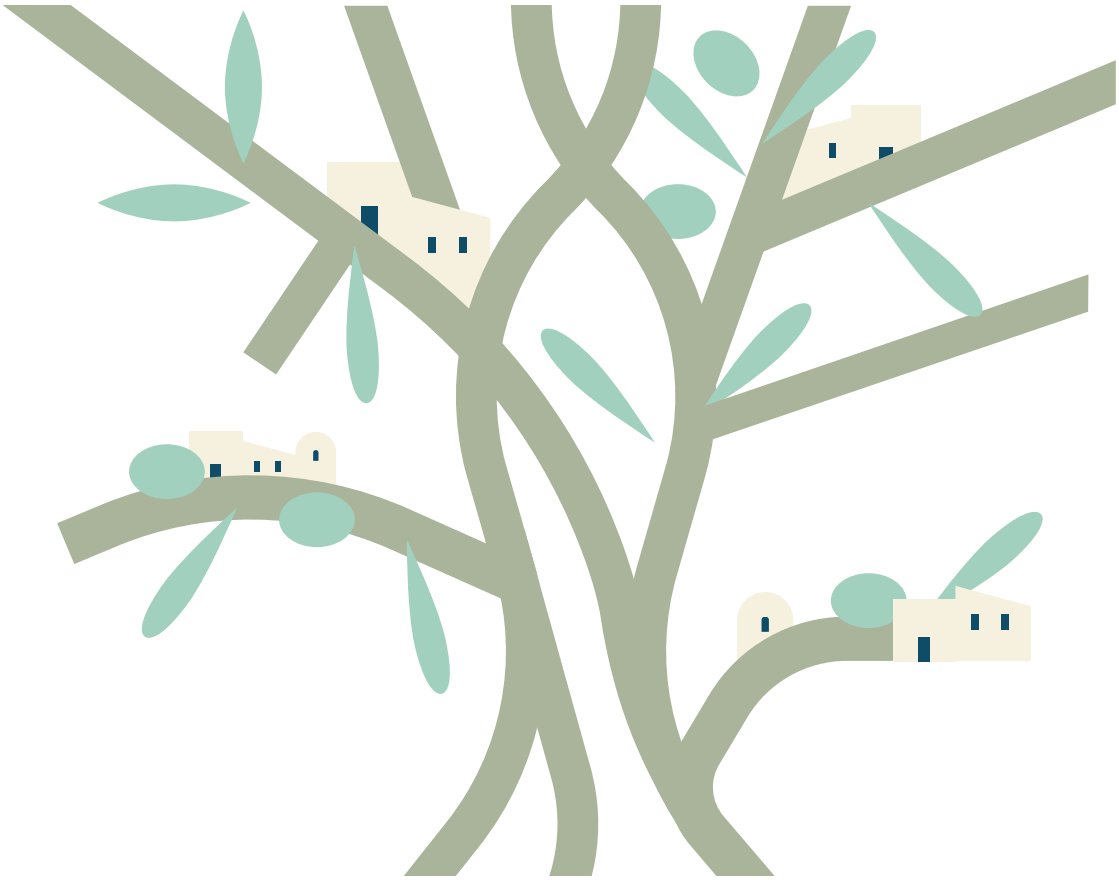
5
QUARTERLY
VOL. XXIV / N. 5
DECEMBER
2025

NEW MEDIT

CIHEAM

Bologna
University Press

MEDITERRANEAN JOURNAL OF ECONOMICS,
AGRICULTURE, ENVIRONMENT AND FOOD



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AGRICULTURE, ENVIRONMENT AND FOOD

VOL. XXIV / N.5 2025

Editor-in-chief
Teodoro Miano

Managing Editor
Giulio Malorgio

Editorial office
Bologna University Press
Via Saragozza, 10
40123 Bologna (Italy)
tel.: +39 051 232882
fax: +39 051 221019
email: newmedit@ciheam.org

Paper submission
https://newmedit.ciheam.org

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Publisher
Bologna University Press
Via Saragozza, 10
40123 Bologna (Italy)
tel.: +39 051 232882
fax: +39 051 221019
email: comunicazione@buponline.com

Subscription rate
Print: Italy: € 40; Foreign: € 90.

Subscription office
ordini@buponline.com

Abstract and Index citation
NEW MEDIT is indexed in: SCOPUS, EBSCO, ISI Web Science, CAB Abstracts, EconLit, AGRIS/FAO database

Web page
https://newmedit.ciheam.org

ISBN: 979-12-5477-719-0

ISSN: 1594-5685

ISSN online: 2611-1128

DOI: 10.30682/nm2505

Registrazione
Tribunale Ordinario di Bari, n. 1546 del 4/1/2002

Direttore Responsabile
Giulio Malorgio

NEW MEDIT è associato alla

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Foreword

Leghrissi and Chebil conduct a stakeholder network analysis to assess groundwater and landscape governance in irrigated areas of central Tunisia. Their findings emphasize the urgent need for more inclusive and effective groundwater management policies—both within Tunisia and across the broader North African and Middle Eastern regions. Key recommendations include addressing the unequal distribution of influence within governance networks, promoting inclusive and collaborative approaches, actively engaging less-connected stakeholders, and strategically leveraging central actors within the network.

Martos-Martínez, Muñoz-Guarasa, and Parrilla-González analyze key internationalization strategies within Spain's olive oil industry, which has faced commercialization challenges both domestically and globally. Their findings help companies develop targeted strategies to expand into new markets, enhance international sales, and strengthen Spain's global position in the olive oil sector.

Calafat-Marzal et al. examine the functional diversity of EIP-AGRI Operational Groups (OGs) in Spain, highlighting their roles as innovation intermediaries. The study identifies three distinct functional profiles—*Collaborative Leaders, Moderate Innovators, and Emerging Explorers*—based on the intermediary roles OGs perform. Key enabling factors are also outlined, supporting the case for differentiated policy interventions aimed at capacity building, streamlining procedures, and fostering strategic partnerships.

Scardigno et al. highlight the value of the Living Lab (LL) approach in co-designing innovative nature-based solutions (NBSs) aimed at enhancing the resilience of endangered Mediterranean dryland socio-ecological systems and restoring degraded ecosystems in arid and hyper-arid areas. The study, conducted within the framework of the SALAM-MED PRIMA project, also recognizes the unique socio-ecological complexities of Mediterranean rural and agricultural contexts. These dynamics—both opportunities and constraints—were addressed through the experiences of six Living Labs involved in the project.

Barreal Pernas et al. examine inbound tourism in Spain's sparsely populated wine-producing regions, where international visitor demand is below the national average. They segment tourists into four groups based on spending habits, motivations, and accommodation choices—ranging from the most spendthrift to the most frugal. The study concludes that attracting more European tourists to these under-visited areas is key to boosting the rural economy and ensuring the long-term sustainability of these regions.

Ramos Galán et al. develop a machine learning model to accurately predict the origin price of Extra Virgin Olive Oil (EVOO) in southern Spain. The model incorporates a wide range of variables, including historical base prices, seasonal factors, production costs, climatic conditions, economic indicators, global oil production, and early predictions of olive crop yields. The results highlight that ensemble models—particularly Gradient Boosting and Random Forest—demonstrate superior predictive performance and are more effective at capturing the complex non-linear relationships and market fluctuations that influence EVOO prices. A distinct pattern of price behavior is identified, significantly shaped by weather conditions, crop production, energy costs, speculation, and global market trends—factors that the ensemble models effectively account for.

Bonguerra et al. assess the impact of climate change on soil loss and its economic implications using the Douimis catchment, located in the northern part of Tunisia, as a case study. The results show that the basin currently experiences significant soil loss, estimated at 18 tons per hectare per year. Climate change is projected to increase erosion risk by 30% by 2050. The economic analysis indicates that the development plan for the Douimis Basin represents a promising investment opportunity, warranting the attention of both local and national authorities in the pursuit of funding.

Assassi et al. analyze the relationship between farm size and performance across three agricultural value chains in Algeria—artichoke, honey, and tomato. They identify structural differentiation levers—internal or external factors rooted in specific spatiotemporal contexts—that indirectly influence performance through techno-organizational practices and economic mediators. The analysis reveals that size-related advantages emerge only when three conditions are met: favorable levers, a farm size suited to those levers, and the farmer's capacity to activate them.

Yioku et al. examine the challenges of low productivity, inefficiency, and food insecurity among smallholder farmers in Zambia. Their results show that age, household size, marital status, cooperative membership, and off-farm income are positively associated with access to the Farmer Input Subsidy Program (FISP), while gender, farm size, and farming experience are negatively associated with FISP access. Access to FISP proves to be a significant benefit for beneficiaries, contributing to increased maize yields and higher farm incomes.

Using stakeholders network analysis to enhance groundwater and landscape governance: A case from arid areas in Tunisia

HAFSIA LEGHRISSI*, ALI CHEBIL**

DOI: 10.30682/nm2505a
JEL codes: Q25, Q28

Abstract

This paper examines groundwater and landscape governance in irrigated areas of central Tunisia, (North Africa). A stakeholders' network analysis was employed to characterize the landscape and assess governance dynamics. The results highlight the necessity of developing inclusive and effective groundwater management policies in Tunisia, which may also be applicable to other North African and Middle Eastern countries facing similar water-related challenges. Key points include addressing the irregular distribution of network influence in groundwater governance, fostering more inclusive and collaborative governance approaches, intentionally engaging less connected actors, and leveraging the centrality of network hubs.

Keywords*: Groundwater, Landscape governance, Irrigated areas, Network analysis, Inclusive, Collaborative, Tunisia.*

1. Introduction

Sustainable agricultural development is essential for addressing global challenges such as food security, rural livelihoods, and environmental conservation (FAO, 2017). Yet, in many developing regions, water scarcity poses a major constraint on the productivity and viability of agricultural activities. Groundwater (GW) serves as the primary source of irrigation water supporting the viability of the agricultural sector and the livelihoods of local populations in several countries (Giordano, 2009). Accordingly, effective groundwater governance is imperative for ensuring the equitable and sustainable water resources use, particularly in areas where surface water supplies are limited (Knieper *et al.*, 2010).

The study of water governance requires landscape governance, which recognizes the complex relationships between water resources, land use, and socioeconomic issues within a landscape (Ghiotti, 2016). The integration of water management into landscape governance is essential for fostering development, needing a muli-stakeholder approach involving governments, local communities, private entities, and

* National Agronomic Institute of Tunisia (INAT), Tunis, Tunisia; National research Institute of rural engineering, Water and Forests (INRGREF), Tunis, Tunisia.
** National research Institute of rural engineering, Water and Forests (INRGREF), Tunis, Tunisia.
Corresponding author: leghrissi88@gmail.com

civil society organizations. A landscape is a socio-ecological system comprising both natural and human ecosystems (Scherr *et al*., 2013). Landscape and water governance (WG) are interconnected and mutually influential components of environmental management and sustainable development. Landscape governance embraces decision-making processes, resource management strategies, and actions that shape landscape use, conservation, and management. Within this broader context, WG focuses specifically on the management, allocation, and preservation of water resources (Zagt *et al*., 2017).

Effective landscape governance requires the development of transparent and inclusive decision-making processes, the enforcement of policies and regulations which protect natural resources, the provision of incentives for sustainable resources use practices and the recognition of rights and needs of local communities (Kusters *et al.*, 2020). However, the dissimilar values and interests of multiple stakeholders, at different scales, present challenges for landscape governance (Kozar *et al.*, 2014). At the same time, efficiently managing and harmonizing water resources use with food production needs an obvious examination of the roles played by local water management institutions and related development areas (Nabiafjadi *et al*., 2021). As highlighted by Knieper *et al.* (2010), a greater understanding of governance systems is critical for effective natural resource management. However, despite some limited success stories (Naustdalslid, 2014), the diversity of physical, legal, institutional and cultural contexts makes it difficult to derive universal lessons or recommendations (López-Gunn, 2003; Jia and Li, 2021; Shiferaw *et al*., 2023).

The landscape governance in rural areas of Tunisia is marked by a decentralized management approach. This strategy aims to enhance sustainable development and improve resource management throughout participatory water management. Water decentralization in Tunisia has progressed through legislative reforms aimed at transferring management responsibilities from the central public institutions to local user associations. These associations, created to oversee irrigation districts, serve as intermediate structures that promote participative and autonomous management of water resources. Despite their supportive role, their effectiveness is often limited by financial, technical, and organizational constraints, reflecting an ongoing shift away from centralized control towards more localized, shared management systems (Al Atiri, 2005; Bachta and Zaibet, 2006). After decades of decentralization and transfer of water resource management to users' associations (GDAs), the limitations of this participative approach – integrating users into irrigation resource management – have become evident and face significant challenges (Ben Nasr and Bachta, 2018). The main issue with the (GDAs) lies in their limited capacity to effectively manage water resources, largely due to insufficient financial, technical, and organizational resources. Their performance remains poor, partly because of stakeholders' capacities to collective management, water shortages, irrigation quotas, and non-compliance with governance regulations (MAHRF, 2021, 2023). The problem of regulation enforcement is a critical challenge facing policymakers, managers, and academics across the world. This lack of effective governance and institutional frameworks to manage and regulate groundwater use can make it challenging to implement sustainable resource management strategies (Molle and Berkoff, 2007). Weak governance systems often lead to landscape-level problems such as conflicts over water resources and social inequities. In fact, effective governance with commitment from key stakeholders is essential for broader water security (Ahopelto *et al*., 2023). Besides, lack of coordination between stakeholders often leads to unsustainable water management practices (Jariego, 2024), intensifying issues such as rural-urban migration, social problems, and poverty (Houdret, 2012).

The success of sustainable water management strategies often depends on the ability to navigate complex relations among a wide range of actors, both within and beyond the water sector (Santos *et al.*, 2023). Therefore, the proposed study applies a governance approach that considers all the issues in the landscape with the potential to inform the development of more in-

clusive and effective groundwater management policies in Tunisia.

This research paper aims to investigate the challenges of landscape governance related to water problems. The fieldwork involves a water stakeholders network analysis to identify key actors and examine collaboration patterns among these actors. Furthermore, the study area represents a transboundary region with deep-rooted social and local development challenges. The insights from this work can be replicated in similar regions across North Africa and the Middle East, where climatic and socio-economic conditions are similar to those found in Tunisia.

The remainder of this paper is structured as follows: it begins with a brief overview of landscape governance and water governance, followed by a detailed methodology section that outlines the methods used in the study. Next, the results section presents the key findings derived from the analysis, culminating in a conclusion that summarizes the main insights and discusses their implications for future research.

1.2. *Landscape governance and water governance concepts overview*

Landscape is an object of both social and natural-spatial conditions, with the benefit of targeting potential societal and environmental dimensions (Görg, 2007). The importance of a landscape approach is increasingly recognized (Reed *et al*., 2015). It can be defined also as an area identified by an actor for a given range of goals (Gignoux *et al*., 2011). The landscape is described in broader conceptual terms instead of just defining it as physical space (Farina, 2000), in fact, landscapes are multi-actors, multi-purposes, and multiscaled.

Landscape governance is a significant aspect of the landscape approach that refers to the multi-sector, multi-actors, and multi-level connection and spatial decision-making process at the landscape level (Van Oosten *et al*. 2014; Ros-Tonen *et al*. 2014). In fact, landscape governance is concerned with the institutional arrangements, decision-making processes, policy instruments, and underlying values by which multiple actors pursue their interests in sustainable food production, biodiversity, ecosystem service conservation, cultural and heritage preservation, and livelihood security, resulting in multifunctional landscapes (Kusters *et al*., 2020; Kozar *et al*., 2014). The nature of governance systems, their functioning, and effectiveness depend upon the interaction of institutions, organizations, and networks including across scales and levels (Kofinas, 2009). The purpose is to bring spatial decision-making relatively close to actors directly impacted by the spatial decisions made; and presuming that landscapes allow stakeholders negotiation and working on collective decisions about their space arrangement (Van Oosten *et al.*, 2014). Another fundamental governance question is about who decides, based on what principles, and who is involved and exempted from activities and incentives related to various features within the complex landscape management (Kozar *et al*., 2014). Water governance varies depending on the organizational governance system (Harlin and Kjellén, 2015). In fact, Water resources are embedded in social systems that are characterized by multi-stakeholders' management based on different values, perceptions and timeframes (Pahl-Wostl and Hare, 2004; Roux *et al*., 2010) Improved WG is path-dependent and needs to be linked to development goals in society (Harlin and Kjellén, 2015).

2. Material and method

The study employed a landscape governance approach to examine the complexities of groundwater management in the study area. This methodology aims to capture the different interactions between all relevant stakeholders within the broader landscape. Combining causal analysis and social network assessment allows a deep understanding of the complex groundwater management challenges within the studied landscape.

