irrigate a similar surface applying diesel motor pumps would cost between 17,606 and 70,424€/year for the consumption of between 14,085 and 56,339 liters diesel/year and produce between 37 and 148 tons of emissions/year depending on the working hours. In the case of electric pumps, we estimate that between 11,998 and 47,993 €/year of electricity costs can be saved as well as between 14 and 55 tons of emissions/year. Therefore, renovation and re-use of traditional irrigation technologies could help to reduce the high energy demand and the resulting emissions of irrigation systems in the Mediterranean region and beyond.

Moreover, our results show that 16 renovated norias in the Ricote Valley could produce 23.8 kW. In comparison to modern water wheels used for electricity generation, the power production potential is limited. Water wheels are very efficient machines to generate electricity in low head sites (below 6m) and low river flows (below 2 mc/s) (Quaranta 2020) with 70 % efficiency, but only if adequately designed to operate in that context. Based on our analysis, the re-use of a noria to generate electricity in the context of this study is feasible, but comes along with several disadvantages: (1) the power developed by a noria in the Ricote Valley is below 3 kW, and 1.5 kW on average; (2) they are designed to lift water, not to generate electricity, thus their efficiency is lower when used for electricity generation (it can even lower down to 1 kW); (3) their rotational speed is very low due to the large diameter (2 rpm), thus, a large gearbox would be needed, including additional power losses and costs, with an efficiency decrease. Therefore, the average power value may further reduce. However, if modern stream water wheels (Quaranta 2018) were used for electricity generation, replacing the norias, it is expected that the developed power would be higher than that estimated for the norias in this study. An additional study would be needed to better investigate this option, since the site characteristics have to be explored in detail. Therefore, we understand the usage of norias for power production as an additional opportunity adding up to its multifunctionality.

As we have shown, power production may not be viable as a stand-alone solution for the norias in the Ricote Valley, but their role as drivers for a multifunctional agriculture becomes clear by considering all the quantitative advantages of using water wheels compared to engines shown in this study: (1) lower emissions, (2) land irrigated, (3) diesel and electricity savings, (4) energy production. Their deployment would reduce the high energy demand and emissions in the Spanish irrigation system, while also enabling economic savings and benefits. On top of that are all the qualitative advantages like (5) shaping the local cultural landscape while also (6) providing areas for recreation and (7) preserving the local water culture (Gil Meseguer 2014), (8) creating water-rich micro-habitats that support biodiversity in agriculture as well as (9) attracting an increasing number of external visitors and (10) public support for heritage protection. This includes the two most valued agroecosystem services in the region of Murcia: biodiversity and recreation opportunities (Zabala et al. 2021). Nevertheless, we must consider that overall construction, installation and operational costs would be higher than for diesel or electric pumps.

Finally, we want to stress that global agriculture must transform in order to address major challenges like reducing emissions, reversing biodiversity loss, adapting to and mitigating climate change, and accommodating population growth and migrant communities. Foley et al. (2011) suggest four global strategies addressing these challenges: 1) stopping the expansion of agriculture, 2) closing yield gaps, 3) increasing resource efficiency, 4) changing to a plant-based diet and stopping food waste (Foley et al. 2011). Increasing resource efficiency includes an increasing irrigation efficiency. Especially, in water-scare regions like the study area, good water and land management practices can increase irrigation efficiency. Agroecology provides principles and practices for a sustainable management of agroecosystems (Altieri and Nicholls 2012; Bernard and Lux 2017; DeLeijster et al. 2019; Pretty 2018). For example, reducing water losses through mulching, cover crops and reduced tillage will increase irrigation efficiency. Beyond that, adapting to local climate conditions or climate warming by cultivating locally adapted crops would reduce irrigation needs even more (Martin-Gorriz et al. 2021).

The dominant crop in the Ricote Valley is lemon. The cultivation of lemon trees sequesters more carbon than other woody crops or vegetables (Martin-Gorriz et al. 2021) and is less exigent in irrigation than the cultivation of vegetables because it is better adapted to water stress due to irregularities in water supply (Confederación Hidrográfica del Segura 2013). Nevertheless, the cultivation of better adapted crops like olive and almond trees could reduce irrigation even further. Furthermore, we stress the importance of crop diversification due to its multiple benefits for biodiversity, water filtration, water retention, and resilience. However, the selection of crops is highly influenced by the market price and farmers have to earn their livelihood. Prices for locally adapted crops like almond and olive are low compared to more water-demanding crops like lemon.

4.7 Conclusion

In this study, we investigated the location and preservation state of norias in the Ricote Valley, explored the reasons for their deterioration during the past decades, and assessed the potential of their renovation. We observed high rates of noria abandonment and deterioration in the Ricote Valley: Only 12 % of the norias are still used to lift irrigation water, 54 % are conserved, 17 % are destroyed, and another 17 % have disappeared. The most important reasons for the deterioration of norias in the Ricote Valley are 1) the use of new technologies, in particular, motor pumps have replaced norias during the last decades; 2) the lack of valorization for traditional technologies, which combined with 3) high maintenance costs for noria preservation has further contributed to their deterioration; and 4) urbanization and the expansion of infrastructures that led to the displacement of agricultural activities, such that norias, located on what used to be agricultural terraces, are now disconnected from their original context.

Based on our results, we argue that rediscovering traditional technologies helps to achieve affordable and clean energy (SDG 7) as well as climate action to reduce GHG emissions (SDG 13). Moreover, these technologies provide multiple functions and services for a sustainable life on land (SDG 15), which needs to be considered within a holistic approach instead of only concentrating on new technologies.

To assess the potential of noria renovation, we proposed four scenarios, which represent different working regimes, due to seasonal variabilities: a full year, with 8760 h/year (100 %), 6570 h/year (75 %, i.e., 9 months), 4380 h/year (50 %, 6 months), and 2190 h/year (25 %, 3 months). Based on these scenarios, 16 norias would produce the following benefits if they would replace diesel motor pumps: 16 norias could mitigate between 37 and 148 tons of emissions/year as well as between 18,000 and 70,000 €/year spent on 14,000-56,000 liters diesel. If they would replace electric motor pumps, 16 norias would produce the following benefits: 16 norias could save between 14 and 55 tons of emissions/year and between 12,000 and 48,000 €/year spent on electricity. Both types of engine are currently used to lift irrigation water on the elevated agricultural terraces. Such savings should be factored in towards the maintenance of norias. Finally, we estimated that 16 renovated norias could produce 23.8 kW and 1.5 kW on average. This is a limited power production potential compared to modern water wheels. The main reasons for the limited potential are: the large diameter resulting in very low rotational speed (2rpm), as well as their design optimized to lift water, which results in a lower efficiency when used for electricity generation. However, we estimated that norias deployed for power production could produce benefits of between 2,600 and 10,400 €/year if the generated electricity were sold.

Our study is limited by the availability of data. We integrated four scenarios to cover variabilities in the working hours of norias. Furthermore, cost offsets are based on current fuel and electricity prices, rather than subsidized prices. We estimate that these costs will change in favor of norias in the near future with increasing CO_2 prices. We recommend renovation, but renovation costs depend on the individual preservation state of each noria and have to be assessed case-by-case by an expert. Therefore, at this stage, we approached these numbers by estimated construction costs.

Finally, we recommend the integrated preservation of norias in the Ricote Valley and beyond, stressing their role as drivers for a multifunctional agriculture. We argue that norias are much more than water-lifting devices. Noria renovation in agricultural landscapes could produce highly valued social, ecological, and economic services compared to engine-based solutions, as we have shown for the Ricote Valley. Apart from their potential to mitigate emissions, norias create freshwater micro-habitats for flora and fauna, contributing to increase biodiversity in agriculture. Furthermore, they shape the cultural landscape and preserve the local water culture while providing recreation opportunities for locals and tourists. Further research is needed to quantify these services, and we will continue our research on multifunctional agriculture, exploring the potential of agroecological practices in Spain.

5 Towards climate-resilient and biodiverse agriculture: Experiences and potentials in agroecological management in Spain[5]

5.1 Abstract

The adoption of conventional monoculture, mechanization, chemical inputs, and intensive irrigation has resulted in agriculture intensification and the massive short-term production of food. At the same time, in the medium and long terms, these practices generate numerous negative outcomes, such as increased greenhouse gas emissions, biodiversity loss, degradation of land, water and ecosystems. They also increase the vulnerability of agriculture to climate change.

In contrast, agroecological practices can combine high production with sustainable land use, by integrating diversified crop systems, the replacement of external inputs with natural processes, and efficient water use. In this study, we explore the potentials of agroecological practices, theoretically and empirically, based on the experiences of farmers in Spain.

To address this topic theoretically, we propose a framework of agroecosystem assessment based on comparing positive and negative services provided by (a) conventional agricultural intensification practices and (b) agroecological practices. In addition, we conduct an online survey among farmers who aim for sustainable food production and promoting biodiversity. Based on their answers, we identify (1) the challenges and opportunities faced in the implementation of agroecological projects, (2) the perceived effects following the introduction of agroecological practices, (3) the ways in which farmers adapt to climate change, (4) an Agroecology Index to assess farm agroecology, and (5) factors contributing to biodiversity and agroecology.

Our results show that farmers apply 9 out of 14 agroecological practices, on average, and 65% consciously adapt their practices to climate change. Non-male and small-scale farmers are more likely to apply agroecological practices. Moreover, farmers observed positive changes in soil properties, biodiversity and pests after using these practices. This shows that agroecological management reduces negative agroecosystem services (e.g., greenhouse gas emissions, soil degradation, biodiversity loss) while increasing positive services (e.g., climate regulation, soil health, biodiversity), thus promoting climate-resilient and biodiverse agriculture.

Keywords: Agroecology, agroecosystem services, biodiversity, climate change, gender, multifunctionality of agriculture, sustainable agriculture

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[5] This chapter is going to be submitted to a peer-reviewed journal before the end of 2021.

5.2 Introduction

The statement that "agriculture is multifunctional" (IAASTD 2009, p.2) is the first key message of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD 2009), an international collaborative project including more than 400 experts of all continents and disciplines. The concept of multifunctionality is applied to agriculture to evaluate and emphasize its diverse functions for individuals and society. Besides food, agriculture can contribute to the protection of regional flora, fauna, water, air, and soil, as well as offsetting emissions and adapting to climate change, depending on the management practices used in an agroecosystem. In addition, agriculture can provide multiple aesthetical landscape values connected to regional histories and traditions. These landscapes can serve as spaces for recreation, facilitating physical activities with positive health effects and attracting tourism. Agriculture can also serve as a source of income and employment, sustaining local livelihoods (Cairol et al. 2009; IAASTD 2009; Jose 2009; OECD 2001; Zagaria et al. 2018). The multiple functions of agriculture can be grouped under ecological, economic, and social dimensions, revealing the close relationship between multifunctionality and sustainability.

Moreover, multifunctional agriculture can help comply with the Sustainable Development Goals (SDGs) and maintain the Earth system within identified planetary boundaries. Indeed, the four main transgressions of planetary boundaries are strongly connected to the negative impacts from the expansion of intensive conventional agriculture: loss of genetic diversity, pollution due to high nitrogen and phosphorus inputs, land-system change as well as high inputs of freshwater, which increase water-scarcity, in particular in the Mediterranean area (Campbell et al. 2017; IAASTD 2009; Rockström et al. 2009; Steffen et al. 2015). In intensive agricultural systems, the negative effects on the environment often offset the positive ones.

The functions of an agricultural system can be assessed by focusing on agroecosystem services (AES) and disservices (AEDS). Zabala et al. (2021) describe an agroecosystem as an anthropized ecosystem, which provides positive and/or negative ecosystem services. Negative services are called ecosystem disservices. In the Region of Murcia, Zabala et al. identified biodiversity followed by opportunities for recreation and tourism as the most valued AES. However, AES and AEDS depend on the management practices used in an agroecosystem (Zabala et al. 2021). In the theoretical part of this study, we build on the approach of Zabala et al. (2021) using the proposed AES/AEDS and review their classification as service/disservice for western Mediterranean agriculture while also including land-use changes. Furthermore, we distinguish agroecosystems under conventional management from agroecosystems under agroecological management, for which we assess AES and AEDS. We also explore how agroecological management promotes the SDGs.

Agroecological management practices can combine high production with sustainable land use. These include the use of diversified crop systems, the replacement of external inputs (e.g., nitrogen and phosphorus) with natural processes and efficient water use while also providing multiple agroecosystem services (Altieri and Nicholls 2012; Bernard and Lux 2017; Hathaway 2016; IAASTD 2009; IPES-FOOD 2016; Via Campesina 2010).