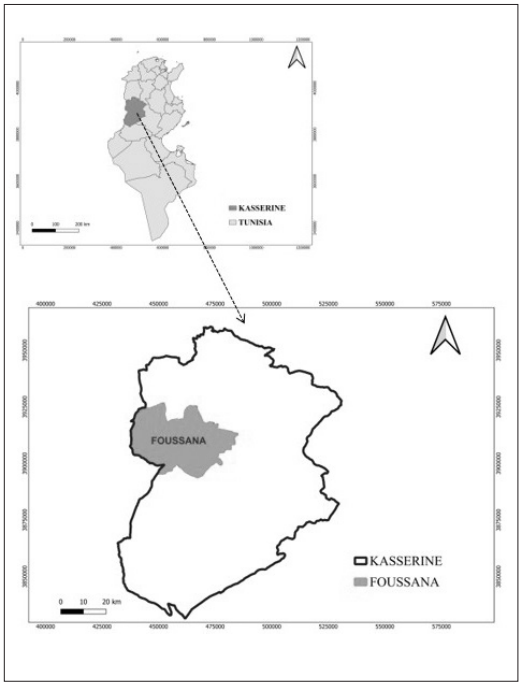
2.1. *Study area*

The data collection was conducted within the Kasserine governorate (Tunisia), with a specific focus on the Foussena delegation. The Kasserine governorate is strategically located in

the central-western part of Tunisia (Figure 1), covering 8,260 Km². Within this area, there are 360,000 hectares of farmland, 80,000 hectares of rangeland, and 304,046 hectares of forests and alfa grasslands (ODCO, 2017). The agricultural land covers 360,000 hectares of farmland, which has expanded significantly due to transformative changes in rural areas, resulting in notable advancements in the production of crops such as apples, tomatoes, and pistachios. This geographical region falls within the arid bioclimatic zone, characterized by an average annual precipitation of approximately 300 millimeters (M'Hamed *et al*., 2008).

This region is characterized by economic struggles and marginalization, and critical reliance on groundwater resources for irrigation and local social and economic development (ITCEQ, 2018). The agricultural sector holds a key role in the economy of the region. Public and private irrigated areas are estimated at 39,788 hectares (CTV Foussena, 2018). The number of GDAs in the Foussena region (Tunisia) is estimated at 18 irrigation GDAs and two mixed GDAs (irrigation and drinking water).

Figure 1 - Geographical localization of the study area.



The number of operators in the public irrigated areas is estimated to be 394 farmers, covering a total area of 747 hectares, of which 526 hectares are irrigated (CTV Foussena, 2018).

The exploitation rate of the deep sandstone aquifer in Foussena is estimated at 356.15%, while the Plio-Quaternary aquifer in the region has a rate of 353.75% (CRDA Kasserine, 2015). This assessment includes a total of 789 wells. As natural resources in Kasserine are depleted at an alarming rate, the agricultural sector faces a significant threat to the viability of small-holder farming and a substantial risk of job loss.

2.2. *System thinking Causal Loop Diagram (CLD)*

The analysis began with the creation of a causal loop diagram for this purpose. This tool was used to systematically map out water-related problems and challenges associated with the irrigated agricultural practices in the region. Causal relationships allow the identification of an initial set of stakeholders directly involved in groundwater management and utilization.

The CLD provides a system-level perspective on the key variables and feedback mechanisms that influence groundwater governance in the studied landscape (Bouchet *et al*., 2022; Van Lap *et al*., 2023). This conceptual model was used to identify water-related issues at the landscape level and identify all stakeholders, both directly and indirectly, involved in the management and decision-making processes within the landscape. The landscape under consideration is limited to the rural areas and the irrigated agricultural zone. Building upon this foundation, the subsequent governance network analysis was able to investigate deeper into the degrees of each actor's position, interests, and capacity to affect change. This multi-layered analysis, combining the system-level perspective of the CLD with the detailed stakeholder network analysis, provides a robust understanding of the groundwater governance challenges in the landscape. This approach sets the stage for the development of more effective and targeted interventions for sustainable groundwater management.

Table 1 - Importance of Social Network Analysis in Participatory Water Management and Good Governance.

Aspect	*Importance of SNA*
Stakeholder Identification	- SNA helps in identifying key stakeholders involved in water management, ensuring no group is marginalized (Prell, 2006).
Understanding Relationships	- Reveals patterns of relationships among stakeholders, which is critical for effective communication and collaboration (Wasserman and Faust, 1994).
Measuring Participation	- SNA provides insights into the level of stakeholder participation, allowing for a more inclusive decision-making process (Yang *et al*., 2011; Gatt, 2016).
Enhancing Inclusiveness	- Throughout connections' visualizing, SNA can identify underrepresented groups and promote strategies to include them in governance (Bulkely, 2005).
Facilitating Communication	- Improves channels for stakeholders to express opinions and constraints, fostering a higher level of societal inclusiveness (Biermann, 2007).
Supporting Decision Making	- Helps decision-makers understand specific community problems and perspectives, leading to more informed and equitable decisions (Allan and Rieu-Clark, 2010).
Securing Ownership	- Encourages stakeholder buy-in and ownership of decisions by recognizing their contributions and roles (Rouse, 2007).
Evaluating Influence	- Assesses the influence of different stakeholders on decision-making processes, helping to identify power dynamics (Yang *et al*., 2011).

2.3. *The analysis of water governance networks*

The study conducted a detailed Social Network Analysis (SNA) to examine the relationships, interactions, and power dynamics between all the identified stakeholders.

SNA is an empirical approach that allows for mapping and analyzing the connections and interactions between different actors, it provides a means to translate the conceptual idea of mutual connections into tangible, measurable terms (Table 2). This enables a deeper understanding of the collaborative dynamics at play within water governance frameworks (Jariego, 2024). Stakeholders network analysis helps to clarify the social factors that lead to governance outcomes (Nabiafjadi *et al*., 2021; Jariego, 2024). Visualization of social networks can be used to portray these networks concisely and easily (Arif, 2015). In this context, Rhodes defines governance as the fact of governing with and through networks (Rhodes, 2007). Network arrangements and relationships can boost the probability of social change and cooperation throughout natural resources governance (Prell *et al*., 2009). Moreover, using SNA offers a strong lens for viewing the WG socio-political process (Horning *et al*., 2016). Stein *et al*. (2011) demonstrated by analyzing WG in the Mkindo catchment in Tanzania, that the SNA is useful to objectively map collaborative SNs between actors affecting water flows directly or indirectly in the catchment (Stein *et al*., 2011). Environmental governance networks could be defined as a series of constant communication relationships between actors or stakeholders involved in resource management, and based on degrees of shared values, mutuality, and collaboration (Chaffin *et al*., 2016).

Table 1 highlights how SNA is helpful in promoting participatory management and good governance in water resource management, emphasizing its role in inclusiveness and effective decision-making.

To address the limitations of SNA in discerning the motivations behind the formation, functioning, and governance of networks over time, this research supplemented the SNA with qualitative methods (Rowley, 1997; Sørensen and Torfing, 2016). SNA alone is unable to fully capture the individual behaviors, attitudes, and beliefs that drive the evolution of networks, or provide answers to important questions about how and why networks are formed, institutionalized, and contribute to effective policy (Sørensen and Torfing, 2016) Therefore, this study combined interviews, documentation analysis, system thinking, and causal diagrams to triangulate the data and gain deeper insights into the network structure (Coviello, 2005).

Table 2 - Social Network Analysis Metrics and Interpretations.

SNA Metric	*Interpretation*	*References*
Density	Indicates how closely actors within a network are connected, reflecting overall group cohesion. It's calculated as the ratio of observed connections to the maximum possible connections. Useful for comparing the interconnectedness of different networks.	Wasserman and Faust, 1994
Degree Centrality	Measures the number of direct connections a stakeholder has to others. High degree centrality identifies active players good at mobilizing the network and bringing others together, often by diffusing information. While they have many ties, these ties can be weak, meaning they can spread information but might not exert significant influence over those they are tied to. It identifies actors extensively involved in direct relationships.	Freeman, 1979; Scott, 2017; Stein *et al*., 2011
Closeness Centrality	Measures how close a stakeholder is to all other stakeholders in the network, representing the average path length to all other actors. A high closeness centrality indicates an actor with fast access to all other nodes within the network, capable of quickly reaching others and disseminating information.	Rodrigues *et al*., 2006
Betweenness Centrality	Measures the extent to which a stakeholder lies on the shortest paths between other pairs of stakeholders. Actors with high betweenness centrality act as «brokers» or «gatekeepers,» controlling the flow of information and resources between different parts of the network. They are crucial for long-term planning by connecting disconnected segments, bringing diversity and new ideas. However, they may feel torn between different network elements.	Freeman, 1979; Wasserman and Faust, 1994; Prell *et al*., 2009; Stein *et al.*, 2011; Kim and Hastak, 2018; Huang *et al.*, 2019; Pérez *et al.*, 2021
Authority	A measure of a user's influence and capacity to disseminate information within a social or professional network, based on their position and interactions within the network structure.	Pérez *et al.*, 2021

2.4. *Data collection*

Fieldwork was conducted during the agricultural campaign 2019-2020 and updated in 2023, essentially through structured and semi-structured interviews. The selection process of stakeholders employed snowball sampling techniques (Pasikowski, 2024) which is a method of sampling that involves identifying new participants through referrals from existing participants after the initial research has begun. This research began with initial interviews with key informants from public agriculture agencies, specifically the CRDA and CTV. These informants provided a first list of actors involved in water management and identified potential relationships among them. This iterative process continued with subsequent interviews featuring stakeholders recommended by earlier participants. After employing the snowball sampling technique, we compiled an extensive list of actors. Subsequently, by identifying challenges and issues related to water management in the studied landscape, we refined our focus to include only those stakeholders who are directly or indirectly linked to water management. Simultaneously, a list of potential relationships and connections among the actors was developed.

The territorial extension unit (CTV) of Foussena directed its efforts towards engaging with GDAs, initiating the study with a pilot survey involving 30 farmers. This survey served to test the field research work and to complete the identification of relationships or links that farmers have with the stakeholders identified

Table 3 - Matrix of actor interactions.

		Actor 1	*Actor 2*	*Actor 3*	.....	*Actor n*
Actor 1		-	L*1	L4		
Actor 2			-	L6/L2/L1		
Actor 3			L1/ L4	-		L6/L3/L1
.....						
Actor n						-

in the landscape. Two types of structured interviews were conducted with the farmers. The first type consisted of five modules and took an average of 45 to 60 minutes per farmer. This interview covered five sections: demographic data, information related to the farm, management of water resources, the institutional framework, production costs, and the value of water. Additionally, interviews related to collecting social network analysis (SNA) data averaged about 15 minutes with each farmer. In total, 159 farmers in public irrigated areas managed by GDAs and 100 farmers in private irrigated areas were interviewed. Furthermore, 12 GDAs were consulted to identify existing challenges within the system.

Following the identification of stakeholders, a matrix of actor interactions (Table 3) was employed during each interview to examine the relationships and linkages among participants. Actor-linkage matrices are a widely used method for describing stakeholder interrelations (Biggs and Matsaert, 1999; Reed *et al*., 2015). In this approach, stakeholders are listed in the rows and columns of a table, creating a grid that allows for the description of interrelations using key terms.

2.4.1. *Data analysis and visualization: the Force Atlas 2 Model*

To visualize the network, we adapted the Force Atlas 2 algorithm. It is an improved version of the original Force Atlas algorithm, which is a force-directed layout algorithm used for graph visualization (Jacomy *et al*., 2014). The main goal of the Force Atlas 2 algorithm is to enhance the structure and readability of graph visualization. The algorithm works by simulating the physical forces acting on the nodes in the network, such as attraction and repulsion, to determine the optimal arrangement of the nodes. The attraction forces draw connected nodes closer together, while the repulsion forces push unconnected nodes apart, creating a more organized and readable graph layout. The model's algorithm uses the following equations to calculate the position and movement of nodes in the graph:

Repulsive force:

The repulsive force between two nodes i and j is calculated as:

F_rep = k_rep / d_ij^2

Where:

F_rep is the repulsive force.

k_rep is the repulsive force constant.

d_ij is the distance between nodes i and j.

Attractive force:

The attractive force between two connected nodes i and j is calculated as:

F_att = k_att * d_ij

Where:

F_att is the attractive force.

k_att is the attractive force constant.

d_ij is the distance between nodes i and j.

Gravity force:

The gravity force acting on a node i is calculated as:

F_grav = k_grav * m_i

Where:

F_grav is the gravity force

k_grav is the gravity force constant

m_i is the mass of node i

Displacement:

The displacement of a node i in the current iteration is calculated as:

d_x = F_x / (m_i + 1)

d_y = F_y / (m_i + 1)

Where:

d_x and d_y are the displacements in the x and y directions, respectively

F_x and F_y are the total forces acting on the node in the x and y directions, respectively

m_i is the mass of node i

The total force acting on a node i is the sum of the repulsive, attractive, and gravity forces:

F_x = Σ F_rep_x + Σ F_att_x + F_grav_x

F_y = Σ F_rep_y + Σ F_att_y + F_grav_y

The new position of the node i after the current iteration is calculated as:

x_new = x_old + d_x

y_new = y_old + d_y

These equations are applied iteratively until the graph layout converges or a certain number of iterations is reached.

3. Results and discussion

3.1. *The Causal Loop Diagram (CLD)*

3.1.1. *GDA-managed perimeters (public irrigated areas)*

CLD has helped identify the key actors involved, both directly and indirectly, in groundwater governance in the studied landscape. The CLD (Figure 2) represents in a systemic way the key issues related to water management in public irrigated perimeters in Tunisia, managed by the Agricultural Development Groups (GDA). It highlights the feedback loops that amplify or mitigate the problems of groundwater overexploitation in these perimeters.

The central loop shows how an "Insufficient supply of groundwater" in the irrigated perimeters leads to "Longer irrigation programs", thus generating "Dissatisfaction of farmers" which results in the digging of "Illegal private wells". This then aggravates the "Overexploitation of groundwater", closing the loop.

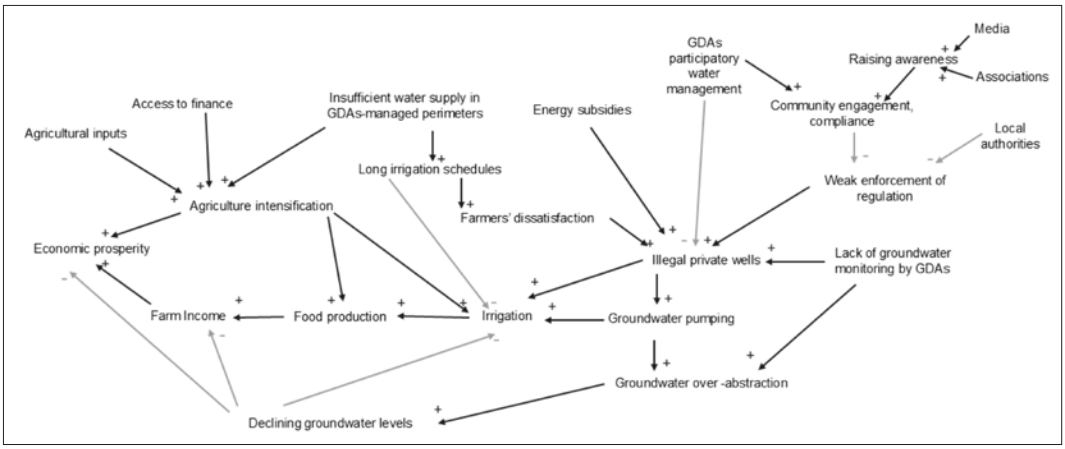
Other loops illustrate the impact of agricultural expansion, supported by subsidies and financial incentives, on the increase in "Demand for agricultural water", thus exacerbating the problem of insufficient water supply. However, it is important to note that the number of farmers who have benefited from financial incentives is not large, and most farmers have problems accessing financing, which hinders their access to technology and modernization of their farms.

The diagram also highlights the role of the media, local associations, and local authorities in raising awareness among farmers about the need to protect water resources, as well as the GDAs' ability to enforce regulations. These stakeholders can therefore play a significant role in breaking some of these negative feedback loops. The model emphasizes the importance of more efficient irrigation management, groundwater monitoring, and enforcement of regulations by the GDAs to reduce groundwater overexploitation in these public irrigation perimeters.