In this study, we give a voice to the experiences of Spanish farmers regarding challenges and opportunities, the effects of agroecological practices, and climate change. Moreover, we aim to provide a tool for the assessment of farm agroecology focusing on the effects of agroecological practices on agroecosystem services and disservices: The Agroecology Index. The index is helpful for authorities to redirect public investment, for farmers for self-assessment, and for consumers to buy food with a positive impact on the environment. This leads to the following research questions:

1. What are the opportunities and challenges facing agroecological projects in Spain?
2. What are the perceived effects on land degradation and regeneration using agroecological practices in Spain?
3. How do Spanish farmers adapt agricultural land and water management to climate change?
4. How can we assess and explain farm agroecology considering agroecosystem services and disservices?

To answer these questions, we propose a concept for agroecosystem assessment focusing on the positive and negative services provided by different management practices (i.e., conventional practices vs agroecological practices) in the theory section. In the third section, we introduce our methodology. We conducted an online survey answered by the members of Spanish agricultural associations, which are committed to sustainable food production and promoting biodiversity. Based on the answers, we explore (1) the challenges and opportunities faced in the implementation of agroecological projects, (2) the perceived effects following the introduction of agroecological practices, (3) the ways in which farmers adapt to climate change, (4) an Agroecology Index to assess farm agroecology, based on agroecological practices and (5) two regression models to explain the Agroecology Index and perceived biodiversity improvements. In the following sections, we present our results and discuss them.

5.3 Theory

Agroecosystems can provide positive or negative ecosystem services to the environment and society. Negative services are called ecosystem disservices. Whether an agroecosystem provides services or disservices depends on the management practices used (Zabala et al. 2021). Zabala et al. (2021) investigated AES and AEDS for western Mediterranean agriculture and conducted a stakeholder valuation for AES/AEDS. However, they did not include previous land use changes from natural ecosystems to agroecosystems in their classification as AES/AEDS of western Mediterranean agriculture.

We stress that a classification of AES and AEDS must integrate a previous land cover or land use. A classification as AES or AEDS compared to no services overlooks human impacts on biodiversity, climate, geochemistry and sediments and its consequences (Dirzo et al. 2014; Zalasiewicz et al. 2018). We suggest integrating land cover changes by assuming (semi-) natural land cover or traditional agriculture as previous land use (Lomba et al. 2019).

Western Mediterranean agriculture comprises traditional agriculture and modern, industrial agricultural systems as well as irrigated and rainfed systems (Zabala et al. 2021). However, industrial agriculture increasingly dominates European agriculture, which leads to cultivation in monocultures and high dependency on external inputs. In 2013, 3.1 % of agricultural companies cultivated more than 50 % of the agricultural area in Europe (Chemnitz 2019). In Spain, we observe the same trend: 5.5 % of agricultural companies cultivated more than 55 % of the agricultural area, while 50 % of agricultural holdings cultivated only 4.2 % of agricultural area in 2016 (Eurostat 2021). Nevertheless, Spain has the largest organic agricultural area in Europe (FiBL & IFOAM - Organics International 2021). In this study, we differentiate between (a) conventional management in agriculture (also called industrial agriculture), which is dependent on external inputs like synthetic fertilizers, pesticides, herbicides, intensive irrigation, intensive tillage and cultivates mainly monocultures and (b) agroecological management.

Agroecology describes a scientific discipline, a set of practices and a social movement. In this study, we refer to agroecology as land management practices, which aim for a sustainable farming system stabilizing and optimizing yields while also providing a wide range of agroecosystem services. Agroecological practices are based, in particular, on a combination of local traditional (ecological) knowledge and innovations (FAO 2018, 2019). Many agricultural movements that are committed to sustainable food production use agroecological practices and principles, e.g., organic agriculture, regenerative agriculture, syntropic farming, biodynamic agriculture, and conservation agriculture.

Agroecological practices aim to (1) build soils along with soil fertility and health, (2) increase water filtration, water retention, and clean and safe water runoff, (3) air purification, (4) enhance and conserve biodiversity, (5) sequester carbon, (6) capacity for self-renewal and resilience, (7) and sustaining local livelihoods. Agroecological management has proved to be especially successful under environmental stress by producing yield increases where additional food is needed most (Elevitch et al. 2018; IPES-FOOD 2016; Jose 2009).

Thus, agroecology increases agroecosystem services while also contributing to achieving some of the Sustainable Development Goals: no hunger (SDG 1), no poverty (SDG 2), good health and well-being (SDG 3), gender equality (SDG 5), clean water and sanitation (SDG 6), decent work and economic growth (SDG 8), reduced inequalities (SDG 10), responsible consumption and production (SDG 12), climate action (SDG 13), life below water (SDG 14), and life on land (SDG 15) (see also Fig. 5.1) (Agroforestry Network 2018; Altieri and Nicholls 2020).

An integral part of agroecology is the diversification of crops, also integrating trees and bushes (agroforestry). Agroforestry represents a multifunctional landscape producing a variety of positive effects. Agroforestry practices include alley cropping, contour hedgerow, forest farming, living fence, multistory cropping, riparian forest buffer, silvoarable systems, silvopasture, and windbreak (Elevitch et al. 2018).

Figure 5.1 shows our classification of AES and AEDS in conventional western Mediterranean agriculture and under agroecological management. We illustrate in this section that agroecosystems can provide all described AES at the same time. Our classification of AES and AEDS contains provisioning, regulating, and cultural services. Moreover, we added economic services to our classification, considering the importance of the multifunctionality of agriculture (IAASTD 2009).

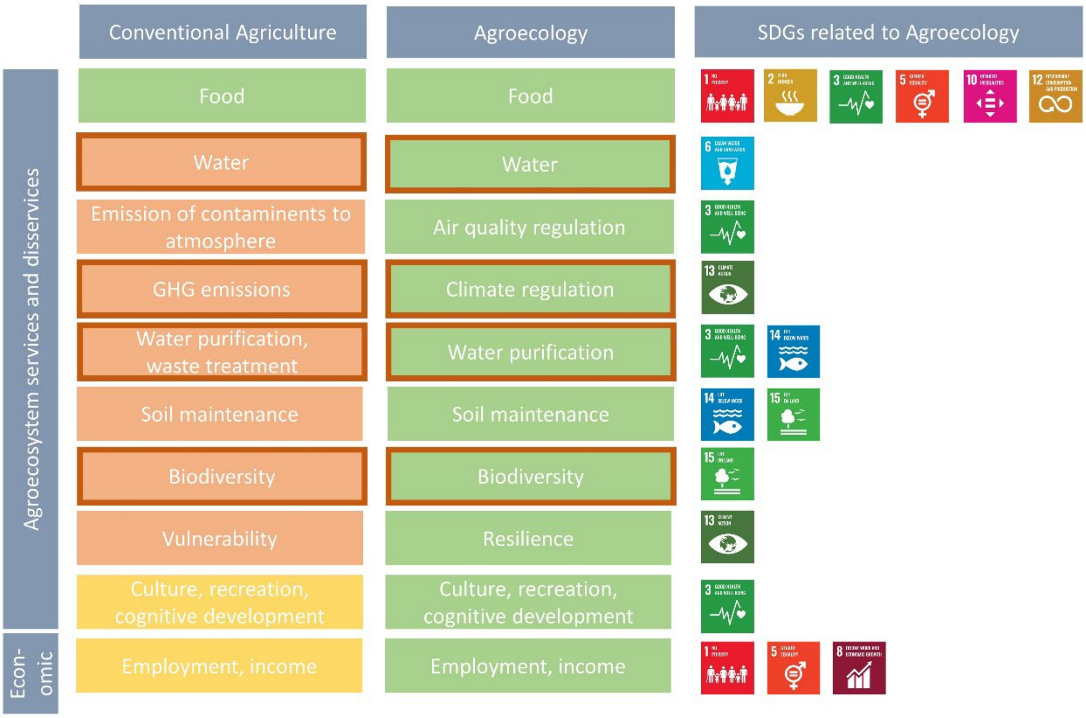

Figure 5.1 Agroecosystem services (green, AES) and disservices (orange, AEDS) in conventional western Mediterranean agricultural systems and agroecological systems. Yellow indicates AES and AEDS at the same time. The Sustainable Development Goals (SDGs) are associated with the AES provided by agroecological management. The red frame indicates where planetary boundaries are exceeded globally, or in the case of freshwater use, locally in the Mediterranean region based on Steffen et al. (2015).

Food: In accordance with Zabala et al. (2021), we classify food as an agroecosystem service in the conventional western Mediterranean agricultural system as well as in agroecological systems. This classification is also valid if we compare both systems to an assumed previous land use of a natural land cover or traditional agriculture. However, agroecological management requires the cultivation of locally adapted crops. In consequence, the type and quantity of food provided in agroecology depends on the local conditions.

Water: In accordance with Zabala et al. (2021), we classify water in conventional western Mediterranean agriculture as a disservice. Intensive irrigation in large areas throughout the western Mediterranean contributes to groundwater depletion. This is especially dramatic in already water-scarce regions (Cramer et al. 2018; van Leeuwen, C. C. E. et al. 2019). Furthermore, the removal of non-crops (e.g., herbaceous plants) on agricultural land and the resulting lack of soil cover prevent water retention and freshwater provision to other ecosystems.

In contrast to conventional western Mediterranean agriculture, agroecological systems use water efficiently. Management practices like cover crops, contour farming, water harvesting, and the cultivation of locally adapted crops reduce evaporation, minimize water runoff, and increase water retention and water availability, using crops with different root depths. Locally adapted crops might not even need irrigation. If additional irrigation is required (e.g., for the cultivation of young plants or vegetables or in the case of droughts), rainwater capture enables the creation of water reserves (Altieri and Nicholls 2012; Elevitch et al. 2018; Jose 2009).

Furthermore, agroecological management can even create a more humid local climate providing water to other ecosystems if conducted on a large scale, regenerating the natural land cover and imitating the natural ecosystem (Sinclair et al. 2019). In consequence, we classify water in agroecological systems as an agroecosystem service.

Emissions of contaminants to the atmosphere/ air quality regulation: Next, we look at regulating services. Following the classification of Zabala et al. (2021), we classify air quality regulation in western Mediterranean agriculture as an AEDS. Agriculture is a significant contributor to atmospheric aerosol loading. Sources for emissions of contaminants to the atmosphere from conventional agriculture are, e.g., the usage of mineral fertilizers, which produces, e.g., ammonia and nitrous oxide (Campbell et al. 2017; Zabala et al. 2021).

In agroecology, farmers avoid external inputs like artificial fertilizer. Instead, they use natural fertilizers like compost, green manure, and legume cultivation. Furthermore, due to the high (agro)biodiversity, agroecosystems under agroecological management, like ecosystems, contribute to air quality regulation as an AES (Bernard and Lux 2017).

GHG emissions/climate regulation: Climate regulation is an important ecosystem service, and agroecosystems can provide this service. Nevertheless, global agriculture (including land-use changes) contributes to 25 % of GHG emissions (Campbell et al. 2017). However, the carbon balance of some popular crops (primarily woody crops) in the Mediterranean area is found to be positive (with no previous land use considered) (Martin-Gorriz et al. 2021). But if we assume a previous land use of natural land cover or traditional agriculture, the effect of conventional western Mediterranean agriculture on climate regulation is less positive. On the one hand, crops remove CO_2 from the atmosphere. On the other hand, conventional agricultural practices in the western Mediterranean produce high emissions, e.g., land clearing, plowing and tillage removes carbon from the soil and/or biomass (Campbell et al. 2017; Duru et al. 2015). Moreover, energy-intensive irrigation, the production and usage of mineral fertilizer, field operations (e.g., burning of crop residues), and the use of large machinery produce emissions (Martin-Gorriz et al. 2021). Thus, climate regulation depends on the applied practices and cultivated crops. Focusing on conventional agricultural practices and considering an assumed previous land use of natural land cover or traditional agriculture, we suggest a classification as an AEDS.

Under agroecological management, agroecosystems provide climate regulation as a service. Agroforestry enables climate mitigation and adaptation. Trees store large amounts of carbon above and below ground (Jose 2009; Martin-Gorriz et al. 2021). At the same time, agroforestry systems are more resilient to climate shocks because of species diversity. Degraded croplands or pasturelands represent a high potential to sequester additional carbon by converting them to agroforestry systems. The sequestering potential increases with increasing species richness (Jose 2009). Furthermore, no energy-intensive external inputs like complex irrigation procedures, large machinery or mineral fertilizers are used, which produce not only large amounts of GHG emissions on-field but also in their production (Campbell et al. 2017; Martin-Gorriz et al. 2021). Instead, agroecological practices, like no-tillage, organic amendments and residue integration (e.g., pruning residues), as well as crop rotation, promote soil carbon sequestration (Martin-Gorriz et al. 2021).