3.1.2. *Private irrigated areas*

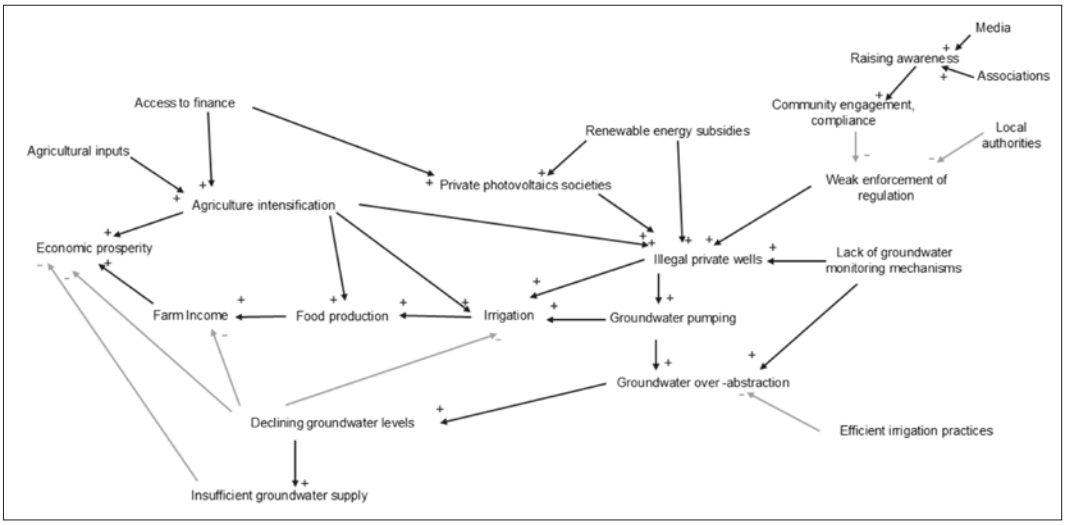
In the case of private irrigated areas in Tunisia, there are strict regulations in place that manage groundwater's use. Farmers are required to obtain authorization from the Ministry of Agriculture (MARHP) to dig wells deeper than 50 meters. However, the CLD (Figure 3) highlights the problem of "Illegal Private Wells" in these private irrigated perimeters, despite the regulatory framework. The CLD illustrates the complex interactions between distinct factors related to groundwater overexploitation in the studied landscape. The nodes represent the different elements of the system, while the arrows indicate the cause-and-effect relationships between these elements. At the core of the diagram is the problem of "Groundwater Overexploitation," which leads to a "Groundwater Level Decline". This decline in groundwater levels drives farmers to drill new wells, increasing their "Groundwater Pumping Capacity." This increased pumping capacity, in turn, fuels the overexploitation of groundwater, creating a positive feedback loop. The agricultural water demand and the expansion of agricultural land also contribute to the overexploitation of groundwater. Crop irrigation supports food production, which in turn contributes to economic prosperity and farmers' incomes.

Figure 2 - Causal loop diagram (CLD) of water governance in public irrigated areas (GDA-Managed Perimeters).



Source: the Authors, 2024.

Figure 3 - Causal loop diagram of water governance in private irrigated areas.



Source: the Authors, 2024.

Factors such as inefficient irrigation practices (Leghrissi *et al*., 2023), lack of groundwater monitoring, and weak enforcement of regulations, also contribute to the overexploitation of groundwater.

Farmers who have illegal, unauthorized wells are not eligible to receive public subsidies from the Agricultural Investment Promotion Agency nor can they access funding from national banks. Crucially, these farmers are also unable to obtain the necessary permits for the electrification of their wells. As a result, some of them have resorted to installing private photovoltaic energy systems to power their unauthorized groundwater extraction, rather than connecting to the electrical grid. Thus, the installation of photovoltaic systems is indirectly linked to the illegal installation of wells, which further aggravates the groundwater overexploitation problem. The prevalence of these illegal wells, coupled with the "Weak Enforcement of Regulations" by local authorities, exacerbates the issue of "Groundwater Overexploitation" in the private irrigated perimeters.

This CLD highlights the complex and interconnected nature of the factors contributing to

Table 4 - Stakeholders description.

Stakeholders	*Description/ Roles*
Regional Commissariat for agricultural Development (CRDA)	• Agricultural planning, implementation, monitoring and evaluation, water resources management.
Territorial Extension Unit (CTV)	• Support farmers, Farmers extension, conduct field visits; coordinate with the boroughs of the CRDA and technical services.
Farmers (F)	• They are the main users of groundwater for irrigation in the perimeters. • Their dissatisfaction with water shortages leads them to dig illegal private wells, exacerbating groundwater overexploitation.
Agricultural Development Groupings (GDA)	• Community based organizations (CBO). • They manage the irrigation water supply in the public irrigated perimeters. • Their ability to enforce regulations and monitor groundwater use is essential to address the overexploitation issue.
Farm Input Providers (FIP)	• They supply farmers with agricultural inputs like seeds, fertilizers, and equipment. • Their pricing and availability of inputs can influence farmers' decisions and water use.
Local authorities	• They play a key role in enforcing regulations and supporting the GDAs in their water management efforts. • Their involvement can help break the negative feedback loops related to illegal well-digging and overexploitation.
Local Associations (ASSO) *Media*	• They can raise awareness among farmers about the importance of sustainable groundwater management. • Their engagement can influence farmers' behavior and support the GDAs' efforts.
Local People's Representatives (PR)	• The Assembly of People's Representatives is where laws are discussed and approved through voting. • Elected representatives in each governorate relay local issues and challenges, ensuring that the concerns of their constituents are addressed. • These representatives act as intermediaries between the population and government institutions, promoting citizen participation and enhancing governance.
Electricity Utility (STEG)	• The Tunisian Company for Electricity and Gas is the exclusive electricity provider in the country. • To submit a request for electrification of a well, an authorization for drilling from the CRDA is required, along with a tax declaration, indicating that the farmer is following tax regulations.
Public Banks (BNA, BTS)	• Agricultural financing

groundwater overexploitation. It highlights the importance of a systemic approach to addressing this complex environmental issue.

3.2. *The analysis of water governance networks*

3.2.1. *Public irrigated areas (GDA-managed irrigated perimeters)*

**) Graph level index: Network statistical description*

The network has a total degree of 14,556, indicating a prominent level of overall connectivity among the stakeholders. The weighted degree of 14,556 suggests that the strength of the connections between actors is also substantial. The network diameter of 5 implies a relatively short path length between the most distant nodes, reflecting a well-connected and compact network structure.

The network density of 0.078, interpreted as a directed network, suggests a moderate level of overall connectedness within the system. This indicates that while there are many linkages between stakeholders, there is still potential for greater integration and collaboration.

The modularity score of 0.247 reveals the presence of distinct subgroups or communities

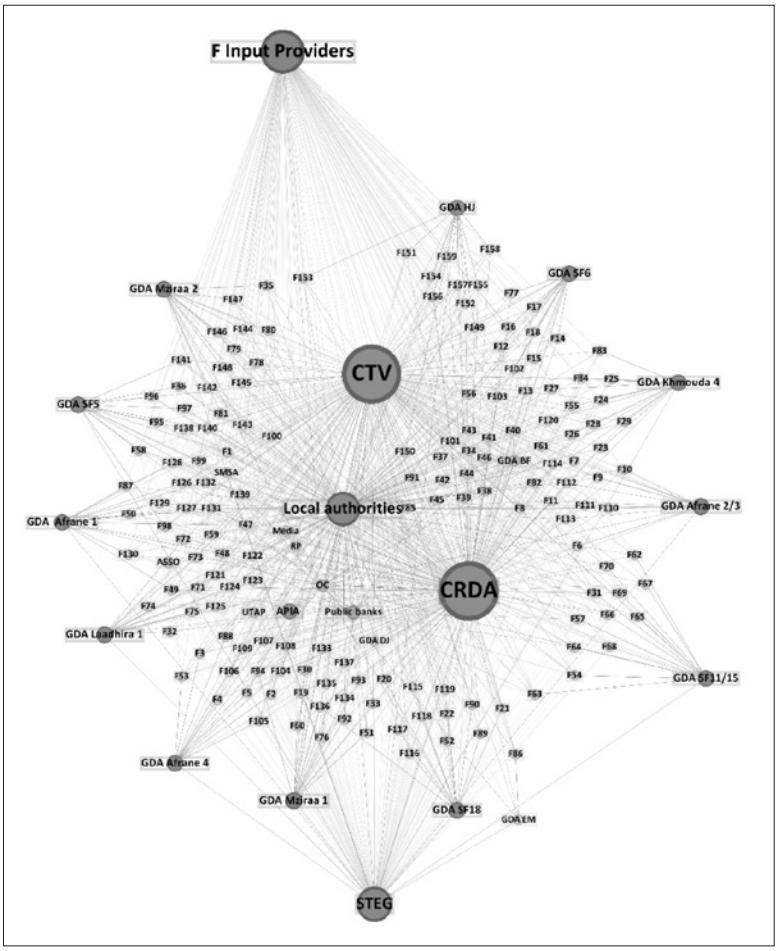


Figure 4 - Stakeholders mapping in public irrigated areas in the study zone.

within the network. This suggests that there are clusters of stakeholders with stronger internal ties compared to their connections with other parts of the network. These modular structures may reflect differences in interests, priorities, or organizational affiliations among the actors.

The high statistical value of 3959.574 suggests an important level of statistical significance in the network structure, indicating that the observed patterns are unlikely to have arisen by chance. This provides confidence in the validity and robustness of the network analysis findings.

**) Stakeholders' positions*

The network analysis (Figure 4) reveals stark differences in the degree centrality of the different stakeholders, highlighting their disparate levels of influence and involvement. The Territorial Extension Unit (CTV) and the Regional Commissariat for Agricultural Development (CRDA) emerge as the most central and well-connected actors, with degree values exceeding 500. These highly influential stakeholders play a crucial role in information sharing, coordination, and decision-making processes within the network. Local authorities also exhibit a high degree of 344, positioning them as another core group of stakeholders with substantial connectivity and potential to drive collective action. In contrast, the involvement of Agricultural development Groupings (GDA) is more nuanced. The active GDAs have a medium-range degree, between 32 and 72, suggesting they are moderately well-connected and play an important, but not necessarily central, role in the network. However, the non-active GDAs have significantly

lower degree values, ranging from 9 to 11, indicating a peripheral position and limited integration with the other stakeholders. This disparity in the degree of GDA involvement highlights the need to better understand the factors influencing the varying levels of participation and influence of these community-based organizations in groundwater governance. The Farmers' Union, media, and local people's representatives have low degree values, suggesting they occupy more peripheral positions and may be less integrated into the broader network.

The centrality of the CTV and CRDA is highlighted also by their closeness centrality values of 522 and 521, respectively. This indicates that they have the shortest path lengths to all other stakeholders in the network, suggesting they are in a prime position to access and disseminate information, coordinate activities, and exert major influence over the total governance processes. The local authorities, with a closeness centrality (CC) of 344, also have a highly central position in the network. This highlights their strategic importance as intermediaries and potential facilitators of collaboration among identified stakeholders.

The farm input providers (CC=246), Electricity utility (CC=184), and public banks (CC=65) demonstrate moderately central roles, while the APIA (CC=47), farmers' union (UTAP) (CC=26) exhibit lower closeness centrality. This suggests these stakeholders may have more limited direct access to the broader network and may need to rely on the more central actors to effectively participate in and influence groundwater governance. The civil society stakeholders (Asso) (CC=7) and local people's representatives (RP) (CC=7) have the lowest closeness centrality scores, indicating their peripheral position in the network and potential challenges in directly shaping the overall governance dynamics. Regarding the GDAs, the active GDAs have closeness centrality values ranging from 32 to 57, suggesting a moderate level of centrality and integration. However, the non-active GDAs have significantly lower scores, between 9 and 11, highlighting their more isolated and marginalized status within the network.

The centrality values of the active and non-active GDAs suggest challenges in maintaining their active engagement and community-level representation in the water governance system, underscoring the need to address this imbalance by empowering the peripheral actors, fostering inclusive multi-stakeholder engagement, aligning incentives, and promoting transparency and accountability to enhance collective action and improve the overall water governance.

The interpretation of the authority values reveals a groundwater governance network characterized by a significant power imbalance, where the Territorial Extension Unit (0.983), the Regional Commissariat for Agricultural Development (0.983), and the Electricity Utility (1.0) wield substantial power and influence as central decision-makers, while the local authorities (0.980) and farm input providers (0.931) also hold considerable sway, but the public banks (0.488), agriculture investment promotion agency (0.621), associations (0.380), farmers' union (0.385), media (0.519), and people's representatives (0.512) possess relatively lower authority values, suggesting that their participation and influence in the governance system may be limited; moreover, the authority values of the groundwater development associations (GDAs), ranging from 0.35 to 0.391, indicate that these community-based organizations are not fully empowered or integrated into the decision-making processes, underscoring the need to address this power imbalance by empowering the less influential stakeholders, fostering more inclusive and collaborative decision-making, and ensuring that the concerns and needs of all affected communities are adequately represented and considered to enhance collective action and improve the overall water governance.

The key points highlighting the marginalization of the GDA include their low centrality metrics, minimal authority and power, and limited brokerage and gatekeeping role within the overall governance network. Specifically, the GDA had low degree centrality, closeness centrality, and eccentricity compared to the highly central actors like the CTV, CRDA, and Local Authorities. This suggests that the GDA are not well-connected and integrated within the overall network, limiting their ability to access and

disseminate information, as well as to quickly coordinate with other stakeholders.

This lack of meaningful participation and influence of the GDAs, which represent the water users and community-level stakeholders, is a significant barrier to achieving true collective action and participatory water management. The findings suggest that the groundwater governance system is not adequately inclusive and responsive to the needs and perspectives of the end-users. To address this gap, the governance framework should be reformed to foster greater integration and empowerment of the GDA and other marginalized stakeholders. This could involve establishing formal mechanisms for shared decision-making, building the capacity of the GDA, and redistributing power and authority more equitably among the diverse set of actors. Only then can the groundwater governance system truly become participatory and effective in managing this critical resource.

The hierarchical network structure and uneven distribution of power may inhibit the development of truly collaborative and inclusive governance approaches, as the peripheral actors, such as the media, local people's representatives, and non-active GDAs, may have limited opportunities to participate in and shape the governance processes, undermining the legitimacy and effectiveness of the overall governance system. Feiock (2013) explored the impact of fragmented authority and externalities on collective action in governance, and he sheds light on the cooperation dynamics among stakeholders and emphasizes the challenges arising from fragmented governance.

The groundwater governance system should adopt an approach that leverages the key role of GDAs to enhance collective action and water governance. Empowering the GDAs, which are peripheral yet crucial actors, can help address the challenges posed by the hierarchical structure and irregular distribution of power by facilitating meaningful participation, decentralizing decision-making, and fostering collaborative governance. A study conducted in a similar context, in Spain, demonstrates that Water User Associations play a critical role in fostering cooperation among stakeholders, thereby enhancing the effectiveness of groundwater management practices (López-Gunn, 2003). This finding aligns with the importance of collective action in sustainable water management, reinforcing the need for collaborative governance models. In fact, better groundwater management requires multi-stakeholder approaches that involve local actors to develop shared visions and improve governance frameworks (Mekki *et al*., 2022).

Strengthening the synergy between public agencies, such as the CRDA, CTV and the GDAs can further strengthen the adaptive capacity and resilience of the groundwater governance system, this finding aligns with previous research indicating that structural and institutional arrangements significantly influence collective action effectiveness in water user associations (Bassi *et al*., 2010; Indranil De *et al*., 2022). Moreover, engaging the media as a central actor can increase public awareness, share critical information, and reduce information asymmetries, thereby enhancing the legitimacy and accountability of the governance processes and promoting more inclusive and equitable groundwater management.

The groundwater governance system must adopt an integrated approach that leverages the influential roles of specific stakeholders, including the central private sector actors such as the farm input providers. Informed by the SNA, this strategy recognizes the critical position of the farm input providers and the need to regulate their input pricing and industry norms to align with sustainable groundwater management. Aligning the incentives of all stakeholders, including the farm input providers, to promote sustainable practices is key to enhancing the overall adaptive capacity and resilience of the groundwater governance system.

4. Conclusions

The study on groundwater governance stakeholder networks reveals a hierarchical structure characterized by an uneven distribution of power and influence. Key actors occupy central positions, while civil society representatives, local community members, and some inactive groundwater associations remain on the periphery. This concentration of power poses significant chal-

lenges to the effectiveness and resilience of the groundwater governance system, limiting the diversity of perspectives necessary for addressing emerging challenges. A key limitation of the applied method is that using organizations as nodes may overlook the influence of individual actors within these entities, potentially missing important nuances in collaboration dynamics. Additionally, this approach might oversimplify the social complexity by focusing solely on organizational structures, thereby ignoring informal or less structured relationships that also impact water governance.

To enhance the governance of groundwater resources, several key actions are essential. First, developing more inclusive and collaborative governance approaches is crucial to actively engaging a broader range of stakeholders, particularly those currently marginalized within the network. Second, strategies must be implemented to redistribute influence and power more equitably, ensuring diverse viewpoints are integrated into decision-making processes. Third, intentional engagement of less connected actors, such as civil society organizations and local representatives, can harness their unique insights and experiences. Finally, leveraging the existing network structure to facilitate information flow and knowledge sharing among all stakeholders will help bridge the gap between central and peripheral actors.

Creating a more inclusive governance framework can significantly improve groundwater management policies. This approach is relevant not only for Tunisia but also for other North African and Middle Eastern countries facing similar water-related challenges.

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Key strategies to internationalization: The case of the Spanish olive oil industry

CLARA MARTOS-MARTÍNEZ*, MARTA MUÑOZ-GUARASA*, JUAN ANTONIO PARRILLA-GONZÁLEZ*

DOI: 10.30682/nm2505b
JEL codes: M16, M21, O13, Q17

Abstract

Olive oil is one of the most important products in the Spanish agri-food sector, with Spain accounting for 50 percent of world production. Despite Spain's leadership in global olive oil production, the sector faces significant challenges in commercialization, both domestically and abroad. This highlights the need to implement more effective international marketing strategies. This article therefore focuses on analysing the key internationalization actions of the Spanish olive oil industry. To that end, the Qualitative Comparative Analysis (QCA) method is used, applying the fuzzy set approach (fsQCA). The results show that for companies in the sector to internationalize they must: (1) have objective knowledge of the market and experience of other internationalization processes; (2) create international networks through relationships with prescribers, chefs and commercial distributors; (3) the founder must be innovative, proactive, proactive, have the autonomy and competitive aggressiveness to offer innovative products, and have commercial units abroad. It is also found that attending international trade fairs is not a key strategy for internationalization.

Keywords*: Agribusiness, Olive oil industry, International Orientation Strategies, Internationalization, Analysis of cases, Fs/QCA.*

1. Introduction

There are numerous positive effects of companies using exports as a way of internationalizing. From a macroeconomic perspective, it contributes to GDP and therefore economic growth and employment. From a microeconomic perspective, companies' access to foreign markets allows them to increase sales, diversify their client base and risk, avoid domestic competition, create economies of scale, and ultimately, grow and consolidate over time. Domestically, exporting firms also exert a positive influence by boosting direct and indirect employment, prompting an imitation effect in other companies, increasing innovation, raising workers' qualification levels, and so on.

The Spanish olive oil industry is of a traditional nature, largely consisting of small and medium-sized enterprises (SMEs), many of them family-owned. Furthermore, most of these companies are located in peripheral areas, such as Andalusia; or more specifically, the province of Jaén, which is the world's largest producer of ol-

* University of Jaén, Spain.
Corresponding author: cmartos@ujaen.es

ive oil. Spain has had problems exporting olive oil despite being the world's leading producer According to Mili and Bouhaddane (2018) there are a set of factors that condition the internationalization process of the olive sector and have led to a lower performance in the foreign market. These include: (1) the lack of marketing strategies and organization in the value chain; (2) the role of producers and marketers in providing a quality product (using appropriate phytosanitary products to guarantee the quality and traceability system) and preserving it throughout the chain; (3) exporters' implementation of new communication technologies and logistical improvements. The traditional trade barriers that this sector has presented need to be restructured in order to become more professional and market-oriented (López-Castro and Parrilla-González, 2024).

They therefore operate at a distance from the big markets. This set of features means that the industry has not substantially internationalized; as such, there is a need for research that helps companies to establish strategies that enable this process. All this, together with the scarcity of studies that pursue this aim, justifies the present study. Analysing the export activity of this industry is a task of vital importance in order to provide conclusions, guidance, resources and appropriate strategies to guarantee the success of olive oil companies and ensure the increased competitiveness of this economic activity (Parras-Rosa, 2022). Olive oil mills are beginning to respond to the demands and aspirations of a global world through internationalization (Parra-López *et al.*, 2016) and they are facing a unique opportunity to develop global initiatives that can harness the extraordinary richness of olive-growing.

In recent decades, the consumption of olive oil has undergone continuous growth worldwide and this oil is currently consumed on a regular basis in 164 countries (International Olive Council, 2023). However, olive oil consumption in the big producers, that is, Spain, Italy and Greece, still represents more than 42 percent of the global total, with a per capita consumption in these countries of 10.3 kg/year, 11.4 kg/year and 15.5 kg/year, respectively (Parras-Rosa, 2021). As indicated in an analysis of the olive oil food chain conducted by Parras *et al.* (2023) and endorsed by the Ministry of Agriculture, Fisheries and Food (2023), the olive oil industry faces marketing problems reflected in a decline in consumption in domestic markets, which necessitates the search for new markets, and, therefore, the creation and development of internationalization departments in olive oil companies.

Given the importance of the Spanish olive oil sector and its weight in the overall global production and consumption (Mielke, 2020) it is necessary for companies to carry out a series of internationally oriented strategies that represent an important solution when marketing olive oils in foreign markets, since these strategic orientations are considered decisive for internationalization (Dimitratos *et al.*, 2004; Jantunen *et al.*, 2005; Cadogan *et al.*, 2012; Hagen *et al.*, 2012; Boso *et al.*, 2012; Gerschewski *et al.*, 2015; Monferrer *et al.*, 2021), and companies perform better (Acosta *et al.*, 2018). Specifically, in this paper we focus on the following international orientation strategies: (1) international market orientation strategies (IMOS) (Cadogan *et al.*, 2012; Chung, 2012, Boso *et al.*, 2013). (2) International network orientation strategies (INOS) (Moen and Servais, 2002; Sullivan-Mort and Weerawardena, 2006; Weerawardena *et al.*, 2007; Ripollés *et al.*, 2012). (3) International entrepreneurship orientation strategies (IEOS) (Hagen *et al.*, 2012 Deutscher *et al.*, 2016; Pehrsson, 2016, Escandón-Barbosa *et al.*, 2016; Ferreras-Méndez, 2021). All of them have been identified as the most relevant for business internationalization (Acosta *et al.*, 2018, Martos-Martínez and Muñoz-Guarasa, 2020, 2021, 2023, 2024).

There is limited research on the internationalization of the olive sector. Mili and Rodríguez-Zúniga (2003) study the macro-factors that condition its global trade. Mili (2006) analyze olive oil marketing trends in traditional markets. Moral-Pajares and Lanzas-Molina (2009) examine the export dynamics of Andalusian olive oil companies. Moral-Pajares *et al.* (2015) focus on the relationship between the export efficiency of Southern European olive oil firms with websites. Mozas-Moral *et al.* (2016) study the favorable factors for the export of or-

ganic olive oil in Spain. Mili and Bouhaddane (2018) include the determinants and future strategies for the internationalization of Spanish olive oil from a value chain perspective. Cano-Rubio *et al.* (2021) delve into the internationalization strategies of olive oil mills.

López-Castro and Parrilla-González (2024) focus on offers, providing new perspectives on the factors that affect the marketing and sale of olive oil. Martos-Martínez and Muñoz-Guarasa (2021) study how four cases of companies in the olive oil sector can convert the advantages of the territory into competitive advantages in order to initiate a process of internationalization. In order to do so, they suggest that companies must achieve dynamic capabilities by following market-oriented strategies, networking and international entrepreneurship. Martos-Martínez and Muñoz-Guarasa (2023) use a combination of case studies and Comparative Qualitative Analyses to analyze whether four companies located in Jaén have followed the strategies of market orientation, networking and international entrepreneurship for their internationalization.

The aim of this study is to find out the key internationalization strategies and activities that companies in the olive sector should carry out, as well as their combination in the internationalization process. The aim is to determine which are the most appropriate in order to obtain the best results when developing the export activity of these companies. Furthermore, our research is particularly important in terms of contributing to the literature, there are clear gaps in the literature on the strategies that olive companies must follow to become international, as well as on whether the strategies of market orientation, networking and international entrepreneurship are applicable to companies in this sector in a generalized way, since previous studies (Martos-Martínez and Muñoz-Guarasa, 2021, 2023) have only studied them in a very small number of cases (four), all located in the south of Spain (Jaén). Therefore, this work is a contribution to the literature as it analyses the strategic actions and the most used combination of 246 companies located at national level.

In summary, this article sheds light on the strategies that companies in the olive sector should follow in order to become international, as well as the combination of key actions for the internationalization process. The analysis consists of the application of the Qualitative Comparative Analysis (QCA) method using the fuzzy sets approach (fsQCA) to establish the study variables. Thus, we include the exporting companies that make up the olive oil sector that the SABI (Iberian Balance Sheet Analysis System) database has available.

Thus, the present study, after this introduction, presents a brief analysis of the olive oil industry at national and international level. Subsequently, a theoretical review is carried out, taking as a starting point the theory of resources and capabilities, as well as the model of dynamic capabilities. Next, the methodological section explains the application of the Qualitative Comparative Analysis (QCA) method, using the fuzzy sets (fsQCA) approach to establish the study variables. The results are interpreted through a discussion and linked to our research objective, and we also note some practical implications. Finally, we set out a series of conclusions related to the necessary implementation and combination of internationally-oriented strategies in the olive oil industry as a key solution to the issue of commercializing this product in foreign markets.

2. Analysis of the olive oil industry

In some countries, such as Spain, Italy, Greece, Tunisia and Morocco, olive oil production is an important economic activity and has experienced growth in recent years. In addition, other countries such as Argentina, Australia and the United States have begun to produce substantial quantities of olive oil (EXTENDA, 2022). Equally, the rise in demand for olive oil has prompted greater investment in technology and an improvement in production processes, which has enabled greater production efficiency and a reduction in costs (Cubillo-Cobo, 2022).

Spain is the world's leading producer of olive oil, with an average annual production of about 1.5 million tonnes, representing approximately 50 percent of global production, followed by Italy as the second largest producer, and then Greece and Tunisia (Ministry of Agriculture, Fisheries and Food, 2023).

According to IOC estimates, in the 2022/2023 season, global production of olive oil stands at around 2.73 million tonnes, while in the previous season it was 3.72 million, which represents a decrease of 19.7 percent. In the case of imports, Spain and Italy are identified as the leading countries in the European Union, with increases of 38.6 percent and 32.2 percent, respectively, relative to the 2021/2022 season.

In the case of exports in the 2022/2023 season, France registered a decline of 63.9 percent compared to the 2021/2022 campaign, followed by Spain with a drop of 35.8 percent, and Italy with 20.9 percent, while in Greece the figure has grown by 14.3 percent. Globally, there has been a 16.6 percent decrease in exports, which can be attributed to low levels of entrepreneurial initiative or difficulties in marketing the product. This, together with climatic factors such as droughts or frosts, and consumers' sensitivity to the variation in olive oil prices at the source, calls for further research and the development of internationalization strategies.

In terms of consumption, International Olive Council (2023) shows that global consumption in the 2022/2023 season is 5.7 percent lower than in the 2021/2022 season. Moreover, Spain heads up the list of countries that have seen a decline in this consumption, with a volume 27.6 percent lower than the previous season, whereas in other countries such as France and Portugal, the reduction is only 5.1 percent and 3.2 percent, respectively. Taking into account the fact that there is a wide range of consumption in olive oil producing areas such as the Mediterranean Basin and that this consumption is in continuous decline, as indicated by Yangui (2022), it is essential to get back on track and develop key marketing strategies for this product through the internationalization of olive oil producing companies. The focus needs to be on new markets, especially given the opportunities that this product offers in terms of its nutritional benefits and its flavour (International Olive Council, 2023).

In this regard, key internationalization strategies are essential when developing these olive oil businesses and as an opportunity for encouraging growth and generating added value in olive oil producing areas.

Focusing on the research on internationalization in the olive oil industry, Mili and Rodríguez-Zúñiga (2003) explore the new economic context in which international olive oil marketing strategies are framed. They discuss the macrofactors that condition its trade on a global scale, examine the main changes in market regulation and the trend in global supply and demand for products.

Mili (2006) analyzes the current and expected trends in olive oil marketing in non-traditional markets. To that end, he investigates: (1) the justifications for the need to foster the international expansion of olive oil outside the producer markets, and (2) the means of access to markets and marketing strategies. Moral-Pajares and Lanzas-Molina (2009) study the export dynamics in which Andalusian olive oil companies play a role, describe the behaviour of the global demand for virgin olive oil, and analyze the volume, value and distribution by country of olive oil exports from Andalusia in the period 1995-2005. Based on the information obtained, they study the conditions in Andalusia that have shaped the commercial activity of its olive oil companies abroad.

Moral-Pajares *et al.* (2015) analyze the relationship between exports and efficiency in Southern European olive oil companies with websites in 2012, investigating the effects of companies' age, export attitude, percentage of output sold abroad, website quality, and use of online commercial transactions on the companies' efficiency The results confirm that the exporting companies are more efficient than the non-exporters.

Mozas-Moral *et al.* (2016) study the organic olive oil industry in Spain. As a result of their comparative analysis they identify factors that are favourable for the exportation activity of firms in this industry: the manager's qualifications, specifically a university education; selling the product through the corporate website; a knowledge of online markets; and a presence in online social networks. Medina-Viruel *et al.* (2016) conduct an in-depth exploration of export decisions in the Spanish organic olive oil industry. They analyze the training of those in charge, the legal form, the use of ICT and the probability that the organic olive oil of Spanish companies can be sold abroad.

Mili and Bouhaddane (2018) study the determining factors and future strategies for the internationalization of Spanish olive oil from the perspective of the value chain. Their study thus helps address the concern about how to enhance internationalization to strengthen the industry's competitive position in non-traditional markets. Among other findings, the results reveal the need to make structural and organizational changes, and to develop appropriate marketing and promotional strategies with public institutions. Cano-Rubio *et al.* (2021) delve into the internationalization strategies of olive oil mills, which are centred around social capital and developed within the context of the family business. Their study does not include the conditions for these companies to become international; that is, it does not address the strategies that companies must follow to enter the foreign market.

We find studies that identify a positive relationship between IMOS, INOS and IEOS strategies and internationalization; for example, the study by Martos-Martínez and Muñoz-Guarasa (2021) examines how olive oil companies can convert the comparative advantages of their territory derived from the olive grove (culture and tradition, among others) into competitive advantages with which to rapidly internationalize and be Born Global (a firm that has internationalized within three years of its creation and that obtains a minimum of 10 percent of its revenues from foreign sales). They carry out an analysis of four cases of exporting companies (two Born Globals and two non-Born Globals) in southern Spain (Jaén). They include IMOS, INOS and IEOS in their analysis, as well as human, organizational, relational and technological capital. Their study does not indicate the actions that are most commonly used by the exporting companies of the olive oil industry in the internationalization process. In the present study, however, we analyze the combination of key actions within the IMOS, INOS and IEOS strategies that are most commonly used by companies in the olive oil industry to internationalize, regardless of when they begin their international expansion.

Martos-Martínez and Muñoz-Guarasa (2023) explore whether companies have implemented IMOS, INOS and IEOS and have acquired dynamic capabilities centred on knowledge, networks and innovation, as measured by their intellectual capital (human, relational and technological capital). In doing so, they study the determinants of the internationalization of four olive oil companies (two Born Globals and two non-Born Globals) that sell premium Extra Virgin Olive Oil (EVOO) (the highest quality olive oil). The companies are based in Jaén (the province with the highest production in the world). Their analysis is based on a combination of methods: a case study and QCA. However, the contribution made by the present study is that we analyze 246 companies located throughout Spain to identify the key actions undertaken in order to embark on the internationalization process. We also identify the combinations of actions that have been decisive for olive oil companies to begin their foreign market entry.

3. Key strategies for internationalization

One of the factors that can influence the internationalization of firms is the strategies they implement to adapt their business to the volatile foreign market environment (Falahat *et al.*, 2018). Strategic orientation determines firm behavior and is rooted in a set of values that guide the development of a business strategy. All of this facilitates the critical thinking of the firm to survive and thrive in a more competitive global marketplace (Caballero and Cavusgil, 2004).

Strategic orientations determine how the firm will adapt and position its internal resources, capabilities and activities and their combinations, both to deflect threats and to take advantage of opportunities present in an external environment (Venkatraman, 1989; Teece *et al.*, 1997). Thus, our starting point is the theory of resources and capabilities (Penrose, 1959), which implies that the differential endowment of organizational resources is an important determinant of strategy and performance. Resources include assets, capabilities, information, information, knowledge, technologies, etc., controlled by the firm that enable it to devise and implement strategies that improve its effectiveness and gain a differential advantage in foreign markets (Wernerfelt, 1984; Collis, 1991; Porter, 1991). This theory helps to

explain how strategic approaches can serve as important advantages in the international activities of firms (Knight, 2001).

Teece *et al.* (1997) highlight the importance of the evolution of resource and capabilities theory leading to the dynamic capabilities model, which focuses on a firm's ability to adapt and respond effectively to changes in its business environment. This model suggests that help firms flexibly manage and leverage resources for competitive advantage. Thus, firms that are able to develop and effectively deploy their dynamic capabilities are more likely to succeed in their internationally oriented strategies. This is because these capabilities enable them to adapt quickly to changes in the global environment, identify opportunities in foreign markets and manage the risks associated with internationalization.

In order to carry out the internationalization process, firms not only use their resources and capabilities, but also develop dynamic capabilities, they perform better in the international arena if they combine different strategic orientations (Laukkanen *et al.*, 2013; Paul *et al.*, 2017). Thus, we focus on: (1) international market orientation strategies (IMOS) (Boso *et al.*, 2013; Cadogan *et al.*, 2003; Chung, 2012). (2) International network orientation strategies (INOS) (Moen and Servais, 2002; Sullivan-Mort and Weerawardena, 2006; Ripollés *et al.*, 2012; Weerawardena *et al.*, 2007). (3) International entrepreneurship orientation strategies (IEOS) (Deutscher *et al.*, 2016; Ferreras-Méndez, 2021; Pehrsson, 2016, Escandón-Barbosa *et al.*, 2016; Hagen *et al.*, 2012). All of them have been identified as the most relevant for business internationalization (Acosta *et al.*, 2018, Martos-Martínez and Muñoz-Guarasa, 2020, 2021, 2023). Furthermore, international market, network and entrepreneurship orientation strategies can enable firms to possess competitive and dynamic advantages (Martos-Martínez and Muñoz-Guarasa, 2021), which facilitates the allocation of resources (He *et al.*, 2020) for higher international performance.

Therefore, in this work we try to verify the combination of strategies that are necessary for the internationalization of the olive sector, as well as to know the key actions that these companies have followed to start their expansion into the foreign market. In this way, we will reflect on determining strategies to guide companies in the sector to become international. Specifically, we focus on a set of strategies oriented towards internationalization from the perspective of the market, the network and entrepreneurship. On this basis, six propositions are put forward and tested through the methodology centred on QCA analysis.