Water purification and waste treatment: In conventional agriculture, crops take up less than 50% of the fertilizer (N and P) applied. The excess fertilizer contaminates water bodies via leaching or surface runoff (Jose 2009). Furthermore, global agriculture is responsible for 85 % of global nitrogen overshoot and > 90 % of global phosphate overshoot (Campbell et al. 2017). This corresponds to our observations in conventional western Mediterranean agriculture. The eutrophication of the Mar Menor, a coastal saltwater lagoon in the Region of Murcia, as well as the high nitrate values in rivers, are negative effects of conventional agriculture on ecosystems (Fenoll Serrano and Sáez Sironi 2009; Foley et al. 2011; Reganold and Wachter 2016). Compared to an assumed previous land use of natural land cover or traditional agriculture, we classify the contribution of conventional western Mediterranean agriculture to water purification and waste treatment as an AEDS.

Under agroecological management, riparian buffers are proposed as a solution, lowering the runoff velocity and favoring infiltration and deposition. Furthermore, the roots take up excess nutrients and therefore improve groundwater quality. In agroecological practices, all agrochemicals (including mineral fertilizers) are substituted by natural processes (Jose 2009). Therefore, we classify the contribution of agroecology to water purification and waste treatment as a service.

Soil maintenance: We classify the contribution of conventional western Mediterranean agriculture to soil maintenance as a disservice compared to an assumed previous land use of natural land cover or traditional agriculture. We agree with Zabala et al. (2021) that the classification depends on the management practices. Intensive tillage, common in conventional agriculture, increases the risk of erosion. The application of agrochemicals (e.g., toxins) is polluting soil, crops, and water. The cultivation of monocultures prevents positive interactions between crops, which would enrich the soil.

Under agroecological management, (agro)biodiversity can increase and maintain soil productivity. Therefore, famers use natural fertilizer. They integrate trees and crops that biologically fix nitrogen into the agroecosystem, and apply compost. Also, non-nitrogen fixing trees enhance soil properties by adding organic matter and recycling nutrients (Jose 2009). Furthermore, the reduction of tillage and the use of soil cover prevent erosion. If we compare this to an assumed previous land use of natural land cover or traditional agriculture, this is still valid.

Biodiversity: The expansion of agriculture worldwide is responsible for c. 80 % of losses in biosphere integrity (genetic biodiversity and functional biodiversity) (Campbell et al. 2017). Furthermore, the expert panel on biodiversity estimates that currently, 1 million species are threatened by extinction, and the most important driver is the expansion of intensive agriculture (IPBES 2019). The use of pesticides and fertilizers has led to a dramatic decrease of pollinators necessary for agricultural production. Therefore, we classify the contribution of conventional agriculture to biodiversity as a disservice.

Agroecological practices increase (agro)biodiversity by crop diversification, integration of trees and bushes, integration of natural zones, integration of livestock etc. aiming at the following outcomes: (1) creating habitats for multiple species; (2) preserving germplasm of sensitive species; (3) creating a buffer against deforestation and reducing the conversion of natural habitats by providing a more productive and sustainable alternative to traditional agricultural systems; (4) providing connectivity by creating corridors between habitats; (5) providing ecosystem services (e.g., erosion control and water recharge), which prevents the degradation and loss of surrounding habitats (Agroforestry Network 2018; Jose 2009).

Vulnerability/resilience: Conventional agriculture is vulnerable to disasters, in particular, due to the cultivation of monocultures and the dependence on agrochemical inputs (Foley et al. 2011). Rapid depletion of groundwater sources due to intensive irrigation and export-oriented industrial agriculture makes southeastern Spanish agriculture in particular vulnerable to climate change due to water-intensive crops like fruit trees or vegetables compared to traditional rainfed crops (van Leeuwen, C. C. E. et al. 2019). Furthermore, wetlands (e.g., marshes) have been drained historically to increase the agricultural and urban surface or damaged following agricultural practices. Yet, they play a major role in protecting agriculture against storm and flood risk and for biodiversity and phyto-purification. Resilience is reduced in conventional western Mediterranean agriculture compared to an assumed previous land use of natural land cover or traditional agriculture. Therefore, we consider it a disservice.

In contrast, agroecological systems are more resilient to extreme events. Resilience describes the capacity of a system to absorb disturbances without changing the structure or losing its function (Adger 2000). Agroecological principles and methods have been used for millennia worldwide and are based on traditional ecological knowledge (TEK) (Elevitch et al. 2018). This knowledge has coevolved with social and ecological systems and can help to deal with disturbances maintaining ecosystem services and functions under conditions of a changing climate (Balbo et al. 2016; Gómez-Baggethun et al. 2013). Thus, TEK plays a key role to maintain agricultural systems and their functions using local resources. Family farms are holders of this knowledge and implement agroecological practices on the ground. Practices are adapted to the characteristics of a location, which make them resilient to a changing climate. A diverse system is more likely to be resilient, stable and maintain its function (Adger 2000; Martin et al. 2019). Increasing (agro)biodiversity by integrating trees, bushes, a natural zone, limited livestock, crop rotation and diversification leads to increasing resilience. Furthermore, the use of locally adapted rainfed crops, the reduction of tillage to minimize erosion and soil disturbances, as well as biological pest control ensure long-term sustainability. Therefore, we classify resilience as a service of agroecosystems under agroecological management (Altieri and Nicholls 2012; FAO 2019).

Cultural services: Cultural services include opportunities for recreation, tourism, and cognitive development connected to a cultural landscape, which represents spiritual, cultural, and aesthetic values. Traditional agricultural landscapes provide these services. Reference examples in this sense may be the terraced landscapes of Batad, in the Philippines, Battir, in the Occupied Palestinian Territories, or Lavaux, in Switzerland, which multiple services and universal value have been recognized with their inscription in the UNESCO World Heritage List, in 1995 and 2014 respectively (UNESCO World Heritage Centre 2021c, 2021b, 2021a). Traditional landscapes still exist among conventional western Mediterranean agriculture, but agricultural intensification and land abandonment are increasingly threatening these landscapes (Heider et al. 2021; Lomba et al. 2019). However, dominant large-scale agriculture does not provide these services. Therefore, we suggest a classification as a service and a disservice.

Agroecology provides cultural services, based on the TEK of smallholders (Elevitch et al. 2018). Furthermore, agroecological management preserves fragmented cultural landscapes, biodiversity, maintains a pollution-free, healthy environment and healthy food production. Moreover, it creates opportunities for recreation, ecotourism, local employment, alternative development pathways and cognitive development in a (bio)diverse landscape. Therefore, we classify it as a service.

Employment and income: Conventional western Mediterranean agriculture provides income and employment to farmers and workers. However, due to increasing mechanization since the 1940s, human work is increasingly substituted by machinery in agriculture, and working conditions have degraded (Reynolds et al. 2014). Therefore, we classify it as a service and a disservice.

Agroecology avoids or minimizes external inputs, including the use of large agricultural machinery. In consequence, more human labor is needed under agroecological management compared to conventional management. Therefore, we classify it as a service.

We have shown the positive influence of agroecology on AES. We conclude that agroecosystems should be designed using a holistic approach considering provisioning, regulating, cultural, and economic services to equal shares.

5.4 Data and methods

To investigate farm agroecology in Spain, we conducted an online survey among farmers committed to sustainable food production and increasing biodiversity. These farmers are weakly institutionalized but of high importance providing AES and complying with the SDGs. Often, individual farmers are part of an agroecological network or association. Collaborating with these associations enabled our survey. We included quantitative and qualitative questions about agroecological practices, their perceived effects on the environment, and agroecological project development in the survey. Based on the answers, we identify (1) the opportunities and challenges faced during the implementation of agroecological projects in Spain, (2) the perceived effects following the introduction of agroecological practices, as well as (3) adaptation measures to climate change, (4) an Agroecology Index to assess agroecological farms, based on selected agroecological practices. Finally, we developed two regression models to explain the Agroecology Index and perceived biodiversity improvements.

5.4.1 Survey

To identify farmers who are committed to sustainable food production promoting biodiversity, we collaborated with five Spanish associations who are committed to these values:

- Sociedad Española de Agricultura Ecológica y Agroecología (SEAE, Spanish Society of Ecological Agriculture and Agroecology)

- Olivares Vivos (Living Olive Trees)
- Asociación de Agricultura Regenerativa Ibérica (Iberian Regenerative Agriculture Association)
- Asociación Española de Agricultura de Conservación - Suelos Vivos (Spanish Association of Conservation Agriculture - Living Soils)
- Asociación para la Agricultura Biodinámica (Association for Biodynamic Agriculture)

We structured the questionnaire in six sections: introduction, agroforestry practices, the state of agricultural land, agricultural practices, project development, and demographic information. We asked the farmers for the practices they apply and their perception about the impact of their practices. Afterwards, we developed and applied the Agroecology Index to assess farm agroecology. The questionnaire contains 51 questions and took participants approximately 40 minutes to answer.

5.4.2 Perceived effects of using sustainable practices

We used content analysis to evaluate qualitative questions, and statistical analysis to evaluate quantitative questions (Kuckartz 2014). To explore the farmers' perception, we asked for (a) their perception of the effects of their agricultural practices on the environment and (b) the changes they have observed after using agroecological practices. Regarding (a), they should classify their agreement between 0 (I don't agree) and 10 (I totally agree) for the following statements: My agricultural practices (1) build soil, (2) preserve biodiversity, and (3) do not contaminate water. For the assessment, we calculated the arithmetic mean of all farmers who have answered these questions. Regarding (b), they should classify land degradation and recovery after applying agroecological practices (i.e., for soil properties from highly degraded to highly improved; for quantity/diversity of flora and quantity of fauna from much less to much more; for the occurrence of pests from much more to much less). In the statistical analysis, we quantified these qualitative answers on a scale from -2 (very negative) to 2 (very positive).

5.4.3 Agroecology Index

We conducted a literature review and chose agroecological principles and practices for the integration in the Agroecology Index (Altieri and Nicholls 2012; Bernard and Lux 2017; Elevitch et al. 2018). Table 5.1 shows three agroecological principles: (1) increasing (agro)biodiversity, (2) maintaining soil health, and (3) efficient water use. Beneath every principle, the associated agroecological practices are listed, and the AES/AEDS promoted by each practice and explained in the theory section. Each practice represents one point for the calculation of the Agroecology Index. Consequently, a farm can reach a minimum score of zero (no practice applied) and a maximum of 14 (all practices applied). Using the index, the individual appliance of agroecological practices per farm, and an overall appliance of agroecological practices among a group of farmers (here: 63), can be calculated.

Table 5.1 Agroecological practices in three categories and agroecosystem services (AES) and disservices (AEDS) related to each practice

Agroecological Practices	AES/ AEDS
Increasing (agro)biodiversity	
Diversification of crops	Biodiversity, soil maintenance, resilience
Integration of trees and bushes	Biodiversity, climate regulation, air quality regulation, water purification, resilience, water
Crop rotation	Biodiversity, resilience, soil maintenance
Integration of livestock	Biodiversity, emissions of contaminants to the air
Integration of natural zone	Biodiversity, resilience, climate regulation, water purification
Maintaining soil health	
Minimization of external inputs	No waste treatment necessary, no emissions of contaminants
Reduction of tillage	Soil maintenance, resilience
Use of natural fertilizers, e.g., compost, green manure, legume cultivation	Soil maintenance, resilience
Efficient water use	
Cover crops	Biodiversity, water, soil maintenance, resilience
Contour farming and terraces	Soil maintenance, water, resilience
Water harvesting	Water, resilience
Locally adapted crops	Water, resilience

Micro-habitats storing water were not included

5.4.4 Regression model

In the next step, we developed two regression models to find statistically significant independent variables to explain (1) the Agroecology Index and (2) perceived improvements in biodiversity (dependent variables). Perceived improvements in biodiversity include increases in vegetation diversity, vegetation quantity, and animal diversity. We aggregated independent variables for the regression model based on the answers of farmers in the online survey. We used Stata 15 to conduct the regression analysis, and the code is available upon request.

The reason for using this ordered regression model are the numeric categories of the dependent variables (e.g., possible values for the Agroecology Index between 1 and 14). Furthermore, the ordered regression model avoids the uncertainty about distances between categories (Long and Freese 2006). Besides, we use different versions of the model to show the stability of the results. We introduce the regression tables for two dependent variables and add stepwise independent and control variables from left to right in the regression tables (see Tables 5.8 and 5.9).