International market orientation strategies (IMOS)

These strategies are customer-centric, and are coordinated and planned in relation to the, market knowledge can influence the adaptation of the product to the customer's needs, based on the information obtained about the size of the market, product characteristics, existing infrastructures, working conditions, type of currency or financial transactions (Zakery and Saremi, 2020). Implementing IMOS entails attaining objective knowledge of the foreign market (for example, through market studies), as well as knowledge drawn from the experience that the founder and/or the head of exports may have of participating in previous internationalization processes (for example, knowledge of customers, markets, competitors, institutions, etc.); as such, companies that wish to internationalize should review their employees' experiential knowledge of foreign markets, since it influences and improves market orientation (Faroque *et al.*, 2021). All this makes it possible to adapt the product to the needs, tastes and demands of potential customers. In line with the theoretical approach, companies that develop internationally with experience in internationalization thanks to the export initiatives belonging to any external promotion institution. For example, among the institutions supporting internationalisation, we name the Spanish ICEX[1]-Next programme aimed at supporting internationalisation or EXTENDA-An-

[1] ICEX: Spanish Institute of Foreign Trade, the national public agency dedicated to promoting Spanish companies' export activity.

dalucía export and foreign investment,[2] will be developing initiatives oriented towards the international market (IMOS). The large amount of data gathered about international customers, competitors and potential partners should be leveraged by companies seeking an internationalization strategy (Reimann *et al.*, 2022).

IMOS are therefore necessary for the internationalization of olive oil companies. In line with the above arguments, we put forward the following propositions:

P1: To be international, companies in the olive oil industry need to have managers with international experience (IMOS1).

P2: To be international, companies in the olive oil industry need to participate in internationalization support programmes provided by public foreign trade promotion agencies (IMOS2).

International network orientation strategies (INOS)

According to Kurniawan *et al.* (2020), networking allows companies to acquire, create and share knowledge, and establish and consolidate strategic partnerships with key stakeholders, including customers; it also allows them to rapidly attain information and skills, which consequently makes them strategically agile, as they are well positioned within the core of their strategic network. Attendance at international trade fairs is especially important for acquiring knowledge, experience and information. Not only do companies establish contacts at trade fairs, but they also gain direct knowledge of the tastes of customers and distributors, which allows them to add value to the product on offer. The socializing that occurs at trade fairs plays an important role in building and developing relationships (Gopalakrishnan *et al.*, 2021; Mendonça *et al.*, 2022).

Therefore, INOS are necessary for the internationalization of olive oil companies. In line with the above arguments, we put forward the following propositions:

P3: To be international, companies in the olive oil industry need to create networks with brand advocates, chefs and commercial distributors (INOS1).

P4: To be international, companies in the olive oil industry need to attend international trade fairs (INOS2).

International entrepreneurship orientation strategies (IEOS)

These are the strategies centred around the innovative and entrepreneurial spirit of the founder and his or her creative capacity (Daengs and Asep, 2020). The propensity to innovate, the attitude towards risk and proactivity affect progress in the early stages of company growth (Zahoor and Lew, 2022) and in the search for opportunities (Silva *et al.*, 2021). As such, the implementation of IEOS becomes a conduit for the company to achieve the competitive advantages needed for internationalization, since innovative behaviour allows it to offer new products/services and capabilities ahead of its competitors (Dias *et al.*, 2021; Zahoor and Lew, 2022).

Therefore, the founder must have the following characteristics: (1) autonomy, referring to the independence and freedom to conceive an idea and carry it to a conclusion; (2) innovativeness, which is the tendency to produce and support different ideas, novelty, experimentation and creative processes that can give rise to a variety of products, services or technological processes that in turn can facilitate the internationalization process, such as the creation of ecological products to break into new markets; (3) proactiveness, which is a forward-looking perspective that accompanies an innovative activity and allows the founder to see new means and ends before others do; (4) proclivity, referring to the inclination to enter foreign markets, which is associated with the founder's values; and (5) competitive aggressiveness, which is the propensity to successfully enter the international market while challenging competitors, for example, engaging in entrepreneurship and developing international business by opening commercial offices and new locations in other countries (Kreiser *et al.*, 2002).

[2] EXTENDA-Andalusia Export and Foreign Investment: Andalusian public company for the promotion of foreign trade.

Table 1 - Keys to business internationalization.

Key strategies	*Author/Authors*	*Brief description*	*Variables*
IMOS	Andreou *et al*. (2020) Daengs and Asep (2020) Zakery and Saremi (2020) Kamarulzaman *et al.* (2021) Faroque *et al*. (2021) Kalil-Reimann *et al*. (2022)	Managers and/or head of internationalization having experiential knowledge	Managers with experience of internationalization
		Objective knowledge of the international market	Participation in internationalization support programmes (public foreign trade promotion agencies,* such as ICEX-Next in Spain)
INOS	Kalafsky and Gress (2020) Kurniawan *et al*. (2020) Sanyal *et al.* (2020) Kryeziu *et al*. (2021) Mendonça *et al*. (2022)	Creation of international networks	The olive oil company has brand advocates, chefs, international distributors
		Attendance at international trade fairs	The olive oil company attends international trade fairs
IEOS	Paul and Rosado-Serrano (2019) Zahoor and Lew (2021) Dias *et al*. (2021) Silva *et al*. (2021) Forcadell and Úbeda (2022)	Characteristics of the founder: innovation (offering innovative products)	Offer innovative products (for example, organic EVOO or related to sustainability)
		Characteristics of the founder: proactiveness, proclivity, competitive aggressiveness	International business units as an example of entrepreneurship (new commercial offices to develop the brand abroad)

Source: Own elaboration.

** Public foreign trade promotion agencies: ICEX-Spain, export and investment (at national level). An example would be EXTENDA-Andalusia, export and foreign investment (at regional level). These agencies help companies by offering information, training and internationalization support programmes. Henceforth they will be referred to as ICEX and EXTENDA.*

IEOS are therefore necessary for the internationalization of olive oil companies. In line with the above arguments, we put forward the following propositions:

P5: To be international, companies in the olive oil industry need to offer innovative products (for example, organic EVOO or sustainability-related products) (IEOS1).

P6: To be international, companies in the olive oil industry need to have commercial offices abroad as a form of entrepreneurship (IEOS2).

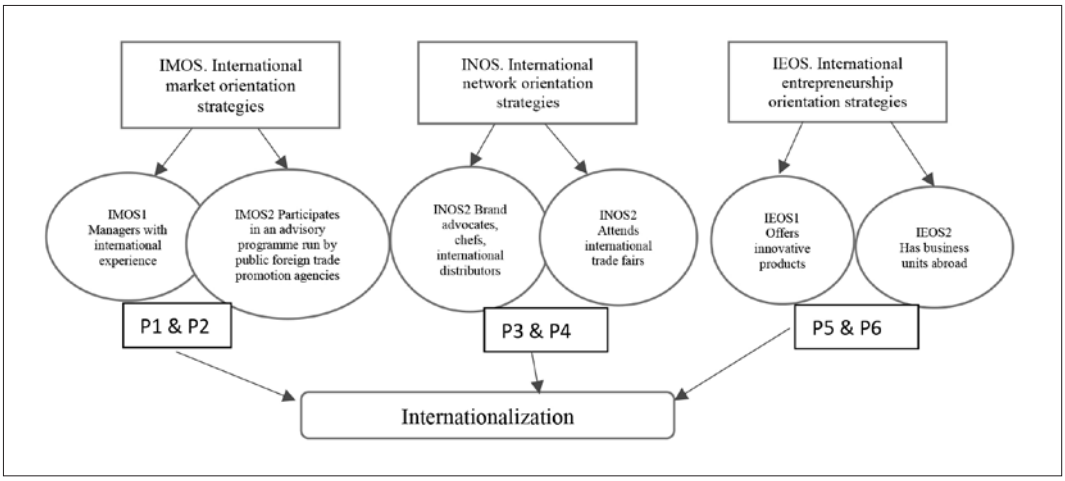
In summary, as shown in Table 1, in this paper we will study the combination of key actions within the strategies cited in the propositions—IMOS (experiential knowledge and objective knowledge of the international market), INOS (network of international contacts and attendance at international fairs) and IEOS (founder's characteristics: offering innovative products and international business units)—that are necessary for olive oil companies to be international.

Below, we use the QCA method to examine the key actions – encompassed within the IMOS, INOS and IEOS strategies – and the combinations thereof needed for the internationalization of olive oil companies. This paper is an empirical novelty for the following reasons. The few studies that jointly study the above propositions in the olive sector apply them to four cases located in southern Spain (Jaén) (Martos-Martínez and Muñoz-Guarasa, 2021; 2023). In contrast, in this paper we extend the sample (246 exporting firms) and the scope of application (Spain).

4. Methodology

This study focuses on analysing the conditions for the internationalization of Spanish olive oil companies. To do so, we have used information from the SABI database, which is produced by Informa D&B, a company responsible for Spanish company databases, and contains the characteristics and financial and marketing information of companies from the Iberian Peninsula (Spain and Portugal).

Figure 1 - Internationalization strategies.



Source: Own elaboration.

To define the population under study, we obtained a register of the entities listed under CNAE code 1043, "Olive oil production". Furthermore, from the olive oil producers and traders listed under code 1043, we selected those with international activity. The total number of companies selected as exporters was 246 out of a total of 541 available companies, which represents 45.47 percent of the total. The criterion for classifying them as exporters was an affirmative response given by these olive oil companies (yes, they export).

We study the variables included in the different internationalization strategies:

- IMOS (strategies oriented towards the international market): managers with experience of internationalization (IMOS1); guidance provided in internationalization support programmes through initiatives run by public foreign trade promotion agencies (for example, ICEX in Spain and EXTENDA in Andalusia) (IMOS2).
- INOS (strategies aimed at building international networks): the olive oil company has brand advocates, chefs, international distributors (INOS1); the company attends international trade fairs (INOS2).
- IEOS (entrepreneurship strategies for the internationalization of companies): the company offers innovative products (IEOS1); the company has commercial offices abroad as a form of entrepreneurship (IEOS2).

By way of summary, they are set out in Figure 1.

The characteristics of this study are summarized in the Table 2.

Table 2 - Technical data sheet of the study.

Study universe	Olive oil mills in the SABI database listed under CNAE code 1043: the analysis focuses on 246 internationalized organizations out of a total of 541 companies.
Geographical scope	Spain
Time frame	March 2022 to May 2022
Population register	Iberian Balance Sheet Analysis System (SABI)
Sample size	246 olive oil mills considered exporters according to CNAE code 1043 in the SABI database
Sample unit	Olive oil producer and trader with international activity registered under «olive oil production» National Classification of Economic Activities (CNAE) number 1043.

Source: Own elaboration.

The QCA technique, which is based on Boolean algebra, uses a verbal, conceptual and mathematical language that yields both qualitative and quantitative results, combining the main advantages of the two (Rihoux and Ragin, 2009). The application of this technique enables the systematic analysis of a set of cases to determine causal patterns in the form of relationships of necessity and sufficiency between a set of conditions and an outcome (Schneider and Wagemann, 2010).

The QCA allows researchers to identify complex interactions and address equifinality, the notion that different combinations of explanatory variables can explain the same outcome of interest. In contrast, statistical analysis allows quantifying the net effect of individual explanatory variables and the causal relationships between explanatory variables and outcome variables (Meuer and Rupietta, 2017). This is why the QCA method has been chosen to find out the different combinations of actions that can lead a company in the olive sector to become international.

The theories included in this paper (EOMI, EORI and EOEI) have been tested through the in-depth study of four cases. Thus, Martos-Martínez and Muñoz-Guarasa (2021) carry out a qualitative case study and Martos-Martínez and Muñoz-Guarasa (2023) include the combination of the 4-case study and the QCA. Moreover, these cases are located in southern Spain (Jaén). Therefore, previous research has focused on the in-depth study of cases located in a geographical area with specific characteristics. However, in the current study we have expanded the number of cases (246 and the geographical scope to the peninsula).

The QCA was originally developed for the analysis of small and medium-sized samples (Ragin, 1987). However, more and more researchers are using this method to analyse large datasets (Cooper and Glaesser, 2010; Meuer and Rupietta, 2017; Thomann and Maggett, 2017). Traditional case-oriented analysis is the thorough analysis of particular cases using deep contextual and intensive knowledge of the cases with a small sample size N (e.g. studies by Martos-Martínez and Muñoz-Guarasa, 2021; 2023). However, QCA can be applied to different sample sizes and case numbers alone do not justify its use (Schneider and Wageman, 2012; Thiem, 2017). Therefore, QCA is applied at large N when the research is oriented towards conditions comprising cases primarily in terms of a well-defined set of conditions. In this way, results are interpreted as patterns across cases and are not complemented by an in-depth qualitative analysis of individual cases (Greckhamer *et al.*, 2013; Seawright and Collier, 2010). Thus, while the case-oriented approach (small N) is oriented towards the complementary use of within-case knowledge, the condition-oriented approach (large N) is based on: (1) inference of cases, (2) in relations between sets, (3) in knowledge of conceptual relations rather than particular cases. Thus, a large N sample does not preclude an interest in particular cases (Thomann and Maggeti, 2017).

Fuzzy-set QCA (fsQCA) has become established as one of the most widely-used QCA variants as it overcomes one of the main drawbacks and critiques levelled at the original model, known as csQCA; namely, its strictly dichotomous approach (Rihoux and Ragin, 2009). The fsQCA method is widely used in business and management research (Schneider and Wagemann, 2012; Rihoux *et al.*, 2013; Denk and Lehtinen, 2014), as well as in entrepreneurship and innovation studies (e.g., Cheng *et al.*, 2013; Dai and Huang, 2015; Mas-Verdú *et al.*, 2015; Wu and Huarng, 2015; Covin *et al.*, 2016; Kraus *et al.*, 2016). Unlike more quantitative methods that rely on correlation, fsQCA seeks to establish logical connections between combinations of causal conditions (conjunctural causality) and an outcome, resulting in rules that summarize the sufficiency between subsets of all possible combinations based on their causal conditions and the outcome. In this sense Woodside (2010) points out that fsQCA achieves both high generalization and professionalization.

One of the main reasons why fsQCA has been used in this work is because it connects qualitative and comparative analysis (Kent, 2005; Crilly, 2011; Aguilera-Caracuel *et al.*, 2014), allowing us to understand which actions are relevant for the internationalization of the olive sector and how to combine internationalization strategies to achieve it. Ultimately, fsQCA is well suit-

Table 3. Variables used for the fsQCA technique

Outcome variable	*Description*	
Oleo_export	Exporting olive oil organizations according to CNAE code 1043 in the SABI database	Dichotomous variable
Condition variables	*Description*	
IMOS1	Managers with experience of internationalization	Dichotomous variable
IMOS2	The company participates in internationalization advisory programmes run by public foreign trade promotion agencies	Dichotomous variable
INOS1	The olive oil company has brand advocates, chefs, international distributors	Dichotomous variable
INOS2	The olive oil company attends international trade fairs	Dichotomous variable
IEOS1	The company offers innovative products. To do this, it develops ecological products and products for new niche markets such as those related to sustainability	Categorical variable
IEOS2	Number of business units abroad or commercial offices opened abroad (with commercial offices considered elements of international entrepreneurship)	Categorical variable

Source: Own elaboration.

ed for social science studies due to its ability to meet the generality and precision of the results, as well as to capture the complexity of causally relevant conditions (Kraus *et al.*, 2018).

For the correct application of this technique, we follow the stages recommended in the literature (Rihoux and Ragin, 2009): the calibration, where needed, of both the condition and the outcome variables; the subsequent analysis of necessity; and finally, the analysis of sufficiency. It is not necessary to a priori assume linear or other types of relationships between the explanatory and the explained variables. Compared to multiple regression, fsQCA has greater explanatory power and can be used alone provide more nuanced information on the relationships under study (Gligor and Bozkurt, 2020). In addition, fsQCA assumes asymmetry, equifinality and causal complexity, thus addressing some of the limitations of multiple regression (Ragin *et al.*, 2006).

In short, fsQCA yields one or several combinations sufficient for a specific outcome; for example, X1*~X2*X3 is sufficient for the outcome (Y). Employing the symbolic notation of this technique

$$X1*\sim X2*X3 \rightarrow Y$$

where X1, X2 and X3 are antecedents; Y, is the outcome; * the union and ~ the absence or negation, in this case the opposite value to X2 (1- X2).

The fsQCA technique is applied to the different variables related to strategies oriented towards internationalization. The variables that make up the proposed model are detailed in Table 3. The result variable is: exporting companies in the olive oil sector, which leads to the purpose of the analysis, which is to find out the combination of actions followed by internationalized companies in the sector. The purpose of this variable is to find out the actions taken by companies that do not export in order to initiate their internationalization process.

The categorical variables considered have been calibrated according to Rihoux and Ragin (2009), who stress the importance of careful calibration to ensure the validity and accuracy of the results. To do so, we have followed: (1) Identify the set of cases to be analyzed and define the membership criteria. (2) Determine the thresholds. (3) Use the thresholds to assign membership values to the cases.