We recognize the limitations of our survey (i.e., short sample and limited knowledge regarding representativeness). Additionally, we must add the weaknesses typical of any survey in the business context, e.g., possible response bias of a given profile of farmers (McCann et al. 2005). However, the purpose of our paper is not to discuss statistical methodology. On the contrary, the objective is to make visible a group of agroecological farmers. In the following, we present the selected independent variables for the models and our hypothesis about the relationship with the Agroecology Index or improvements in biodiversity.

Explaining the Agroecology Index

Agroecology Index and biodiversity: As we have described in the theory section, biodiverse production systems are one of the outcomes of agroecological management (Agroforestry Network 2018; Altieri and Nicholls 2012; Reganold and Wachter 2016; Tscharntke et al. 2012). Therefore, we test the hypothesis of a positive relationship between biodiversity improvements and the Agroecology Index.

Agroecology Index and soil change: As we have described in the theory section, fertile soils result from agroecological practices. One of the principles is maintaining soil health and creating the most favorable soil conditions for plant growth (organic matter, soil biological activity) (Altieri and Nicholls 2012; Bernard and Lux 2017; Reganold and Wachter 2016). Therefore, we test the hypothesis of a positive relationship between soil property improvements and the Agroecology Index.

Agroecology Index and farm size: Agroecology is mostly discussed in the context of smallholder agriculture and family farming (Altieri and Nicholls 2012; Björklund et al. 2019; FAO 2019; Mestmacher and Braun 2020; Morel et al. 2017; Oliver 2016). Therefore, we test the hypothesis that the smaller the size of farms the higher the Agroecology Index.

Agroecology Index and cost-effectiveness: The relationship between agroecology and cost-effectiveness or profitability is discussed in the literature. On the one hand, the authors discuss the yield gap connected to organic agricultural practices (Muller et al. 2017). On the other hand, authors argue for the high potential of agroecological practices to increase yields even on small plots by increasing cropping density and the potential of agroecology under water stress. Moreover, the reduced costs due to low inputs are discussed as an opportunity (IPES-FOOD 2016; Morel et al. 2017; Pretty 2018; Pretty et al. 2003; Reganold and Wachter 2016). Consequently, we have no hypothesis about this relationship.

Agroecology and self-supply of food: Increasing agrobiodiversity is one of the principles of agroecology. This creates diverse local food production, which serves self-sufficiency and local consumption (food sovereignty) (Altieri and Nicholls 2012, 2020; Björklund et al. 2019). Therefore, we test the hypothesis of a positive relationship between self-sufficiency on a farm and the Agroecology Index.

Agroecology Index and gender: Several authors state the important role of women in promoting the agroecological transition in Latin America (Mestmacher and Braun 2020; Oliver 2016). Moreover, research has shown that women are, on average, more conscious and active about climate change (Velasco Gisbert et al. 2020). Therefore, we test the hypothesis of a positive relationship between non-male farmers and the Agroecology Index.

Explaining perceived changes in biodiversity

The loss of genetic diversity is among the main transgressions of the planetary boundaries and has entered the red zone of high risk (Rockström et al. 2009; Steffen et al. 2015). Agriculture is estimated to play a major role in this transgression (Campbell et al. 2017), and further loss of biodiversity hotspots is projected (Habel et al. 2019). Thus, it is important to identify positive factors to support biodiversity improvements in agriculture.

Biodiversity and agroecology: As explained above, agroecology has a positive effect on biodiversity. Therefore, we test the hypothesis of a positive relationship between changes in biodiversity improvements and the Agroecology Index.

Biodiversity and soil change: Diverse and abundant vegetation contributes to healthy soils, and healthy soils favor biodiversity (Sinclair et al. 2019). Therefore, we test the hypothesis of a positive relationship between biodiversity and soil improvements.

Biodiversity and farm size: As explained above, biodiverse farms under agroecological management are mainly discussed in the context of smallholders. Therefore, we test the hypothesis of a negative relationship between farm size and biodiversity.

Biodiversity and cost-effectiveness: Following the explanation above, we are unable, at this point, to propose a hypothesis about the relationship.

Biodiversity and self-supply: Farmers who cultivate a high diversity of crops are more likely to cover a larger share of their diet. Therefore, we test the hypothesis of a positive relationship between biodiversity and self-supply.

Biodiversity and gender: Following the explanation above, we test the hypothesis of a positive relationship between non-male farmers and biodiversity.

5.5 Results

5.5.1 Challenges and opportunities for agroecological projects

In the online survey, we asked the farmers about their farm profitability as well as the challenges and opportunities they are facing. Overall, 36 % of the farmers responded that their farm is profitable, 53 % responded partly profitable, and 11% responded not profitable (N=56). The most important source of subsidies for farmers is the common agricultural policy of the European Union (CAP). 77 % of consulted farmers receive subsidies from the CAP, and 63 % of these farmers explained that their farm would not be profitable without those subsidies.

The farmers mentioned as most important challenges (1) the low prices they obtain for their agricultural production; (2) the comparatively high costs they have; and (3) a lack of production to cover their costs (Table 5.2). Furthermore, they complained about the high bureaucracy in Spain, e.g., the permission procedure to integrate livestock in agriculture using a holistic management approach (Savory and Butterfield 1999). Farmers mentioned a lack of climate adaptation, especially regarding the high irrigation needs for the cultivated crops conflicting with the water scarcity in some regions. Moreover, some farmers mentioned difficulties selling their products due to a lack of clients in the surrounding area, difficulties in selling their products online, and the expectation of clients for low prices of agricultural products. Finally, farmers mentioned a lack of motivated workers.

Table 5.2 Challenges (N=36) and opportunities (N=50) for farm profitability

	Absolute	Relative [%]
Challenges		
Low price	14	39
High costs	8	22
Not enough production	6	17
Bureaucracy	4	11
Lack of climate adaptation	3	8
Difficulty of sale	3	8
Lack of motivated workers	2	6
Opportunities		
Low inputs/ costs	15	30
High quality/ organic	9	18
Processing of products	5	10
Direct sale	5	10
Diversity/ diversification	3	6
Dedication/ pleasure	3	6

Nevertheless, the consulted farmers identified multiple opportunities for agroecological projects in Spain. The most important opportunities for agroecological projects are seen in (1) the low costs due to low inputs used in agroecology; (2) the high quality of products and organic production, which differentiates agroecological products from products under conventional management, the latter being exposed to the use of agrochemicals during the production; (3) in-house processing of products and direct sale, which enable to add value and a higher income for farmers as well as the exclusion of intermediaries. Furthermore, the farmers identified the diversity of products and a diversification of on-farm activities as an opportunity, which makes them more resilient to disturbances. Finally, some farmers mentioned their dedication and pleasure as an important non-monetary opportunity for a good life.

Comparing the support farmers get for their agroecological activity, they felt the strongest support from associations followed by their clients. In contrast, they identified a lack of political support on various levels (i.e., EU, Comunidad Autónoma, village/city).

5.5.2 Perceived effects of using sustainable practices

In the online survey, we asked about the perceived effects on land degradation and regeneration using agroecological practices in Spain. Table 5.3 shows the farmers' perception of the effects of their agricultural practices on the environment. The farmers should classify their agreement between 0 (I don't agree) and 10 (I totally agree) for the following statements: My agricultural practices (1) build soil, (2) preserve biodiversity, and (3) do not contaminate water. The arithmetic means for all three statements vary between 8.42 and 8.69, and the medians are 10 with standard deviations between 1.8 and 2.1. Consequently, farmers perceive their agricultural practices as positive or very positive for the environment.

Table 5.3 Perception of the environmental effects of own agricultural practices on soil building, biodiversity preservation, and water quality. Farmers were asked to classify their agreement between 0 (I don't agree) and 10 (I totally agree) for the following statements: My agricultural practices (1) build soil, (2) preserve biodiversity, and (3) do not contaminate water.

	Min	Max	Mean	Median	Std. dev	N
Soil building	0	10	8.42	10	2.1	69
Biodiversity preservation	2	10	8.69	10	1.8	69
No water contamination	2	10	8.63	10	1.9	69

Moreover, we asked the farmers about the changes in soil properties, biodiversity, and the occurrence of pests they observed since they started their agroecological practices. They could classify the observed change of soil properties in five classes from highly degraded (negative) to highly improved (positive), in the case of biodiversity from much less (negative) to much more (positive), and in the case of pests from much more (negative) to much less (positive). In Table 5.4, a negative change is represented by a negative value (-2, -1), no change is shown as 0 and a positive change as a positive value (2, 1). Table 5.4 shows that the arithmetic mean of the observed changes after applying agroecological practices is positive for all categories. In almost all cases, the arithmetic mean lies between improved (1) and highly improved (2). Only the arithmetic mean of pest occurrence lies between no change (0) and improved (1). The highest values are reached for the change of biological soil properties, where the arithmetic mean is 1.44 and the median value 2. The average age of agricultural projects in the survey is 15 years.

Table 5.4 Perception of degradation and recovery of agricultural lands after using sustainable agricultural practices. Farmers were asked to classify land degradation and recovery after applying agroecological practices from highly degraded (-2) to highly improved (2) as well as the effect on biodiversity from much less (-2) to much more (2) and pests from much more (-2) to much less (2).

	Min	Max	Mean	Median	Std. dev.	N
Change of soil properties						
Biological properties	0	2	1.44	2	0.66	63
Chemical properties	0	2	1.28	1	0.52	60
Physical properties	0	2	1.33	1	0.62	63
Hydrological properties	-1	2	1.37	1	0.65	62
Biodiversity						
Quantity of flora	0	2	1.40	1	0.61	62
Diversity of flora	0	2	1.28	1	0.66	61
Diversity of fauna	-1	2	1.20	1	0.65	60
Pests	-1	2	0.67	1	0.75	60

5.5.3 Adaptation to climate change

Next, we asked farmers about their experiences with climate change as well as their adaptation measures. Climate change is present in the life of farmers. The agricultural activity of 96.8 % of 63 farmers suffered under climate-related extreme events. A drought had negative effects on agricultural production for 84.1 % of farmers, and heat waves affected 66.7 % of farmers. 41.3 % of farmers mentioned negative effects on agriculture due to heavy rainfall.

As shown above, most agroecological practices help to adapt to a changing climate. 65 % of 63 farmers adapted their agricultural activity consciously to climate change. The most popular adaptation strategies are shown in Table 5.5. 22.2 % of farmers mentioned soil cover as an adaptation strategy, followed by the reduction of tillage (11.1 %). 9.5 % of farmers adapted their activity by collecting rainwater for irrigation, and 7.9 % integrated livestock. Due to observed changes in the growing period, 4.8 % of farmers adapted their sowing and harvesting dates. The same percentage installed drip irrigation using solar panels as a renewable energy source mitigating emission from the irrigation system. Furthermore, 3.2 % of farmers changed their cultivated crops to climate-adapted crops, and the same percentage applied contour farming to reduce runoff, soil erosion and better use of water and nutrients (i.e., the keyline approach (Yeomans 1958)).

Table 5.5 Overview of practices used to adapt to climate change (N=63)

Practice	Absolute	Relative
Soil cover	14	22.2
Reduction of tillage	7	11.1
Rainwater collection	6	9.5
Integration of livestock	5	7.9
Change of harvest/ sowing date	3	4.8
Installation of drip irrigation	3	4.8
Usage of solar panels for irrigation	3	4.8
Cultivation plants adapted to climate	2	3.2
Contour farming (Keyline)	2	3.2

5.5.4 Agroecology Index

In this section, we assess farm agroecology among the consulted farmers. Table 5.6 shows the appliance of 14 agroecological practices in three categories (i.e., increasing (agro)biodiversity, maintaining soil health, efficient water use) among farmers. The subsequent AES provided depend on the practices used (see Table 5.1). On average, 55.2 % of the farmers applied agroecological practices from the first category: increasing (agro)biodiversity, i.e., diversification of crops, integration of trees and bushes, crop rotation, integration of livestock, integration of natural zone. The most popular practices in this category are integrating trees and bushes (73 % appliance) and integrating a natural undisturbed zone (61.9 %). On average, 73.7 % of the farmers applied the practices from the second category: maintaining soil health. In this category, every practice was applied by at least 66.7 % of the farmers. The most popular practices are the use of natural fertilizer (79.4 %) and the reduction of tillage (77.8 %). The practices from the category increasing water use efficiency were applied by 55.6% of the farmers on average, and the most common practice is the usage of cover crops (77.8 %). The least popular practices among all categories are the integration of livestock (36.5 %) and three practices to increase water use efficiency, i.e., water harvesting (46 %), contour farming (49.2 %), and the use of locally adapted crops (49.2 %).