The categorical variable EOEI1 "the company offers innovative products" has been identified as developing environmentally friendly products and new niche markets such as those related to sustainability. In this case, following Rihoux and Ragin (2009), the variable has been created from a combination of variables related to internation-

al entrepreneurship and innovation; namely, the production of ecological and sustainable products (econ), the focus on new international activities such as olive oil tourism or oleotourism (oleotur), and belonging to agri-food innovation collectives such as the British Retail Council or Industrial Food Standard (innova). So, IEOS1 = (econ + oleotur + innova) divided by 3, giving a weight of 33% to each simple variable that comprises the complex variable IEOS1. The categorical variable EOEI2 number of business units abroad and commercial offices opened abroad (with commercial offices considered elements of international entrepreneurship).

5. Results and discussion

To obtain the results, a QCA has been carried out, specifically using the fsQCA approach. The aim of this analysis is to identify the most commonly used actions and combinations thereof that are most beneficial for exporting olive oil companies in their internationalization process. The actions in question are those included within the international market (IMOS), international network (INOS) and international entrepreneurship orientation strategies (IEOS).

It should be noted that, as an initial step, an analysis of necessity was performed to confirm that no single condition variable exceeds the recommended limit of 0.9 established by Ragin (2006). Then, following the analysis of the truth table, Table 4 presents the results of the fsQCA for the key internationalization factors of the analyzed olive oil organizations taken from the SABI database. The findings allow us draw attention to these factors for other companies seeking to internationalize. The solution table includes set-theoretic consistency scores for each configuration as well as for the overall solution, with a value above the recommended minimum threshold of 0.75 (Rihoux and Ragin, 2009). The causal configurations have been ordered from highest to lowest raw coverage.

Overall, the model presents a total coverage of 66.44 percent, which denotes the proportion of exporting olive oil organizations explained by the six variables included in the analysis, and a total consistency of 92.47 percent of the cases, which indicates the reliability of the model. Thus, the most commonly used combination of actions in the largest number of internationalized companies are presented in the first three configurations, as these are the ones that have the greatest coverage.

The results reveal that the first configuration, which has a raw coverage of 0.34, includes key factors such as managers' experience in internationalization; the company having brand advocates, chefs, journalists and distributors at its disposal; and, lastly, a commitment to offering innovative products (developing ecological products and products for new niche markets, such as those related to sustainability).

In the second configuration, which comes close to the first with a raw coverage of 0.30, the key factors considered in the analysis are the company's participation in advisory programmes for internationalization, such as the internationalization support offered by the public organizations ICEX and EXTENDA at national and regional level; the company having brand advocates, chefs, journalists and distributors at its disposal; and lastly, the company opting to

Table 4 - Results of the fsQCA.

	Raw coverage	*Unique coverage*	*Consistency*
IMOS1*INOS1*IEOS1	0.348259	0.144129	0.945946
IMOS2*INOS1*IEOS1	0.300249	0.081096	0.916818
IMOS2*INOS1*IEOS1*IEOS2	0.268358	0.053235	0.932734
IMOS2*IEOS1*IEOS2	0.18408	0.068109	0.918114
Model coverage		0.6644	
Model consistency		0.9247	

Source: Own elaboration.

diversifying its international activity by offering innovative products, as well as ecological products and products aimed at new niche markets such as those related to sustainability.

Given the close values for the configurations of the different models, we comment on the third, with a raw coverage of 0.26. In this combination, the key factors for internationalization are participating in public advisory programmes run by public foreign trade promotion entities; having access to brand advocates, chefs, journalists and distributors; offering innovative products (developing ecological products and products for new niche markets such as those related to sustainability); and lastly, opting to open commercial offices and business units abroad.

The results show that in order for companies in the olive oil industry to consider pursuing the goal of exporting, they must have a manager or head of internationalization with experiential knowledge of other internationalization processes (IMOS1) as well as objective knowledge of the foreign market through participation in advisory programmes run by public foreign trade promotion agencies (IMOS2); they must also create international networks through relationships with brand advocates, chefs and commercial distributors (INOS1); and the founder must have the traits of innovativeness, proclivity and proactiveness, as well as the autonomy and competitive aggressiveness to offer innovative products (IEOS1) and open business units abroad (IEOS2). We also find that the variable capturing attendance at international trade fairs (INOS2) has not been used by exporting companies to start their internationalization process, so proposition 4 is the only one out of the six that is not confirmed.

The strategic action that international olive oil companies in this study have not used is creating international networks by attending international trade fairs. However, there are studies that highlight the positive relationship between attending international trade fairs and business internationalization. For instance, Gerschewski *et al.* (2020) state that networking at trade fairs can have positive implications for the company, especially when it comes to entering international markets. Similarly, according to Bettis-Outland *et al.* (2021) international trade fairs are considered important events for promoting exports, as they make it easier to adapt to the customer. Silva *et al.* (2022) highlight the positive implications of attending international trade fairs for business internationalization, since companies make maximum use of networks to access foreign markets. Therefore, it would be worth further exploring this variable in future studies.

Focusing on research related to the internationalization of the olive oil sector, Mili and Rodríguez-Zúñiga (2003) explore the new economic context in which international olive oil marketing strategies are framed. Mili (2006) analyses the current and expected trends in the marketing of olive oil in non-traditional markets. Moral-Pajares and Lanza-Molina (2009) describe how world demand for virgin olive oil is behaving. Moral-Pajares *et al.* (2015) analyse the relationship between export efficiency of southern European olive sector firms with websites. Mozas-Moral *et al.* (2016) study the organic olive oil sector in Spain. Mili and Bouhaddane (2018) study the determinants and future strategies for the internationalization of Spanish olive oil from a value chain perspective. Cano-Rubio *et al.* (2021) delve into the internationalization strategies of olive oil mills, which are focused on social capital and in the context of the family business. Finally, we find works that positively relate EOMI, EORI and EOEI strategies to internationalization, as in the work of Martos-Martínez and Muñoz-Guarasa (2021, 2023), who carry out a study of four cases located in southern Spain (Jaén).

In short, after the study carried out here, we observe the shortage of research on the internationalization of the olive oil industry, especially papers related to strategic actions that facilitate this international expansion. Thus, our contribution is that the present paper includes the key actions and the combinations thereof most commonly used by exporting olive oil companies, which are then presented in recommendations for managers or entrepreneurs to put into practice in their international expansion. To that end, we have used a wide-ranging sample of companies throughout Spain that produce and export olive oil. This reinforces the

results obtained, since the only related studies we are aware of are those by Martos-Martínez and Muñoz-Guarasa (2021, 2023), which analyze the IMOS, INOS and IEOS strategies of four companies in the olive oil industry of the province of Jaén. Therefore, the main contribution of the present paper is the analysis of the strategic actions and combinations thereof most commonly used by 246 olive oil companies located throughout Spain.

6. Conclusion: practical implications and limitations

This study examines the strategic actions and combinations thereof most commonly used by olive oil companies in their internationalization process. Our starting point has been the internationalization strategies from a previous theoretical framework: IMOS, INOS and IEOS. The analysis focuses on the companies that manufacture olive oil in Spain, since this country is the world's largest producer of olive oil.

Therefore, if the owners/managers of olive oil companies want to be international these actions are shown to be the most commonly associated with successful internationalization and should be considered by managers:

- On the one hand, they should carry out the actions most commonly used by companies in this industry in their foreign market entry process. They should thus (1) acquire experiential knowledge from the founder's and/or manager's experience of having participated in internationalization processes with other companies; (2) create contacts in the foreign market through relationships with international brand advocates, chefs and distributors; and (3) offer innovative products by creating ecological products and products for new niche markets, such as those related to sustainability (for example, organic oil or olive oil-based cosmetics), as well as developing actions related to sustainability (such as olive oil tourism or oleotourism).
- On the other hand, they should adopt other strategic actions that have been carried out, albeit by relatively fewer by internationalized companies. Said actions are as follows: (1) gain knowledge of clients, competitors and international partners through participation in internationalization support programmes run by foreign trade promotion agencies (for example, ICEX in Spain); and (2) the owner/manager should be proactive and open business offices or business units abroad. Finally, the one action that the analyzed companies have not used to become international is attendance at international trade fairs; this finding feeds into the gap on whether or not attending international fairs is important for internationalization.

Introducing sustainability into trade relations is dominating the international debate with the aim of creating fairer links between areas and countries. Thus, the social dimension is both an economic and environmental challenge facing the agricultural sector (Fort *et al.*, 2025). The olive sector is characterized by rural areas with smallholder farmers, and increasing the power of these farmers through capacity building initiatives, access to financial resources and technical training will enable them to fully participate in ecological and technological developments to cope with the effects of climate change (Ballet *et al.*, 2009) and the dynamism of the international market. As a result, rural areas would benefit from improved infrastructure, education and access to markets (Grumiller *et al.*, 2018). This will enable them to have a more internationally competitive sector. Therefore, it is recommended that institutions promote the following economic policies:

- Transform the olive sector into an inclusive segment, boosting exports with an equitable distribution of benefits (Fort *et al.*, 2025).
- Promote national marketing and branding strategies for bottled oil exports and boost quality assurance (Fort *et al.*, 2025).
- Create incentives for sustainable production and promote sustainability certifications.
- Promote sustainable trade agreements such as environmental protection and labour rights to ensure that international trade in olive oil is fair and sustainable.
- Provide education and training programmes for producers and workers in the olive sector on sustainable practices and environmental

management, which improves the efficiency and competitiveness of the sector.

This paper makes a threefold contribution. First, we test for the IMOS, INOS and IEOS strategies in a sample of 246 companies located in Spain. Second, we identify the key actions that the internationalized olive oil companies have implemented. Thirdly, we determine the combinations of actions most commonly used by these companies for their international market entry. Finally, we formulate a set of recommendations for companies' owners/managers that can guide them in the process of business internationalization. We also propose a set of public policies to promote the sustainable development of the sector, which contributes to the social and economic inclusion of the territory. Furthermore, after conducting this analysis, we confirm the scarcity of research on the determinants of olive oil companies' internationalization. As such, our research contributes to and complements the existing literature with new knowledge

Finally, in future research, efforts should be made to study new key actions (for example, based on digitalization) within the IMOS, INOS and IEOS strategies which can lead to olive oil companies becoming international. The coverage of the model has been high (66 per cent). Despite this, there are approximately one third of exporting companies that do not follow any of the combination of actions proposed. Therefore, it is proposed to analyze the generalization of the results to other olive oil producing countries and other agrifood sectors. Thus, it is proposed to apply these results in companies located in the producing countries of the Mediterranean Basin, since olive oil is produced, consumed and exported to more than 165 countries. In this study, some contextual variables such as size, age, legal form have not been considered, which is why in future research it is proposed to carry out the study applying some control variable.

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Unravelling the functions of knowledge communities in Spain's agri-food system: An examination of Operational Groups

CONSUELO CALAFAT-MARZAL*, VERONICA PIÑEIRO**,
FRANCESC J. CERVERA*, JOSÉ MARÍA GARCÍA-ÁLVAREZ-COQUE*

DOI: 10.30682/nm2505c
JEL codes: O31, 038, Q16, Q18

Abstract

This study analyses the functional diversity of EIP-AGRI Operational Groups (OGs) in Spain, focusing on their roles as innovation intermediaries. It seeks to identify intermediary functions and enabling conditions that support the achievement of innovative solutions in the agri-food sector. Based on a national survey of OGs, the study applies a mixed-methods design, combining hierarchical cluster analysis and Necessary Condition Analysis (NCA). The intermediary functions performed by OGs are classified into operational profiles, and key enabling factors are identified. Three distinct functional profiles emerged: Collaborative Leaders, Moderate Innovators, and Emerging Explorers. Human capital and consortium composition were identified as necessary conditions for successful innovation among advanced OGs. Moderate Innovators were characterised by the need for simplified administrative procedures and cost-effectiveness. Emerging Explorers displayed latent potential but required further capacity building. These results provide evidence for differentiated policy support, particularly for capacity building, simplification of procedures, and strategic partner selection.

Keywords*: Innovation intermediaries, Agri-food systems, Knowledge communities, Operational groups, Multi-actor programmes.*

1. Introduction

The agri-food system requires transformation to meet increasing food demand, address climate challenges and ensure the resilient rural communities (El-Nasser and Ibrahim, 2024; OCDE, 2021). Collaboration among diverse stakeholders within knowledge communities is crucial for agri-food innovation (Howells and Thomas, 2022; Oulmane *et al.*, 2024; Zhang and Liu, 2023). Through its Operational Groups (OGs), the European Innovation Partnership for Agriculture (EIP-AGRI), facilitates innovation through multi-actor alliances(Cristiano and Proietti, 2022; Fieldsend *et al.*, 2022, 2021).

These OGs are a type of knowledge community, with over 3,000 groups across the European Union with a varying composition including farmers, foresters, researchers, advisors, businesses, environmental groups, and

* Departamento de Economía y Ciencias Sociales, Universitat Politècnica de València, Spain.
** Departamento de Agronomía, Universidad Nacional del Sur, Bahía Blanca, Argentina.
Corresponding author: macamar3@upv.edu.es

NGOs, aiming at co-creating practical solutions.[1] However, their effectiveness varies by group composition, goals and funding (Kilelu *et al.*, 2013; Klerkx and Leeuwis, 2009). This variation underscores the need for innovation policy to account for the diverse nature of OGs. The EIP-AGRI initiative is grounded in the interactive model of innovation, which contrasts with linear models by emphasising co-creation, iterative feedback, and the exchange of knowledge among diverse actors within innovation systems (Klerkx *et al.*, 2012; Hekkert *et al.*, 2007)). This perspective acknowledges that innovation emerges not from a single source but through continuous interaction between producers, advisors, researchers, market actors, and policymakers. Accordingly, OGs are conceived as multi-actor platforms designed to foster collaborative problem-solving and practical innovation. The present study adopts this interactive approach as a guiding framework for examining how OGs perform intermediary functions and the extent to which these functions contribute to innovation outcomes.

Innovation policy is key when evaluating European Union (EU) rural, Agricultural Knowledge and Innovation Systems (AKIS) related policies (Fieldsend *et al.*, 2021; Giarè and Vagnozzi, 2021). In the Spanish context, this diversity is aligned with national priorities for agri-food research and innovation, which emphasise the need for sustainable production, circular economy models, and resilience under climate change (El-Nasser and Ibrahim, 2024; Rojas-Serrano *et al.*, 2024).

Further research is needed to understand how OGs perform different innovation functions and to identify the facilitating factors that are necessary for their success (Caloffi *et al.*, 2023; Cholez *et al.*, 2023; Cronin *et al.*, 2022; Ingram *et al.*, 2022; Moschitz *et al.*, 2021). Hence, the following research questions can be posed:
RQ1. Do the functions of OGs as knowledge communities uniformly influence the achievement of their objectives?
RQ2. What facilitating factors are essential to enable OGs to provide innovative solutions?

This study contributes to the literature on agricultural innovation systems by providing a functional characterisation of EIP-AGRI Operational Groups (OGs) in Spain, based on the intermediary roles they perform. Drawing on a national survey and a combined methodological approach—hierarchical cluster analysis and Necessary Condition Analysis (NCA)—the paper identifies distinct behavioral profiles among OGs and examines the conditions that facilitate the achievement of their objectives.

In addition, the study proposes an operational framework that adapts and refines existing typologies of innovation intermediary functions (e.g., Howells, 2006; Piñeiro *et al.*, 2021) to the empirical context of multi-actor innovation projects. By doing so, it provides a basis for analysing OGs not only in terms of outcomes, but also through the roles and functions that underlie their performance.

Finally, the use of NCA introduces a complementary perspective to existing analytical tools in the field, enabling the identification of non-compensatory conditions that are necessary—though not sufficient—for innovation to occur. This approach may inform future assessments of intermediary organisations and support the design of targeted policy instruments within AKIS frameworks.

2. Literature review

OGs established under the EIP-AGRI framework represent a key instrument for promoting agricultural innovation in Europe through collaborative problem-solving. These are formal consortia of farmers, advisors, researchers and firms formed to implement innovation projects. As defined in Regulation (EU) No 1305/2013, OGs are legally bound to a single innovation plan and have a limited duration. They should therefore not be understood as long-standing communities or programs, but rather as tempo-

[1] See the webpage of the EU CAP network https://eu-cap-network.ec.europa.eu/operational-groups-eu-member-states_en.

rary alliances organized around specific goals. The theoretical foundation of the EIP-AGRI initiative lies in the interactive model of innovation, which highlights the role of collaboration, mutual learning and feedback among heterogeneous actors in the innovation process (Hekkert *et al.*, 2007; Klerkx *et al.*, 2012). This model challenges linear conceptions of innovation transfer by framing it instead as a co-evolutionary process shaped by social interactions, institutional settings, and context-specific knowledge. In this view, innovation intermediaries such as OGs play a central role in linking research and practice, articulating demands, and fostering networked problem-solving. The conceptual approach adopted in this study builds upon this interactive model, which aligns with the design principles of EIP-AGRI and underpins the functions and behaviours analysed in our framework.

The growing interest in the role of OGs has highlighted their intermediary character within AKIS. Innovation intermediaries are actors or entities that facilitate the circulation and coordination of knowledge among diverse stakeholders, often bridging research and practice. In the agricultural domain, intermediaries are critical for enabling co-innovation processes and for tackling systemic failures that prevent innovations from being adopted. Early contributions such as Howells (2006) identified key functions performed by innovation intermediaries – such as demand articulation, knowledge exchange, and network brokerage. These foundational ideas have since been expanded and contextualised in agricultural innovation systems. In particular, Piñeiro *et al.* (2021) offer a synthesis of intermediary roles adapted to the EIP-AGRI framework, drawing on both innovation systems literature (e.g. Kilelu *et al.*, 2011) and empirical studies in multi-actor settings. These functions are often informal, localised and context specific in agriculture.

From a conceptual standpoint, the role of innovation intermediaries is rooted in the systemic model of innovation, which emphasises the importance of dynamic interactions among diverse actors—such as researchers, farmers, advisors, and businesses—embedded in institutional and policy environments (Klerkx and Leeuwis, 2009; Hekkert *et al.*, 2007). This model contrasts with linear approaches by viewing innovation as a co-evolutionary process shaped by feedback loops, contextual knowledge, and coordination mechanisms. Within this framework, innovation brokers or intermediaries emerge as essential actors who facilitate connections, manage uncertainty, and enable the co-creation of solutions. The AKIS approach gives institutional form to this perspective by promoting integrated, multi-actor structures that link science, practice, and policy. In this context, OGs under the EIP-AGRI initiative represent a concrete policy instrument that operationalises the systemic and AKIS-based logic of innovation. OGs are thus designed to act as knowledge communities and innovation intermediaries, translating the principles of interaction, coordination and learning into tangible innovation outcomes.

Recent research has adapted and expanded this framework to better suit the particularities of innovation support in agriculture. For instance, Faure *et al.* (2019) and Mathé *et al.* (2016) proposed typologies of innovation support services based on empirical studies of multi-actor processes, while Cristiano and Proietti (2022) analysed the strategic roles of support actors in the Italian AKIS. These studies suggest that intermediary functions in agriculture are often distributed across multiple actors and emerge dynamically during the innovation process. In the case of OGs, such functions may be performed by different members of the consortium, especially project coordinators and advisory entities, even if not formally designated as intermediaries.

As García-Álvarez-Coque *et al.* (2020) argue, effective innovation governance in agri-food systems requires strategic directionality, well-aligned evaluation frameworks, and multi-level institutional coordination. However, as highlighted by Schebelin *et al.* (2021, 2022), this directionality is not neutral. Innovation governance involves political and normative choices that shape which actors, sectors, and knowledge systems are prioritised. In this sense, policies such as EIP-AGRI embed a deliberate orientation toward multi-actor collaboration, sustainability, and applied research, thereby influencing

the kinds of innovation that are supported and legitimised. OGs, as policy instruments grounded in this institutional logic, operate within these value-laden frameworks. Analysing their performance thus requires acknowledging the broader, non-neutral context in which their intermediary functions are enacted. Furthermore, intermediary functions are closely linked to actors' capacity to learn, adapt, and apply new knowledge. Ramos-Sandoval *et al.* (2016), in their study of small-scale agricultural holdings, demonstrated that innovation outcomes are strongly correlated with learning orientation and access to extension services. These findings suggest that intermediary roles are not only organisational but also behavioural, and that capacity-building mechanisms remain essential for enabling effective knowledge brokerage in innovation systems.

Building on this literature, the present study adopts a functional perspective that conceptualises OGs as distributed innovation intermediaries. The analysis draws on a national survey of OG representatives conducted in Spain and aims to identify distinct patterns in the way these groups perform intermediary functions. Importantly, only officially recognised OGs were surveyed; other types of innovation projects were excluded, thus ensuring consistency with the regulatory framework of the EIP-AGRI programme.

To operationalise intermediary functions within this empirical context, we use a conceptual framework adapted from the typology proposed by Piñeiro *et al.* (2021). This framework is the result of an analytical synthesis of the literature on innovation intermediaries, tailored to the specific features of EIP-AGRI Operational Groups. The functions identified in their study were translated into observable roles reported by OG members through the survey. Some of these roles preserve their theoretical labels, while others have been redefined to better capture practical realities in the Spanish implementation of EIP-AGRI. A synthesis of this conceptual alignment is presented in Table 1, which reconciles the original intermediary functions with their adapted equivalents for field application.

The intermediary roles presented in Table 1 are critical to the functional characterisation of OGs and form the foundation for the clustering analysis developed in this paper. Specifically: the Mentor provides technical guidance and knowledge transfer; the Leader ensures project coordination and drives the innovation process; the Connector builds trust and facilitates collaboration among members; the Organiser manages administrative tasks and formal requirements; the Networker promotes external visibility and establishes links beyond the OG; and the Inte-

Table 1 - Correspondence between theoretical and applied intermediary functions.

Theoretical function (adapted from Piñeiro et al., 2021; based on Howells, 2006 and others)	*Applied roles in this study*	*Comments / adjustments*
Demand articulation	Prospector, Explorer, Opportunist	Adapted to reflect early-stage innovation framing in practice.
Institutional support	Advocate, Educator, Stimulator	Broadened to include awareness, mobilisation, and lobbying activities.
Network brokerage	Connector, Engager, Collaborator	Associated with engagement and network building within and beyond the OG.
Capacity building	Instructor, Mentor, Catalyst	Focused on strengthening skills and knowledge within the group.
Innovation process management	Informer, Harmoniser, Guide, Assessor	Related to planning, monitoring, and coordination of the innovation process.
Knowledge exchange	Communicator, Interpreter	Covering communication and translation between actors and systems.

**Note: The classification of functions used in this study is adapted from Piñeiro et al. (2021), who reviewed and operationalised intermediary roles in the context of EIP-AGRI Operational Groups. Their framework synthesises previous contributions, including the typology of Howells (2006) and functionalist approaches to innovation systems such as Hekkert et al. (2007).*

grator ensures coherence between goals, contributions, and expected impacts. These categories were used to design the survey and serve as the analytical basis for the behavioural profiles discussed in the results.

This approach makes it possible to categorise OGs not only by their thematic orientation but by their functional behaviour, providing new insights into how they operate as intermediaries. The correspondence between theory and practice reflects the necessity of tailoring conceptual frameworks to the complex institutional realities of innovation in agriculture. As argued by Neuberger *et al.* (2023), intermediary functions vary not only with the composition and maturity of the actors involved, but also with the policy frameworks and support instruments available.

By understanding OGs through this lens, it becomes possible to evaluate their contribution to innovation in a more nuanced way. Instead of focusing solely on outputs or success stories, this perspective allows for the identification of specific configurations of roles and functions, which in turn can inform targeted policy support.

3. Materials and methods

3.1. *Survey design and data collection*

The survey design was initially based on previous experience with a survey of OG members (Piñeiro *et al.*, 2021). This experience was used to evaluate the items selected from the literature. Once the questionnaire had been developed, it was validated by an expert panel consisting of five knowledge management researchers and innovation agents linked to existing OGs.

The questionnaire had seven sections, each with a different scope. Table 2 summarises these sections. It also includes the open access link to the questionnaire and data. Although the survey provided data to assess the performance of OGs.

The target population for the survey consisted of the 967 Operational Groups (OGs) officially recognised in Spain up to July 2022. This figure was established through the consolidation of registries from the 17 Autonomous Communities (ACs) and the Ministry of Agriculture, Fisheries and Food (MAPA). The database included basic information on the name, location, and thematic focus of each OG. Regional administrations were contacted to validate and update the available records, and they also collaborated in distributing the survey.

The survey was administered online between September and November 2022 using Google Forms. An invitation was sent by email to all OGs, addressed to the person indicated as the legal representative or technical contact. Reminder messages were sent after two and four weeks. In some cases, the survey was redirected to other members of the OG, particularly when respondents considered they were not the most suitable person to answer. Additional support was provided through phone calls to increase the response rate.

A total of 164 responses were received, of which 159 were considered valid after reviewing for consistency and completeness. This represents a valid response rate of 16.4%. The sampling error was estimated using the finite population correction formula for proportions, assuming maximum variability ($p = q = 0.5$), a confidence level of 95%, a population size of 967 OGs, and a sample of 159 valid responses. Under these conditions, the estimated sampling error is approximately ±7.1%.

Readers can use the Zenodo open platform to access the questionnaire and survey data. The questionnaire and data set are organised into sections corresponding to innovation functions and roles (Cervera *et al.*, 2023).

The final sample includes OGs from all Autonomous Communities in Spain, with representation across diverse agri-food sectors and thematic areas. Respondents mainly consisted of technical coordinators, project leaders, or representatives of the leading organisation, most of whom had been directly involved in the preparation and implementation of the innovation project. The diversity of respondent profiles and the territorial coverage of the sample provide a robust basis for analysing the intermediary functions of OGs within the EIP-AGRI framework. In terms of territorial distribution, the OGs included in the survey operate across diverse rural contexts in Spain.

Table 2 - Sections and scope of the questionary.

Questionnaire section	*Scope*
General information	Name of the OG, funding, personnel
Type and scope of innovation	Targeted type of innovation included in the Rural Development Programme 2014-2020
Achievement and scope of objectives	Likert-type scales to measure the achievement of the innovative solution and the influence of factors that facilitate and hinder innovation (7 response options ranging from 'not influential' to 'totally influential')
Innovation functions of OGs	Likert-type scales to measure the importance of innovation functions (7 response options ranging from "not at all" to "totally")
Target audience and results transfer	Likert-type scales to determine preferred audiences for communicating results and dissemination activities
Group composition	Type of organisations involved and percentage of women
Project continuity	Future of the OG

Notes: The data set is available at https://zenodo.org/records/10118180.

Although specific geolocation data were not collected, the participating OGs are formally recognised at regional or supra-regional level and predominantly rooted in rural and semi-rural environments. These include both remote or marginal rural areas and peri-urban rural zones. The thematic focus of their innovation projects—targeting primary production, value chain organisation, sustainability, or local development—further reflects their anchoring in rural territories. Additionally, the profiles of the most represented stakeholders, including farmers, cooperatives, rural associations, and public research institutions, confirm the strong rural orientation of the surveyed OGs.

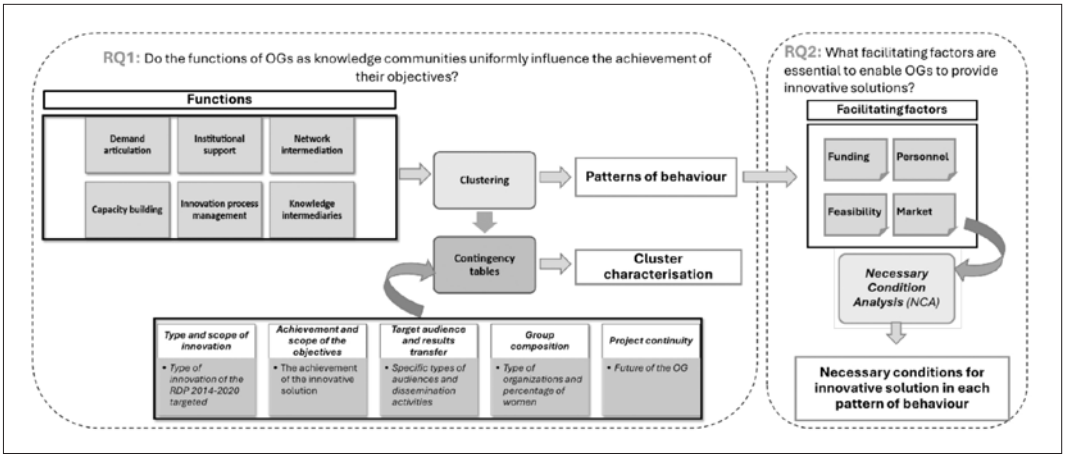
The number of respondents in Spain is larger than in previous OG assessment surveys (Fieldsend *et al.*, 2021; Knotter and Kretz, 2019). To ensure the validity of the sample and the robustness of subsequent analyses, several key statistical tests were conducted (Appendix A). The Student's t-tests for each variable indicated highly significant differences in means, with p-values less than 0.001 in all cases. This reflects remarkable consistency among the items analysed and a homogeneous distribution of the evaluated characteristics. Moreover, the Chi-square tests showed no significant associations in most variables, confirming the independence of the categories. The Cronbach's Alpha for the set of variables was 0.927, exceeding the threshold of 0.7 and

Table 3 - Facilitating factors needed to provide an innovative solution.

Dimension	*Factors*
Funding	Sufficient funding and commitment from group members
	Sufficient funding from external private sources
	Sufficient funding from public subsidies or grants
Personnel	Qualified staff among the group members
	Suitable composition of the consortium in terms of the number and characteristics of partners
	Sufficient access to external expertise
Market	Certainty regarding market demand for the innovative solution
Feasibility	Acceptable costs of the innovative solution
	Streamlined administrative procedures

Note: Terms such as "sufficient", "qualified" and "acceptable" reflect subjective assessments by OG members as reported in the survey. Definitions are provided in the main text for clarity.

Figure 1 - Methodological workflow of the present study.



demonstrating high internal consistency and excellent reliability of the scales used.

The survey addressed the facilitating factors that support OGs' efforts to provide innovative solutions (RQ2) in the section titled "Achievement and scope of objectives". This section also included Likert-type scale items, with seven options ranging from "Not influential" to "Totally influential". Table 3 shows the questionnaire items that referred to the influence of these facilitating factors.

The terms used in Table 3 reflect response categories from the survey designed to capture OG representatives' perceptions of key enabling factors. All items were measured using a seven-point Likert-type scale, ranging from "Not influential" (1) to "Totally influential" (7), based on how each factor was perceived to affect the achievement of the OG's objectives. For instance, "qualified staff among the group members" refers to the respondent's subjective evaluation of whether the consortium included personnel with the technical or scientific competencies needed to implement the project. Similarly, "sufficient funding" indicates that the available budget was perceived as adequate to meet project needs, and "acceptable institutional support" denotes a functional, if not optimal, level of administrative and policy support. These categories were developed in line with terminology used in previous AKIS-related studies (Klerkx & Leeuwis, 2009; Moschitz *et al.*, 2021).

3.2. *Methods*

Figure 1 illustrates the workflow followed to answer the research questions. In response to RQ1, cluster analysis was performed to identify patterns of OG behaviour related to the importance of OGs' innovation functions, according to respondents. Although the specific functions considered in this study are aligned with the principles and objectives of the EIP-AGRI, their implementation and particular emphasis may vary depending on the structure and specific interests of each OG.

The clustering process had three phases (Schulze Schwering *et al.*, 2022). First, a hierarchical cluster analysis was performed using the Ward method and the squared Euclidean distance to identify possible clusters. This method minimised the variance within each cluster, thereby enhancing the homogeneity of the resulting groups and ensuring a more precise classification. Second, after systematic comparison of the clustering possibilities, a dendrogram indicated the ideal number of clusters. It thus enabled identification of natural groupings and aided the decision-making process for establishing the optimal number of clusters. Finally, the Kruskal-Wallis test was applied to check whether the variables included in this study differed significantly between the clusters. It thereby provided a robust method to verify the distinctiveness of the clusters. Contingency tables were then used to examine the links

between the composition of clusters and various aspects. This step provided deeper insights into operational dynamics and potential areas for improvement for OGs.

Answering RQ2 required identification of the necessary conditions to provide innovative solutions in the clusters. To this end, NCA was employed as a set-theoretic method that identifies conditions that must be present (though not sufficient) for a desired outcome to occur (Dul, 2016). Unlike correlational approaches, NCA assumes an asymmetric relationship and focuses on non-compensatory constraints that block the outcome unless a minimum level of the condition is met.

NCA revealed the minimum levels of factors required for the desired outcome (Dul, 2016). Although the outcome of interest occurs, when necessary, conditions are satisfied, multiple necessary conditions may be required to produce the outcome. NCA examines the necessary conditions and their degree of necessity. The type of necessity indicates that a specific condition is necessary for a specific outcome. The degree of necessity describes the condition that is necessary to achieve a specific outcome.

In this study, the analysis was carried out using the R package NCA (version 3.1), applying both ceiling envelopment (CE-FDH) and ceiling regression (CR-FDH) techniques. Bottleneck tables were generated to determine the minimum level of each condition needed for a specific level of the outcome. A necessary condition is considered meaningful if its effect size exceeds 0.1 (Dul *et al.*, 2020). XY scatter plots and ceiling lines help visualise the upper-bound envelope, which represents the threshold beyond which the condition must be satisfied to reach the desired outcome (Hauff *et al.*, 2021).

This methodological approach has been increasingly applied in the agri-food and sustainability domains. For instance, Chaparro-Banegas *et al.* (2024) applied NCA to identify necessary factors for eco-innovation in European agri-food SMEs. Other relevant examples include Richter *et al.* (2017), who explored sustainability strategies in small firms, and Gölz and Hofmann (2021), who used NCA to study barriers to renewable energy adoption in rural areas.

4. Results

4.1. *Operational Groups within Agricultural Knowledge and Innovation Systems*

The survey allowed OGs to assess their implemented functions. The responses collected provided detailed data on the structure and functioning of the OGs. These data enabled evaluation of OG interactions, collaborations and the integration of various actors in the innovation process. Characterising OGs was therefore the first step in answering RQ1.