Table 5.6 Percentage of farmers applying agroecological practices. Practices are assigned to three categories (bold): Increasing (agro)biodiversity, maintaining soil health, efficient water use. For each category, the absolute and relative arithmetic mean is calculated based on the assigned practices.

Agroecological Practices	Absolute	Relative	N
Increasing (agro)biodiversity	**34.8**	**55.2**	**63**
Diversification of crops	32	50.8	63
Integration of trees and bushes	46	73.0	63
Crop rotation	34	54.0	63
Integration of livestock	23	36.5	63
Integration of natural zone	39	61.9	63
Maintaining soil health	**46.4**	**73.7**	**63**
Reduction of external inputs:			
no herbicide	44	69.8	63
no pesticide	47	74.6	63
no chemical fertilizer	42	66.7	63
Reduction of tillage	49	77.8	63
Use of natural fertilizers, e.g., compost, green manure, legume cultivation	50	79.4	63
Efficient water use	**35**	**55.6**	**63**
Cover crops	49	77.8	63
Contour farming and terraces	31	49.2	63
Water harvesting	29	46.0	63
Only locally adapted crops	31	49.2	63

Based on the practices, which each farmer applies, we calculated the Agroecology Index. Farmers can reach a maximum score of 14 if they apply all practices shown in Table 5.6. Table 5.7 shows the basic statistics of the aggregated Agroecology Index for 63 farmers. The arithmetic mean is an index of 8.7, the maximum index reached among 63 farmers is 13, and the minimum index is 2.

Table 5.7 Basic statistics of the Agroecology Index (N=63)

	Agroecology Index
Min	2.0
Max	13.0
Mean	8.7
Median	9.0
Std dev.	2.5
N	63

The proposed Agroecology Index does not directly include economic or cultural services. Nevertheless, the results from the online survey show that 68 % of farmers have employees promoting the local economy.

5.5.5 Regression analysis

The first regression model uses three statistically significant variables to explain the Agroecology Index: perceived biodiversity changes, area, and gender (Table 5.8). The coefficients of the logistic regression are difficult to interpret numerically. However, it is more interesting whether the statistically significant relationships are positive or negative. Through our analysis, we found a statistically significant positive relationship between the Agroecology Index and observed biodiversity. This supports the idea that the higher the perceived biodiversity, the higher the Agroecology Index. Furthermore, we found a positive and statistically significant relationship between the Agroecology Index and non-male farmers. Finally, we found a very small negative relationship between farm size and the Agroecology Index. The hypothesis tested here is that the smaller the farms, the higher the Agroecology Index. The other selected variables were not found to be statistically significant and are therefore not further discussed. Moreover, all the models are statistically significant (χ^2) at 5 % (Tables 5.8 and 5.9).

Table 5.8 Regression model 1: Ordered logit regression model to explain the Agroecology Index. BIODIV = perceived biodiversity change, SOIL = perceived soil change, AREA = farm size, PROFIT = profitability/ cost-effectiveness, SELFSUF = self-supply of food

	Model 1		Model 2		Model 3		Model 4	
	Coef.	Std. error	Coef.	Std. error	Coef.	Std. error	Coef.	Std. error
BIODIV	2.304**	1.026	2.021*	1.039	2.046*	1.064	1.917*	1.061
SOIL	-1.424	0.869	-1.260	0.868	-1.136	0.888	-1.098	0.885
AREA	-0.002*	0.001	-0.002*	0.001	-0.002*	0.001	-0.002*	0.001
PROFIT	-0.243	0.422	-0.253	0.428	-0.049	0.457	0.048	0.463
SELFSUF	0.007	0.008	0.008	0.008	0.005	0.008	0.007	0.008
EDUCATION	-	-	-0.082	0.239	-0.213	0.254	-0.222	0.254
GENDER	-	-	-	-	1.505*	0.777	-1.535*	0.787
LOCATION	-	-	-	-	-	-	0.046	0.206
LR χ^2	13.98		13.52		17.36		17.37	
Prob > χ^2	0.0157		0.0354		0.0152		0.0265	
No. of observations	49		47		47		46	
Log likelihood								
Pseudo R^2	-96.87		-93.24		-91.33		-89.19	
	0.0673		0.0676		0.0868		0.0887	

The second regression model shows two statistically significant variables to explain perceived changes in biodiversity (Table 5.9). The coefficients show that the higher the Agroecology Index, the higher the perceived biodiversity; similarly, the higher the perceived soil improvement, the higher the perceived biodiversity. The other selected variables were not found to be statistically significant and are therefore not further discussed. The model's explanatory power is expressed in the pseudo R^2 and must be interpreted carefully because the certainty of pseudo R2 is not similar to an R^2 of the ordinary least square method (Long and Freese 2006). This caveat apart, we see that the second model, which explains changes in perceived biodiversity, fits better than the first one, which explains the Agroecology Index. This is valid for pseudo R^2 and χ^2.

Table 5.9 Regression model 2: Ordered logit regression model to explain changes in biodiversity. AE INDEX = agroecology index, SOIL = perceived soil change, AREA = farm size, PROFIT = profitability/ cost-effectiveness, SELFSUF = self-supply of food

	Model 1		Model 2		Model 3		Model 4	
	Coef.	Std. error	Coef.	Std. error	Coef.	Std. error	Coef.	Std. error
AE INDEX	0.252*	0.145	0.241	0.148	0.272*	0.156	0.265*	0.158
SOIL	4.611***	0.862	4.442***	0.854	4.445***	0.858	4.364***	0.854
AREA	-0.000	0.001	-0.000	0.001	-0.000	0.001	-0.000	0.001
PROFIT	-0.122	0.465	-0.129	0.466	-0.180	0.479	-0.156	0.486
SELFSUF	0.008	0.009	0.008	0.009	0.009	0.009	0.009	0.010
EDUCATION	-	-	-0.060	0.319	-0.006	0.331	-0.012	0.329
GENDER	-	-	-	-	-0.581	0.877	-0.544	0.876
LOCATION	-	-	-	-	-	-	0.084	0.247
LR χ^2	46.58		43.78		44.22		43.20	
Prob > χ^2	0.0000		0.00		0.00		0.00	
No. of observations	49		47		47		46	
Log likelihood								
Pseudo R^2	-53.16		-51.64		-51.42		-50.44	
	0.3046		0.2977		0.3007		0.2999	

5.6 Discussion

This study shows that agroecological management can convert AEDS into AES. The consulted farmers use practices, which they perceive as positive for the environment (see Table 5.3). Furthermore, they observed positive changes in soil properties, biodiversity, and pests after applying agroecological practices (see Table 5.4). The average Agroecology Index is 8.7 among 63 farmers. We found the highest appliance of 73 % for practices to maintain soil health. Additionally, more than 50 % of farmers applied agroecological practices to increase (agro)biodiversity and efficient water use. All this contributes to reducing negative agroecosystem services (e.g., GHG emissions, soil degradation, and biodiversity loss) and increasing positive services (e.g., climate regulation, soil health, and biodiversity), establishing climate compatible and biodiverse agriculture. However, due to practicability and replicability, we could not include all agroecological practices that positively affect the environment in the index. Therefore, we selected 14 practices, which were not weighted.

We conducted two regression models to better understand which variables interrelate with the Agroecology Index and perceived biodiversity improvements. In both models, we saw that biodiversity improvements and applying agroecological practices go hand in hand. Moreover, we found a statistically significant positive relationship between non-male farmers and the Agroecology Index. This stresses the important role of gender diversity in the agroecological transition and shows the need to make non-male farmers more visible and facilitate their integration in the male-dominated agricultural sector. Our findings confirm experiences from Latin American countries where women and women's groups have promoted the agroecological transition (Mestmacher and Braun 2020; Oliver 2016).

Moreover, we found a statistically significant negative relationship between small farms and the Agroecology Index and small farms and biodiversity improvements, which shows the potential advantage in supporting smallholders for an ecological transition in agriculture. Nowadays, smallholders with small properties (< 1 hectare or smaller) are often not eligible to apply for funding (e.g., CAP), although they represent the large majority of farmers worldwide (Anderies 5/9/2017; Heider et al. 2021). Therefore, for the attribution of financial aid, we would suggest concentrating on the practices applied and the AES produced rather than on farm size, giving smallholders the chance to expand while at the same time following the principle of public money for public (agroecosystem) services. This is especially important because the most important challenge mentioned by agroecological farmers is the low income. Unfortunately, most public funding is still granted to large-scale agriculture applying conventional practices and producing mainly AEDS (see Fig. 5.1). At the same time, agricultural enterprises, which produce AES for the environment and society, struggle to make a living. Here, we suggest the Agroecology Index as a tool to assess public services provided by agroecosystems as an incentive for public investment.

We propose to use the index as a tool for different stakeholders. First, local, regional, and national authorities can use it to redirect public investments in projects and programs, which support sustainable development based on agroecology. Authorities can also take advantage of subsidies for youth and non-male persons through the CAP, even more knowing that our results show a statistically significant relationship between gender and the implementation of agroecological projects. This could significantly support this type of project, favor the entrepreneurship of young people, and boost the local economy. The index could also be used to monitor the advances in the ecological transition in a territory, in the context of the European Green Deal, for example. Second, farmers can use the index as a tool for self-assessment on the way to agroecology, which helps them implement new methods as best practices. Furthermore, they can use it in their communication, considering the increasing demand for local organic food. Third, consumers can use it to support farmers, which produce AES, thus, contributing to the ecological transition.

On an international scale, the support of agroecological management allows a country to comply with its international obligations regarding the reduction of CO_2 emissions (Paris Agreement), biodiversity protection (Convention on Biological Diversity), combating land degradation (Convention to Combat Desertification), and complying with the SDGs. At the same time, it offers an inestimable potential for food autonomy, regenerating degraded lands and increasing resilience to extreme events. Currently, agriculture is one of the biggest GHG emitters and one of the main drivers for biodiversity loss (Campbell et al. 2017), but using agroecology, it can be one of the biggest GHG storages while also increasing biodiversity. This study gives a first impression of a beginning transition to agroecology in Spain, which is led by committed farmers organized in associations, regional cooperatives and networks (i.e., SEAE, Olivares Vivos, Associación de Agricultura de Conservación, Associación de Agricultura Regenerativa Íbera, Associación de Agricultura Biodinámica).

This study is limited by its small sample size. We were dependent on the collaboration of agricultural associations and networks to distribute our survey among their members or subscribers via email or social media. Furthermore, we were dependent on the goodwill of farmers to spend approx. 40 minutes to fill out the questionnaire containing 51 open and closed questions and share personal as well as economic data. We suggest expanding this survey among a larger number of farmers, in several Mediterranean countries, by reducing the number of questions to gain a more representative sample size. In the meantime, we consider this an exploratory study, which gives a first impression of tendencies in Spain opening new research questions.

5.7 Conclusion

In this study, we explored agroecological management in Spain. To do this, we conducted an online survey among farmers committed to sustainable food production and increasing biodiversity.

First, we investigated the challenges and opportunities facing agroecological projects in Spain. The most important opportunities mentioned by farmers are the low inputs needed for agroecological management, which enables them to reduce costs, and the high, organic quality of their products. However, the most pressing challenge is the low income due to low crop prices. Therefore, we argue that farmers who use agroecological practices and produce positive services for society and the environment should be supported by European, national, and local policies.

Second, we explored the perceived effects of using agroecological practices and explored the adaptation measures to climate change. The consulted farmers perceive their agricultural practices as positive or very positive for the environment. Since they started using these practices, farmers have observed a recovery of their land: improved soil properties, an increase in biodiversity and fewer pests in their crops. Moreover, 65 % of farmers have adapted their practices consciously to climate change.

Finally, we assessed and explained farm agroecology using the Agroecology Index, considering agroecosystem services. Assessing their agricultural practices, we were able to confirm the perception of the consulted farmers. On average, they have used 9 out of 14 agroecological practices. 73 % of farmers have integrated trees and bushes to increase (agro)biodiversity. Almost 80 % of farmers have reduced tillage and have used natural fertilizers to maintain soil health. The same percentage has used soil cover for efficient water use. We found that non-male farmers and smallholders are more likely to use agroecological practices and that agroecological management and improvements in biodiversity go hand in hand.

Different stakeholders can use the index. Local, regional and national authorities can use it to redirect public investment. Farmers can use it for self-assessment and communication to customers. Finally, consumers can use it to support the provision of agroecosystem services and the ecological transition. However, this study is limited by its small sample size. We propose the Agroecology Index to be tested on a larger sample before implementing it at the policy level.

This study has shown that agroecological management reduces negative services provided by agroecosystems (e.g., greenhouse gas emissions, soil degradation, biodiversity loss) while increasing positive services (e.g., climate regulation, soil health, biodiversity), thus promoting climate-resilient and biodiverse agriculture. Further research is needed to quantify the multiple positive services produced under agroecological management in a holistic approach and long-term studies.

6 Synthesis

The thesis has been structured along four articles. This last chapter summarizes the findings of each article, answering the research questions and addressing the overall objective. Finally, conclusions are drawn to give policy recommendations and inform further research.

6.1 Summary

The expansion of intensive conventional agriculture led to massive short-term production of food. At the same time, in the medium and long terms, this type of agriculture produces negative outcomes in many ways: GHG emissions, biodiversity loss, degradation of land, water and ecosystems, while also increasing the vulnerability of agriculture to climate change (Campbell et al. 2017; Reynolds et al. 2014). Diversified multifunctional agriculture can help to address these challenges (IAASTD 2009; IPES-FOOD 2016).

In this thesis, I explored the following overarching research questions: (1) How to support multifunctional agriculture in the Mediterranean region? (2) What are the challenges and opportunities for Mediterranean smallholder agriculture, focusing on the Ricote Valley in south-eastern Spain? My aim is to identify leverage points to increase the multifunctionality of agriculture and contribute to sustainable rural development in the Mediterranean region, also giving a voice to the needs of smallholders.

One major challenge identified by local stakeholders in the study region is the fragmentation of agricultural properties. Therefore, I aimed to assess agricultural land properties considering the influence of land fragmentation in traditional Mediterranean agroecosystems predominantly made of small farms in the second chapter. The average farm in Ricote has an area of 3178 m², two to three water counters and a standard distance of 240 m between plots. I developed a Fragmentation Index for Drip Irrigation and Distance Assessment (FIDIDA), which quantifies the fragmentation of farms considering their transaction costs. Based on these costs, FIDIDA combines mean plot size, *degree of separation* (i.e., number of water counters) and *degree of dispersion* (i.e., standard distance) of land parcels on farm level. The index can be used to compare the individual fragmentation of farms or the land fragmentation between different study areas. FIDIDA aims at supporting the management of reasonable land fragmentation thresholds in the context of communities made of traditional small farms. It also suggests possible pathways for a gradual inversion of high land fragmentation trends through agreed plot fusion where necessary. Thus, the index offers solutions to land fragmentation without counteracting the positive services of fragmented plots, e.g., biodiversity and recreation opportunities in a cultural landscape.

Another challenge for smallholders all over Europe is land abandonment. In the third chapter, I aimed to detect and quantify the progression of cultivated and abandoned terraced fields in the Ricote Valley between 2016 and 2019 while also exploring reasons for land abandonment over the past decades. The results show high rates of abandonment compared to the total available agricultural terraced area in the Ricote Valley. Between 2016 and 2019, the percentage of detected not-cultivated terraces decreased from 56 % to 40 %. Small parcels (< 556 m²) are cultivated to a higher percentage than large (> 1533 m^2) or medium-sized parcels (556 - 1533 m^2). Five main reasons underlying land abandonment could be identified: 1) Low income of farmers; 2) Land fragmentation resulting in higher transaction costs; 3) Lack of interest in agricultural activities among young generations; 4) Lack of modernization; 5) Emotional bonds preventing the sale of abandoned parcels.

To address mitigation opportunities for GHG emissions in agriculture, I explored the state of preservation and the potential for the deployment of traditional water wheels known as *norias* in the Ricote Valley while also investigating the reasons for their widespread abandonment. The findings show that engine-based water-lifting technologies have mostly replaced *norias* in the Ricote Valley. The reactivation of traditional irrigation technologies could contribute to reduce the high energy demand and the resulting emissions of irrigation systems in the Mediterranean region and beyond. To assess the potential of *noria* renovation, we proposed four scenarios, which represent different working regimes, due to seasonal variabilities: a full year, with 8760 h/year (100 %), 6570 h/year (75 %, i.e., 9 months), 4380 h/year (50 %, 6 months), and 2190 h/year (25 %, 3 months). It was estimated by data extrapolation that 16 renovated *norias* included in the analysis could irrigate 140.3 hectares in the Ricote Valley for a total achievable power of 23.8 kW. Based on the scenarios, 16 *norias* would produce the following benefits if they would replace diesel motor pumps: 16 *norias* could mitigate between 37 and 148 tons of emissions/year as well as between 18,000 and 70,000 €/year spent on 14,000-56,000 liters diesel. If they replaced electric motor pumps, 16 *norias* would produce the following benefits: 16 *norias* could save between 14 and 55 tons of emissions/year and between 12,000 and 48,000 €/year spent on electricity. Both types of engines are currently used to lift irrigation water on elevated agricultural terraces. Such savings should be factored in towards the maintenance of *norias.* Apart from their potential to mitigate emissions, *norias* create freshwater micro-habitats for flora and fauna, contributing to increased biodiversity in agriculture. Thus, the reactivation of traditional technologies has the potential to contribute to achieving several Sustainable Development Goals of the United Nations (SDG): climate action to reduce GHG emissions (SDG 13) and fostering sustainable life on land (SDG 15).

Another opportunity to increase the multifunctionality of agriculture is to apply agroecological management. Agroecological practices can combine high production with sustainable land use, including the use of diversified crop systems, the replacement of external inputs with natural processes, and efficient water use. In chapter five, I explored the potentials of agroecological practices theoretically and empirically, based on the experiences of farmers in Spain. The results show that agroecological management is able to avoid negative effects on the environment restoring the multiple services that can be provided by agriculture. On average, the consulted farmers apply 9 out of 14 agroecological practices, and 65 % adapt their practices consciously to climate change. Non-male farmers and smallholders are more likely to apply agroecological practices. Moreover, after applying these practices, almost all farmers observed positive changes in soil properties, biodiversity and pests. All this contributes to reduce negative agroecosystem services (e.g., GHG emissions, soil degradation, biodiversity loss) and increase positive services (e.g., climate regulation, soil health, biodiversity), establishing climate-resilient and biodiverse agriculture. Hence, applying agroecological management in agroecosystems also contributes to complying with the Paris Climate Agreement, with biodiversity protection (Convention on Biological Diversity), and combat land degradation (Convention to Combat Desertification). At the same time, several SDGs are fostered, e.g., climate action to reduce GHG emissions (SDG 13), sustainable life below water (SDG 14), sustainable life on land (SDG 15), responsible consumption and production (SDG 12), good health and well-being (SDG 3).

In summary, the four chapters identified (1) significant challenges for Mediterranean smallholder agriculture, (2) the reasons underlying these challenges and (3) opportunities to increase the multifunctionality of agriculture. This research would not have been possible applying a monomethod approach. The mixed-method approach applied in three chapters helped to integrate local perspectives bringing light to the reasons underlying land abandonment and *noria* deterioration in the Ricote Valley as well as the experiences of agroecological farmers in Spain. In this thesis, local stakeholders have been involved since the beginning of the research process. They participated in workshops in the study area, as authors of scientific articles, and as respondents in surveys. The site-specific and mixed-method research enabled a comprehensive understanding of the study area, its needs and opportunities.

6.2 Conclusion

This thesis has shown multiple challenges for smallholders in Spain. The example of the Ricote Valley, representative for many remote villages all over Europe, has shown that the expansion of industrial agriculture and land abandonment threatens the existence of small-scale agriculture and cultural landscapes. Moreover, the low income of smallholders has been identified in several surveys. It represents not only a barrier to the modernization of agriculture but also to the ecological transition, as we have seen in chapters three and five.

This thesis has also shown multiple opportunities to increase the multifunctionality of agriculture by combining tradition and innovation. Re-using traditional technologies can help mitigate GHG emissions from agriculture while preserving cultural landscapes, providing recreation opportunities for locals and tourists, and creating freshwater micro-habitats for flora and fauna. Furthermore, agroecological management is based on traditional ecological knowledge (TEK). The experiences of farmers committed to sustainable food production and increasing biodiversity confirmed that agroecological management reduces negative agroecosystem services while increasing positive agroecosystem services.

Therefore, I argue that especially farmers, who produce positive agroecosystem services for the environment and society, should be supported politically on the European, national and local levels. In this respect, smallholders must be included. The findings of this thesis have shown that smallholders and non-male farmers are more likely to use agroecological practices, thus, providing positive services. Following the principle of public money for public services, agricultural subsidies should promote multifunctional agriculture. This makes a paradigm shift in agriculture necessary. Agricultural management must change from a focus on productivity to a focus on multifunctionality, providing services for the environment, society and economy.

For example, promoting farms that use agroecological practices, sell directly to urban customers, process their products in-house and preserve traditional agricultural landscapes can contribute to (1) mitigating the negative impacts of agriculture on the environment, (2) recovering and counteracting land degradation and land abandonment, (3) reinforcing local food chains, and (4) reviving local employment. Furthermore, support for young farmers who address global challenges locally is needed to counteract the lack of interest in farming activities among young generations and to favor sustainable farming activities in the long term. A reformed agricultural policy can make one of the greatest contributions to mitigating the effects of climate change, protecting biodiversity, supporting social innovation, and reducing rural exodus.

Further research is needed to quantify multiple services provided by a sustainably managed agroecosystem. First, traditional technologies like *norias*, discussed in chapter four, provide multiple services (e.g., shaping cultural landscapes, preserving the local water culture, creating freshwater micro-habitats, providing recreation opportunities for locals and tourists, and creating local employment), which have not been quantified yet. Moreover, site-specific calculations for the cost of *noria* renovation is needed to apply for funding, putting research into practice. We further suggest expanding the study to explore the potential of *norias* in other study regions and several Mediterranean countries. Second, research on the multiple positive agroecosystem services produced under agroecological management, discussed in chapter five, needs to be extended using a larger sample size. Third, positive agroecosystem services should be quantified in a holistic approach and during a long-term study.

Furthermore, research is needed for the implementation of indices. FIDIDA can assess land fragmentation on the farm level. The index has been developed and tested in Ricote. In the next step, it needs to be tested in other regions with similar characteristics. Moreover, the willingness of people to swap land needs to be assessed to reduce the distance between plots and deal with the high transaction costs of farmers in the Ricote Valley and beyond.

The Agroecology Index can assess farm agroecology by looking at agroecological practices. Thus, it helps to make positive agroecosystem services visible. In the next step, the index should be tested on a larger sample size. Then, local, regional and national authorities can use the index to redirect public investment. Farmers can use it for self-assessment and communication to customers. Finally, consumers can use it to support farmers who produce positive agroecosystem services and, thus, support the ecological transition.

This thesis has identified multiple challenges and opportunities for smallholder agriculture in the Mediterranean region. It has proposed local solutions to address global challenges. But more than anything else, it has shown the huge potential of smallholder agriculture to contribute to sustainable rural development in the Mediterranean region and beyond. It has shown that the renovation of old and almost forgotten technologies as well as agroecological management in small-scale agriculture have a positive effect on the environment, society, and economy. Favoring small initiatives in many locations can multiply these effects while also achieving multiple SDGs.

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Appendices

Appendix 1: Expert survey on land abandonment

Nº __________ FECHA _________

EL ABANDONO DE PARCELAS AGRÍCOLAS

En el Valle de Ricote hay muchas parcelas “no cultivadas”.

P.1) ¿Qué razones considera usted más importantes para explicar el estado “no cultivado”?

Elija un número entre 0 y 4 siendo 0 (sin importancia) y 4 (mucha importancia)

	Sin		Moderado		Mucho
	0	**1**	**2**	**3**	**4**
Sin derecho de regar					
Alto precio del agua					
Propiedad no clarificada					
Sin ayudas económicas de la UE					
Precios bajos de limones					
Precios bajos de otros productos agrícolas					
Fragmentación de parcelas					
Las parcelas no están aterrazadas					
Otro 1: Cantidad excesiva de obra a mano					
Otro 2: Apego emocional					
Otro 3:					

INFORMACIÓN SOCIOECONÓMICA

Edad: ________ Sexo: [ ] Mujer [ ] Hombre

Nivel de estudios: [ ] Sin estudios [ ] Estudios primarios [ ] Bachiller [ ] Formación profesional [ ] Estudios universitarios

Organismo a quien representa/ cargo: ____

Nombre: ______________________________ Teléfono:______________________________

E-mail: ____

¿Permite que su nombre aparezca en el listado de expertos consultados en el presente estudio? [ ] Sí [ ] No
¿Qué otros expertos recomienda usted consultar sobre este tema? ______________________________

Appendix 2: Expert survey on noria deterioration

Nº __________ FECHA _________

EL ABANDONO DE NORIAS

En el Valle de Ricote hay muchas norias en mal estado de conservación.

P.2) ¿Qué razones considera usted más importantes para explicar el mal estado de conservación?

Elija un número entre 0 y 4 siendo 0 (sin importancia) y 4 (mucha importancia)

	Sin	Moderado			Mucho
	0	**1**	**2**	**3**	**4**
Uso de riego por goteo					
Uso de bombas para transportar el agua					
Falta de valoración de tecnologías tradicionales					
Propiedad privada					
Propiedad no clarificada					
Sin ayudas económicas de la UE					
Bajos ingresos de la agricultura					
Altos costes del mantenimiento					
Expansión de infraestructuras y urbanización					
Otro 1:					
Otro 2:					
Otro 3:					

P.3) ¿Considera usted importante la conservación de las norias? [1] Sí [0] No

Si no: ¿Por qué? Valor histórico [1]

Si sí: ¿Quién considera usted responsable para financiar la consideración de las norias?

[1] Propietarios privados [2] Ayuntamiento [3] Comunidad autónoma de Murcia [4] 1+2 [5] 1+ 3 [6] 2+3 [7] 1,2,3,

INFORMACIÓN SOCIOECONÓMICA

Edad: ________ Sexo: [ ] Mujer [ ] Hombre

Nivel de estudios: [ ] Sin estudios [ ] Estudios primarios [ ] Bachiller [ ] Formación profesional [ ] Estudios universitarios

Organismo a quien representa/ cargo: ____

Nombre: ______________________________ Teléfono: ______________________________

E-mail: ____

¿Permite que su nombre aparezca en el listado de expertos consultados en el presente estudio? [ ] Sí [ ] No
¿Qué otros expertos recomienda usted consultar sobre este tema? ______________________________

Appendix 3: Online survey on agroecology

Agricultura y tierra en España – juntos para un futuro sostenible!

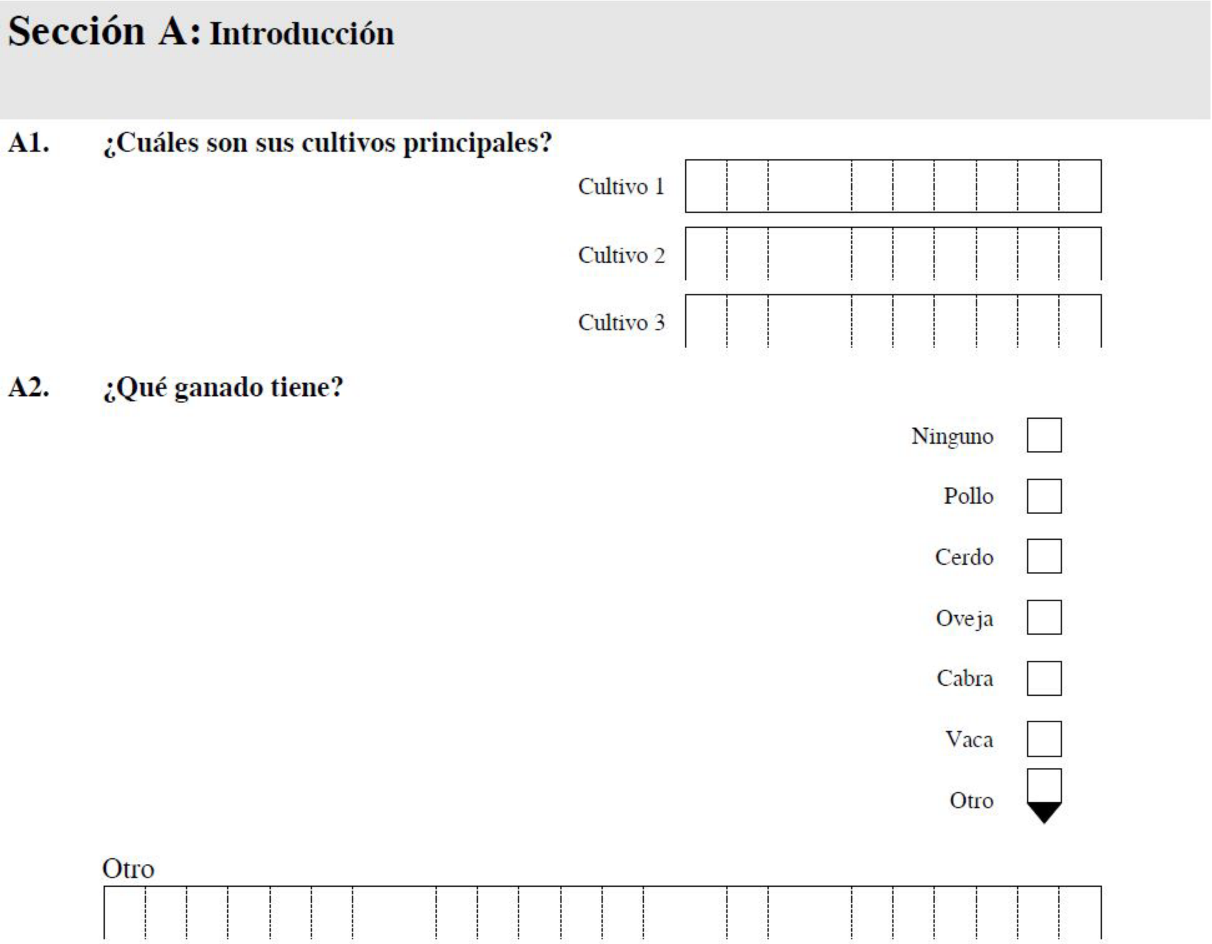
En esta encuesta queremos aprender más de las prácticas agrarias sostenibles y su potencial para regenerar tierras degradadas y abandonadas en España. Invitamos a las agricultoras y los agricultores a compartir su experiencia. El objetivo del estudio es ofrecer caminos alternativos para una mejor gestión del agua y de las tierras. ¡Gracias por compartir su experiencia para promover una agricultura sostenible!

Su información será tratada con estricta confidencialidad y tendrá fines puramente científicos. Sus datos no serán compartidos con terceros. Si tiene más preguntas sobre la encuesta, póngase en contacto con Katharina Heider: katharina.heider@studium.uni-hamburg.de

Tiempo estimado: 30 minutos

Para el éxito de la encuesta, le pedimos que conteste todas las preguntas posibles.

Hay 51 preguntas en esta encuesta



Sección A: Introducción

A1. ¿Cuáles son sus cultivos principales?

Cultivo 1

Cultivo 2

Cultivo 3

A2. ¿Qué ganado tiene?

Ninguno ☐
Pollo ☐
Cerdo ☐
Oveja ☐
Cabra ☐
Vaca ☐
Otro ☐

Otro

A3. **¿Qué porcentaje de su dieta está cubierto por su propia producción? Por favor, estime.**

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100 %
Porcentaje de su dieta cubierto por producción	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

A4. **¿Cuántas especies de plantas cultiva? Por favor, estime.**

A5. **Estime el porcentaje de variedades autóctonas.**

Variedad autóctona = una variedad adaptada al clima y suelos locales

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100 %
Porcentaje de variedades autóctonas	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

A6. **¿Por que cultiva/ pastorea?**

Para ganar dinero ☐

Para producir productos saludables ☐

Para aumentar la biodiversidad en las tierras agrarias ☐

Para continuar las actividades de mi familia ☐

Por ocio ☐

Otro ☐

Otro

Sección B: Mis prácticas agroforestales

En esta sección queremos aprender más de sus prácticas agroforestales. La agroforestería combina la actividad agraria con los árboles. La actividad agraria incluye cultivos y ganado. En este trabajo entendemos que las tierras agrarias con más de 10% de árboles se definen como agroforestales. Existen varias prácticas agroforestales.

B1. **¿Cultiva árboles en su tierra agraria?**

Sí ☐

No ☐

B2. ¿Cómo describiría su práctica agroforestal?

Silvoarable / Cultivo intercalado: árboles ampliamente espaciados intercalados con cultivos anuales o perennes Agricultura forestal: áreas boscosas utilizadas para la producción o cosecha de cultivos especializados naturales para usos medicinales, ornamentales o culinarios. Búfer ribereño: franjas de vegetación perenne (árbol / arbusto / prado) entre tierras de cultivo / pastos y fuentes de agua (por ejemplo, arroyos, lagos, humedales, estanques) para proteger la calidad del agua. Silvopastoril: Masas silvopascicolas o dehesas, formaciones que combinan arbolado con pastizales / prados con aprovechamiento forrajero o "a diente" Cortavientos: árboles plantados o naturales y / o arbustos como barreras para disminuir la velocidad y el impacto del viento

Silvoarable / cultivo intercalado ☐

Agricultura forestal ☐

Búfer ribereño ☐

Silvopastoril ☐

Cortavientos ☐

Otro ☐

Otro

B3. ¿Qué porcentaje de su tierra está cubierta por plantas perennes leñosas (árboles, arbustos, palmeras, etc.)? Por favor, estime.

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100 %
Tierra cubierta por plantas perennes leñosas	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

B4. ¿Está de acuerdo con las siguientes declaraciones?

No estoy de acuerdo en absoluto 0 - 2 - 4 - 6 - 8 - 10 Estoy totalmente de acuerdo

	0	2	4	6	8	10	No sé
Mis prácticas agrarias construyen suelo	☐	☐	☐	☐	☐	☐	☐
Mis prácticas agrarias preservan la biodiversidad	☐	☐	☐	☐	☐	☐	☐
Mis prácticas agrarias no contaminan el agua	☐	☐	☐	☐	☐	☐	☐

Sección C: El estado de mi tierra

En esta sección queremos aprender del nivel de degradación y regeneración en su terreno desde que usted empezó a cultivar/ pastorear hasta ahora. Nosotros asumimos aquí que la degradación de la tierra es la disminución de la capacidad productiva de la tierra. Las causas de la degradación de la tierra incluyen variaciones climáticas, así como la gestión no sostenible de la tierra y el agua.

C1. **¿Cuál era el estado de su terreno inicialmente, cuando usted empezó a cultivar/ pastorear?**

Cultivado	☐
Restos de cultivos anteriores (abandonado)	☐
Vegetación pequeña natural (hierbas y pastos)	☐
Vegetación alta natural (arbustos y árboles)	☐
Suelo desnudo	☐
Otro	☐

Otro

C2. **¿Cómo ha cambiado el estado del suelo en su terreno desde que usted empezó a cultivar/ pastorear hasta ahora?**

	Empeorado mucho	Empeorado	No cambió	Mejorado	Mejorado mucho	No sé
Propiedades biológicas del suelo, por ejemplo, presencia de lombrices de tierra, bacterias y micorrizas	☐	☐	☐	☐	☐	☐
Propiedades químicas del suelo, por ejemplo, presencia de nutrientes disueltos (humus) en el suelo	☐	☐	☐	☐	☐	☐
Propiedades físicas del suelo, por ejemplo, formación de costras y compactación de la superficie	☐	☐	☐	☐	☐	☐
Propiedades hidrológicas del suelo, por ejemplo, infiltracion y retencion del agua de lluvia	☐	☐	☐	☐	☐	☐

C3. **¿Cómo ha cambiado el estado de la biodiversidad en su terreno desde que usted empezó a cultivar/ pastorear hasta ahora?**

En este trabajo entendemos que cuanta más cantidad/ diversidad de vegetación/ animal, mejor es.

	Empeorado mucho	Empeorado	No cambió	Mejorado	Mejorado mucho	No sé
Cantidad de vegetación (incluye la cubierta vegetal del suelo)	☐	☐	☐	☐	☐	☐
Diversidad vegetal	☐	☐	☐	☐	☐	☐
Enfermedades de la vegetación	☐	☐	☐	☐	☐	☐
Diversidad animal, por ejemplo, insectos/ pájaros/ anfibios/ mamíferos	☐	☐	☐	☐	☐	☐

C4. **¿Qué otro tipo de degradación y/o regeneración y/o efectos que no mencionamos ha notado en su terreno? Por favor, explique.**

Sección D: Mis prácticas agrarias

Ahora queremos aprender de su gestión del agua y la tierra, así como las prácticas tradicionales que utiliza. Si bien recientemente han surgido muchas iniciativas agroecologicas, la mayoría de sus principios y métodos se han utilizado durante miles de años en todo el mundo y se basan en el conocimiento ecológico tradicional. El conocimiento ecológico tradicional incluye conocimientos, creencias, tradiciones, prácticas, por ejemplos prácticas de cultivo, colección y transporte del agua, uso de plantas medicinales o comestibles, etc. El conocimiento ecológico tradicional puede ayudar a encontrar una gestión más sostenible de la tierra y el agua, así como adaptarse al cambio climático.

D1. **Indique las prácticas de la Agricultura de Conservación que practica, por favor.**

Siembra directa (no labranza) ☐
Cubiertas vegetales ☐
Rotación de cultivos ☐
Diversificación de cultivos ☐

D2. **¿Qué usa para cubrir el suelo?**

Nada ☐
Hierbas espontáneas ☐
Hierbas espontáneas seleccionadas ☐
Hierbas sembradas ☐

Residuos vegetales ☐
Piedras ☐
Otro ☐

Otro

D3. **¿Ha integrado intencionalmente una zona sin cultivo (por ejemplo, para preservar la biodiversidad)?**

Sí ☐
No ☐

D4. **¿Qué función tiene el ganado?**

Producción de estiércol ☐
Reciclaje de residuos orgánicos como forraje ☐
Producción de carne ☐
Producción de productos lácteos ☐
Producción de huevos ☐
Otro ☐

Otro

D5. **¿Cómo definiría el tipo de pastoreo de ganado que se realiza, en las fincas que tienen animales?**

Manejo Holístico en la agricultura es un enfoque para gestionar los recursos que fue desarrollado originalmente por Allan Savory. El pastoreo planificado holístico es similar al pastoreo rotacional, pero se diferencia en que reconoce de manera más explícita y proporciona un marco para adaptarse a los cuatro procesos básicos del ecosistema: el ciclo del agua, el ciclo mineral, incluido el ciclo del carbono, flujo de energía y dinámica comunitaria (la relación entre organismos en un ecosistema), dando igual importancia a la producción ganadera y al bienestar social.

El Pastoreo Racional Voisin (PRV) es basado en las cuatro leyes universales de pastoreo desarrolladas en la década de 1950 por André Voisin (1903-1964). Las leyes incluyen el período de descanso para la hierba, el período de ocupación de la parcela, la elección de la mejor parcela cada día, la priorización de los animales con las necesidades más grandes (p.e. vaca lechera).

Ninguno ☐
Intensivo ☐
Extensivo ☐
Rotacional ☐
Trashumancia ☐
Manejo Holístico ☐
Pastoreo Racional Voisin ☐
Otro ☐

Otro

D6. **¿Cuántos días permanece el ganado en una misma parcela aproximadamente?**

D7. **¿Cuántos días de reposo se da a cada parcela antes de volver a meter el ganado aproximadamente?**

D8. **¿Qué tipo de fertilizante utiliza?**

Ninguno ☐
Abono verde ☐
Compost ☐
Estiércol ☐
Fertilizante químico ☐
Otro ☐

Otro

D9. **¿Qué manejo de malezas utiliza?**

Ninguno ☐

Animales ☐

Segar ☐

Control manual ☐

Herbicidas ☐

Otro ☐

Otro

D10. **¿Qué control de plagas utiliza?**

Ninguno ☐

Pesticida ☐

Control biológico de plagas ☐

Otro ☐

Otro

D11. **¿Cómo limita la contaminación del medioambiente? Por favor, indique el grado de implementación.**

No implementado 0 - 2 - 4 - 6 - 8 - 10 Totalmente implementado

	0	2	4	6	8	10	N/A
Abonar de acuerdo con las deficiencias de suelo y las necesidades de cultivo (sin exceso)	☐	☐	☐	☐	☐	☐	☐
Establecimiento y mantenimiento de franjas vegetales a lo largo de los cursos de agua y lindes de las fincas (márgenes multifuncionales)	☐	☐	☐	☐	☐	☐	☐
Utilización de tecnologías modernas en la aplicación de productos fitosanitarios (Agricultura de Precisión)	☐	☐	☐	☐	☐	☐	☐
Optimización del uso de los productos fitosanitarios (dosis y productos apropiados)	☐	☐	☐	☐	☐	☐	☐
Prevención de la contaminación de fuente puntual de productos fitosanitarios en las fincas (limpieza de áreas de llenado y gestión de los productos)	☐	☐	☐	☐	☐	☐	☐
Desarrollar un manejo optimizado de los residuos de la fincas en áreas específicas (residuos vegetales, efluentes, vertidos, envases vacíos de productos fitosanitarios, etc.)	☐	☐	☐	☐	☐	☐	☐

D12. **¿Cómo limita la erosión? Por favor, indique el grado de implementación.**

No implementado 0 - 2 - 4 - 6 - 8 - 10 Totalmente implementado

	0	2	4	6	8	10	N/A
Uso de cobertura permanente del suelo en cultivos herbáceos (cobertura vegetal o restos de cultivos)	☐	☐	☐	☐	☐	☐	☐
Uso de cubiertas vegetales en cultivos leñosos	☐	☐	☐	☐	☐	☐	☐
Mínima alteración de las propiedades físicas del suelo de forma mecánica	☐	☐	☐	☐	☐	☐	☐
Adecuadas prácticas agrícolas tomando en cuenta la curva de nivel, por ejemplo, terrazas	☐	☐	☐	☐	☐	☐	☐
Afianzar las pendientes con plantas y arbustos que fijan el terreno	☐	☐	☐	☐	☐	☐	☐
Cortavientos vegetales	☐	☐	☐	☐	☐	☐	☐

D13. **¿Qué tipo de gestión del agua tiene?**

Secano ☐
Regadío ☐
Mixto ☐

D14. **¿Qué tipo de riego usa?**

Riego por goteo ☐
Riego por inundación (cuenca) ☐
Riego por aspersión ☐
Riego por surcos ☐
Riego manual ☐
Otro ☐

Otro

D15. **¿Para qué utiliza el agua de lluvia capturada?**

No capturo el agua de la lluvia ☐
Riego de agricultura ☐
Uso domestico ☐

Otro ☐

Otro

D16. **¿Cuáles eventos climáticos extremos han afectado su agricultura?**

Ninguno ☐

Sequías ☐

Olas de calor ☐

Eventos de lluvia intensa ☐

Tempestades ☐

Otro ☐

Otro

D17. **¿Cómo ha adaptado el manejo del agua y de la tierra a las tendencias climáticas de calentamiento proyectadas y al aumento de eventos climáticos extremos? Por favor, dé algunos ejemplos.**

D18. **¿Cuáles prácticas ecológicas tradicionales o tecnologías tradicionales que no mencionamos utiliza?**

Sección E: Desarollo de mi negocio/ proyecto

E1. **¿Desde cuándo tiene este trabajo / negocio / proyecto?**

(Por ejemplo "2011")

E2. **¿Cuál es el tamaño de su área agraria global incluyendo zonas salvajes?**

E3. **¿Cómo vende su producción?**

No vendo ☐

Producto primario ☐

Producto transformado ☐

E4. **¿Dónde vende sus productos?**

Local (pueblo y provincia) ☐

Comunidad autónoma ☐

Nacional ☐

Internacional ☐

E5. **¿Por qué bienes o servicios intercambia su producción?**

No intercambio ☐

Por producción agraria ☐

Por servicios ☐

Otro ☐

Otro

E6. **¿Sus productos son orgánicos?**

Certificado orgánico ☐

Orgánico, pero no certificado ☐

Convencional ☐

E7. **¿Cuántas personas trabajan en su granja? Por favor, escriba el número.**

Empleados ☐

Voluntarios ☐

Familia ☐

Amigos/ vecinos, etc. ☐

E8. ¿Es rentable su granja?

Sí ☐
No ☐
En parte ☐

E9. ¿Cuáles diría que son los factores clave que la hacen rentable?

E10. ¿Cuáles diría que son los factores que no la hacen rentable?

E11. ¿De qué entidad recibe subvenciones?

Ninguno ☐
UE ☐
Gobierno español ☐
Comunidad autónoma ☐
Ayuntamiento ☐
Otro ☐

Otro

E12. ¿Podría ser rentable sin subvenciones de la política agrícola común (PAC)?

Sí ☐
No ☐

E13. **¿Está de acuerdo con las siguientes declaraciones?**

No estoy de acuerdo en absoluto 0 - 2 - 4 - 6 - 8 - 10 Estoy totalmente de acuerdo

	0	2	4	6	8	10
Me siento respaldado por la política de la UE con mi producción agraria	☐	☐	☐	☐	☐	☐
Me siento respaldado por las políticas españolas con mi producción agraria	☐	☐	☐	☐	☐	☐
Me siento respaldado por las autoridades de la comunidad autónoma con mi producción agraria	☐	☐	☐	☐	☐	☐
Me siento respaldado por las autoridades locales (pueblo/ciudad) con mi producción agraria	☐	☐	☐	☐	☐	☐
Me siento respaldado por las redes / asociaciones de las cuales soy miembro con mi producción agraria	☐	☐	☐	☐	☐	☐
Me siento respaldado por los consumidores (clientes/ asociaciones de consumidores)	☐	☐	☐	☐	☐	☐

E14. **¿Cómo califica su satisfacción general con la vida?**

No satisfecho en absoluto 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 Completamente satisfecho

	1	2	3	4	5	6	7	8	9	10
Satisfacción general	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Sección F: Información demográfica

F1. **¿A qué género se asigna?**

Femenino ☐
Masculino ☐
Diverso ☐

F2. **¿Cuántos años tiene?**

F3. **¿Cuál es su nivel de estudios?**

Sin estudios ☐
Estudios primarios ☐
Bachiller ☐
Formación profesional ☐
Estudios universitarios ☐

F4. **¿Dónde está el sitio del negocio/ proyecto?**

Código postal

Localidad

F5. **Nos gustaría tener la posibilidad de contactarle en caso de preguntas.**
La información es voluntaria y no se cederá a terceros.

Nombre

Contacto (email, teléfono)

¡Gracias por su participación y por promover una agricultura sostenible!

Acknowledgements

First of all, I thank my supervisors for our long-lasting collaboration at the Universität Hamburg and their continuous support. I thank Jürgen Scheffran for taking me as a PhD student, sharing his extensive knowledge with me and for his helpful advice and assistance at any time. I thank Juan Miguel Rodriguez Lopez for encouraging me to pursue a PhD in the first place. I thank him for sharing his enthusiasm about science, motivating me to realize my ideas and his guidance during my whole time in research. I thank Olaf Conrad for being my panel chair and for his contributions and discussion during our panel meetings.

Without my co-authors, the publications would not have been possible in their current form. I thank Andrea Balbo for involving me as a student assistant in his research project “Adaptive Resilience in Drylands” (ARiD) in the Ricote Valley. This was the starting point of my work on smallholder agriculture in Spain. I thank him for presenting me to his contacts and network in Spain and inspiring my research by sharing his vision and ideas. I thank José María García Avilés. Without him, the fieldwork would not have been possible. I thank him for helping me find research contacts, organizing accommodation in Ricote and our successful workshops. Moreover, he helped me to understand the local conditions, and I am deeply thankful to him and his family, Ginesa Abenza Turpín, Inmaculada Abenza Turpín and Juan Luís Salinas Imbernón, for welcoming me like a family member in Ricote. I thank Andreas Bischoff for sharing his views and values with me, our theoretical discussions and practical work on agroecology and his effort to promote biodiversity. I thank Emanuele Quaranta for his spontaneity to collaborate and write a scientific article together, as well as his fast contributions and calculations.

I thank the Friedrich-Ebert-Stiftung (FES, Germany) for funding my PhD and the constant support via courses and personally. I also thank the FES for sharing their values and providing an incredible network.

I thank the School of Integrated Climate System Science (SICSS) for their support, course offer and interdisciplinary discussions. I thank the CLICCS Cluster of Excellence funded by the German Research Foundation (DFG) for funding the publication of my research as open access.

I thank the Irrigator’s Community of Ricote, who kindly provided access to their database. I thank the experts for participating in the surveys. I thank the members of the association La Carraila in Abarán for their support during our research and their effort to preserve norias in the Ricote Valley. I thank the farmers who answered my online survey as well as the Spanish agricultural associations and networks, which helped to distribute and co-design my survey: Sociedad Española de Agricultura Ecológica y Agroecología (SEAE), Olivares Vivos, Asociación de Agricultura de Conservación – Suelos Vivos, Associación de Agricultura Regenerativa Íbera, Associación de Agricultura Biodinámica.

And I thank my friends and family for their constant support during the time of my PhD.

Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertationsschrift selbst verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

I hereby declare upon oath that I have written the present dissertation independently and have not used further resources and aids than those stated.

Hamburg, den 29.11.2021 Katharina Heider