Regarding types of innovation, most respondents reported having promoted process innovations (50%), product innovations (35%), organisational innovations (12%) and marketing innovations (3%). Regarding the targeted priorities of the Rural Development Programme (RDP), most respondents reported that their OGs were oriented towards innovation and knowledge transfer, viability and competitiveness and efficient and sustainable use of resources. According to the survey results, 54% of respondents reported that their OGs had achieved their objectives satisfactorily, and 12.6% reported having exceeded expectations.

Concerning the types of organisations that form part of multi-actor OGs, 88% included universities and primary sector entities, and 54% included cooperatives. A total of 41% of respondents reported that more than 50% of team members were women. Regarding continuity, 76% of respondents reported that the multi-actor group would continue to work similarly in the future and further develop the innovation project with new funding sources.

4.2. *Patterns of behaviour according to the functions of Operational Groups*

Cluster analysis resulted in the identification of three distinct groups of OGs (Kruskall-Wallis, $p < 0.05$). Table 4 presents the mean values for each cluster and for the overall sample, based on the different intermediary functions assessed through the survey. These functions include knowledge mediation, innovation development,

Table 4 - Clusters based on the roles of OGs as innovation intermediaries.

Functions	*OG roles*	*CL1 Collaborative Leaders*	*CL2 Moderate Innovators*	*CL3 Emerging Explorers*	*Mean whole sample*	*Kruskal-Wallis H(*)*
Demand articulation	Prospector	5.44	4.44	3.73	4.76	43.028
	Explorer	**6.10**	**5.44**	**4.10**	5.48	51.485
	Opportunist	**6.15**	**5.47**	**4.17**	5.53	56.986
	Enabler	5.50	4.65	3.90	4.89	32.039
Institutional support	Advocate	5.88	5.02	4.23	5.26	36.231
	Educator	5.54	4.25	2.77	4.55	71.016
	Stimulator	**6.21**	**5.23**	3.97	5.43	63.501
Network intermediation	Connector	5.65	4.54	3.00	4.75	70.000
	Engager	5.65	4.47	2.80	4.69	76.615
	Collaborator	**6.29**	**5.05**	3.70	5.36	85.968
Capacity building	Catalyst	4.63	4.05	3.10	4.13	16.720
	Instructor	5.39	4.53	3.60	4.74	30.316
	Mentor	**6.33**	**5.51**	**4.83**	5.75	37.204
Innovation process management	Informer	**6.33**	**5.28**	**4.07**	5.53	80.364
	Harmoniser	**6.33**	**5.35**	**4.23**	5.58	63.975
	Guide	6.14	4.35	3.10	4.92	88.658
	Assessor	5.71	4.32	2.90	4.68	81.910
Knowledge intermediaries	Communicator	**6.17**	**5.18**	**4.37**	5.47	45.442
	Interpreter	5.60	4.28	3.60	4.75	46.411

(*) p value = 0.000.

dissemination, demand articulation, and coordination. It is important to note that the term "Enabler" in this context does not refer to a functional role of OGs, as outlined in Table 1, but rather to an external condition or environment that facilitates their capacity to innovate. This includes aspects such as institutional support, regulatory clarity, or favourable funding frameworks.

Each cluster was characterised to reveal how the OGs in each cluster operate and their challenges and success factors. Table 5 provides a detailed characterisation of the three clusters, revealing statistically significant differences across a wide range of variables.

Cluster 1 (CL1), *Collaborative Leaders* comprised 72 OGs (45% of the sample). Respondents reported above-average values for all innovation functions. The name *Collaborative Leaders* refers to the fact that these OGs show a highly innovative mentality, shared goals and catalytic leadership. The highest scores for roles were for Mentor, Informer and Harmoniser, highlighting the importance of providing ongoing support, training and facilitating the effective transfer of knowledge and experiences that allow the group to share lessons and best practices. It contains OGs that have been highly successful (83.3%) in providing innovative solutions. They prioritise innovation, resource efficiency (76.4%) and agri-environmental issues (68.1%), particularly those linked to the Rural Development Programme priority of restoring, preserving, and improving ecosystems[2]—such as soil quality, biodiversity, and water resources. Their commu-

[2] It is important to clarify that the term 'ecosystems' is used here in line with EU policy language and does not imply the adoption of an ecosystemic analytical framework in this study.

Table 5 - Cluster characterisation.

Cluster characterisation	*CL1*	*CL2*	*CL3*	*Total*	*Chi-square*	*Cont. Coeff*	*p-value*
% observations	45.28	35.85	18.87				
No. observations	72	57	30				
OG expectations achieved (%)							
Moderately/acceptably	16.7	31.6	50.0	28.3	12.066	0.266	0.002
Met satisfactorily/exceeded	83.3	68.4	50.0	71.7			
Targeted priorities of the Rural Development Programme 2014-2020 (% of highly/totally)							
Knowledge transfer and innovation	84.7	77.2	56.7	76.7	13.366	0.278	0.01
Food chain organisation and risk management	36.1	26.3	10.0	27.7	14.062	0.285	0.007
Restoring, preserving and improving ecosystems	68.1	52.6	43.3	57.9	8.877	0.230	0.065
Resource-efficient and climate-change-resilient economy	76.4	61.4	53.3	66.7	14.588	0.290	0.006
Target audience to communicate the results (% of highly/totally)							
Researchers	66.7	49.1	43.3	56.0	19.820	0.235	0.007
Professionals	95.8	93.0	66.7	89.3	32.703	0.286	0.001
Public decision makers	63.9	36.8	23.3	46.5	22.185	0.286	0.001
Agricultural and rural associations	86.1	83.5	60.0	79.9	31.132	0.269	0.003
Characteristics of the dissemination activities (% of highly/totally)							
- Multimedia content is tailored to the audience	95.8	78.9	43.3	79.9	77.888	0.471	0.000
- Complex results are communicated in a simple message	94.4	78.9	40.0	78.6	53.868	0.342	0.000
- Language is inclusive, and a gender focus is incorporated	80.6	68.4	43.3	69.2	34.420	0.310	0.000
- Knowledge products are disseminated with a social marketing vision through networks and platforms	77.8	70.2	10.0	62.3	66.495	0.255	0.002
- Results, tools and data are easily accessible and reusable	83.3	61.4	20.0	63.5	59.690	0.402	0.000
Women participating in activities (More than 30%)	83.4	61.5	56.6	70.5	12.210	0.268	0.006
Project continuity							
Similar work will continue	75.0	82.5	70.0	76.7	12.555	0.71	0.014
Will not continue, but they will have regular meetings	25.0	14.0	16.7	19.5			
Will not continue, and they will end the collaboration	0.0	3.5	13.3	3.8			

Source: Survey administered to OGs (https://zenodo.org/records/10118180).

nication strategies are innovative, accessible and gender-sensitive, with a strong commitment to continued collaboration, displaying multimedia skills. They are open innovation intermediaries (Caloffi *et al.*, 2023). High female participation (30% of OGs with >50% women) also defines this group. In total, 75% of respondents in this cluster report that their OGs will continue to collaborate in a similar manner. This result is particularly relevant considering the underrepresentation of women in agri-food innovation networks reported in the literature. For example,

Carvalho *et al.* (2020) analysed women's participation in scientific innovations in Ibero-America and found persistent gender imbalances in both visibility and leadership. Our findings are consistent with this trend, although Cluster 1 stands out positively within our sample, suggesting that collaborative environments with shared goals and inclusive communication strategies may be more conducive to female involvement. Similarly, Puertas *et al.* (2023) and Nhundu *et al.* (2023) emphasise the need for rural development policies to foster gender equality through participatory approaches.

Cluster 2 (CL2), *Moderate Innovators*, comprised 57 OGs (36%). Respondents reported below-average scores for intermediation functions that were nonetheless close to those for Collaborative Leaders. The respondents in this cluster reported that the most important roles were Mentor, Opportunist and Explorer, the priority in this group appears to be on providing expert support, identifying market opportunities and actively exploring solutions. These functions, which align with capacity building and demand articulation, reflect a more operational profile that favours internal reinforcement of capabilities over institutional engagement. In line with the work of Klerkx and Leeuwis (2009), these findings suggest that intermediaries in this cluster contribute by bridging knowledge gaps and promoting learning-by-doing dynamics, rather than acting as institutional brokers or systemic facilitators. This is further supported by Howells (2006), who highlights that technical and cognitive support roles are essential in contexts where innovation capacities are still emerging. Therefore, OGs in this group may benefit from capacity-enhancing policies that reinforce internal skills, while progressively promoting structured interaction with external stakeholders. The performance of this group reflects a mix of moderately and satisfactorily achieved expectations, indicating potential for further consolidation of their innovation capacity. It contains a mix of moderately and satisfactorily achieved expectations. OGs in this cluster prioritise knowledge transfer and innovation (77.2%), resource efficiency (61.4%) and ecosystem restoration (52.6%). Although their communication is effective, they have some shortcomings in disseminating results to researchers and policymakers. However, they show a willingness to engage in future collaboration.

Cluster 3 (CL3), *Emerging Explorers*, comprised 30 OGs (19% of the sample). The values reported by the respondents were notably below the average. The highest-scoring functions in this group had values greater than 4 and coincided with those of CL2. The most valued roles were Mentor, Opportunist, and Explorer, reflecting a profile that prioritises individual learning, opportunity recognition, and early-stage innovation exploration. Within the Institutional support function, the roles of Educator and Stimulator received the lowest scores, suggesting limited engagement in formal capacity-building or institutional reinforcement. Similarly, in the Innovation process management function, the Guide and Assessor roles were among the least valued, indicating a need for structured support in planning and evaluating innovation initiatives. These findings are consistent with a group of intermediaries that are still consolidating their innovation identity and require targeted support to transition towards more systemic and integrative roles, as discussed by Howells and Thomas (2022) and Caloffi *et al.* (2023). This cluster represents a segment with modest innovation performance but clear potential for growth, particularly if provided with mentoring and knowledge network integration. The OGs in this Cluster display varying degrees of success (50%) in innovation. OGs in this cluster prioritise knowledge transfer and innovation (56.7%), resource efficiency (53.3%) and ecosystem restoration (43.3%). According to the classification described by Caloffi *et al.* (2023), these OGs can be considered intermediaries that support innovation and competitiveness. However, they cannot be considered open innovation intermediaries or transition intermediaries because they fail to promote institutional change. Zhang and Liu (2023) position these OGs as intermediaries in a segment characterised by innovation performance and knowledge networks. These OGs require targeted support to fully exploit their potential strengths, in line with the proposals of Howells and Thomas (2022).

4.3. *Discussion and policy implications*

In summary, this cluster analysis of OGs reveals that a single innovation programme can encompass a diversity of intermediaries' profiles, directly addressing RQ1, and demonstrating that OGs operate as hybrid knowledge communities. This diversity is a positive feature of the EIP-AGRI approach, reflecting the flexibility and inclusivity of the programme. These characteristics have been instrumental in fostering a range of innovation pathways adapted to the heterogeneity of actors and context within the agri-food system.

From a policy perspective, the findings offer several relevant insights. First, they highlight the need for differentiated support mechanisms in the design, implementation and evaluation of OGs. Rather than applying uniform criteria, managing authorities should adopt functional diagnostics when allocating resources and defining technical support. Second, the intermediary functions identified in this study provide a robust basis for policy evaluation, particularly in the context of the CAP Strategic Plans and the development of AKIS. The variation in functional profiles also reflects the multiplicity of needs and capacities among OGs, offering useful guidance for targeted public interventions.

Overall, this research contributes to the growing body of literature advocating a shift from output-focused evaluations toward function-oriented governance of innovation. By identifying the enabling conditions and intermediary dynamics within OGs, the study provides a foundation for more informed, context-sensitive policy design and the consolidation of support structures for agricultural innovation in Europe.

4.4. *Necessary conditions for providing innovative solutions*

The necessary facilitating factors are shown in Table 6. Appendix C provides XY scatter plots of the facilitating factors in each cluster. These results show that, in CL1 and CL3, personnel are a necessary facilitating factor for innovative solutions, with a medium effect size. Conversely, in CL2, feasibility is a necessary facilitating factor, with a medium effect size.

Personnel include qualified staff, consortium composition and external expertise; feasibility includes cost acceptability and streamlined procedure.

These facilitating factors can be assessed in detail using bottleneck tables (Table 7).

In CL1 (*Collaborative Leaders*), adequate consortium composition (understood as an appropriate configuration in terms of number and diversity of partners, including producers, cooperatives, researchers and technical advisors) gradually increases as the percentage of expectations achieved increases. It peaks in the 100% category with a value of 84.4%. These findings suggest that the appropriate consortium configuration becomes more crucial as OGs seek a higher level of achievement. These results are in line with those reported by (Molina *et al.*, 2021). In a case study of an Italian OG, they underscored the importance of the choice of members from the outset of the project, the search for synergies and the contribution of their different skills to the achievement of the common goal. In that study, Cirella and Murphy (2022) found that networking and partnering are two relevant practices for initiating collaboration.

In contrast, having qualified staff among the members of the OG does not contribute significantly to 80% to 90% achievement of expectations, and it does not apply to 100% achievement. Sufficient access to external expertise does not significantly contribute to results in any analysed category.

As in CL1, in CL3 (Emerging explorers), the adequate composition of the consortium gradually increases in relevance as the target percentage increases, peaking in the 100% category with a value of 73.3%. This finding indicates that this facilitating factor becomes more crucial as OGs seek a higher level of achievement. Qualified staff within the group and sufficient access to external expertise do not make a significant contribution until a target of 70% is reached. However, to reach a target of 100% requires all three staff-related facilitating factors, in contrast to the results for CL1.

These findings support the view that human capital is not only a structural asset, but a func-

Table 6 - Effect size (d) and significance level of the facilitating factors (CR-FDH).

Construct	*CL1*	*CL2*	*CL3*
Funding	0.07 *(0.402)*	0.07 *(0.374)*	0.07 *(0.736)*
Personnel	**0.21 (0.011)**	0.17 (0.480)	**0.26 (0.029)**
Market	0.11 (0.377)	0.10 (0.427)	0.13 (0.379)
Feasibility	0.17 (0.137)	**0.21 (0.008)**	0.06 (0.724)

Table 7 - Bottleneck table with percentages in each cluster.

EA	*CL1*			*CL3*			*CL2*	
	QS	*CC*	*EE*	*QS*	*CC*	*EE*	*AC*	*SA*
0	NN	NN	NN	NN	NN	NN	NN	NN
10	NN	NN	NN	NN	NN	NN	6.7	NN
20	NN	NN	NN	NN	8.2	NN	13.3	NN
30	NN	9.8	NN	NN	16.8	NN	20.0	NN
40	NN	20.4	NN	NN	25.5	NN	26.7	NN
50	NN	31.1	NN	NN	34.1	NN	33.3	NN
60	NN	41.8	NN	NN	42.7	NN	40.0	6.7
70	NN	52.4	NN	7.5	51.4	7.5	46.7	13.3
80	20.0	63.1	NN	30.0	60.0	30.0	53.3	20.0
90	60.0	73.8	NN	52.5	68.6	52.5	60.0	26.7
100	NA	84.4	NN	75.0	73.3	75.0	66.7	33.3

(*) EA: Expectations achieved. QS: Qualified staff. CC: Consortium composition. EE: External expertise. AC: Acceptable

tional prerequisite for success in innovation processes. This conclusion is further supported by earlier research. Ramos-Sandoval *et al.* (2016) found that, in small-scale farming contexts, farmers' learning orientation and the effective use of research and extension services are key enablers of innovation. Although their analysis focused on individual behaviour, and ours on organisational dynamics, both studies point to the same underlying mechanism: the capacity of actors to absorb, interpret and apply knowledge. The convergence of evidence across different scales underscores the strategic importance of human capital development and knowledge facilitation in innovation policy.

In CL2 (Moderate Innovators), the relevance of the costs of innovative solutions increases steadily as the target percentage increases. It reaches a maximum in the 100% category with a value of 66.7%. This finding indicates that this facilitating factor becomes more crucial as OGs seek a higher level of achievement. Additionally, streamlining administrative procedures increases in relevance as the target percentage increases, reaching a maximum in the 100% category with a value of 33.3%.

In CL2, these factors support goal achievement. This finding highlights their importance when seeking higher levels of expectation achievement. Turner *et al.* (2023) reported similar findings. Furthermore, the absence of data in the "Not Necessary" ("NN") category suggests that these variables are significant for all analysed categories of achievement of expectations.

These findings address RQ2 and confirm the importance of tailored support for each cluster. It thus contributes to meeting the overall objectives of the EIP-AGRI programme. These findings provide empirical support for the strategic differentiation of innovation support services in AKIS, as recommended by Proietti & Cristiano (2022) and Neuberger *et al.* (2023). The profile-specific

bottlenecks identified herein could guide targeted interventions in the CAP Strategic Plans.

NCA adds precision by identifying non-compensatory factors by identifying non-compensatory factors that constrain innovation outcomes. Cluster analysis revealed intermediary profiles, and NCA the structural prerequisites without which innovation cannot occur, regardless of the strengths in other project components. Applying this logic helps anticipate weaknesses and better allocate support.

5. Conclusions

This study examined OGs acting as knowledge communities. It explored their internal management differences and their functions as innovation intermediaries. After assessing these differences, the facilitating factors that are necessary to provide innovative solutions were identified.

The study's findings address RQ1 by showing that the intermediary functions of OGs do not uniformly influence the achievement of their objectives. Instead, the influence varies across the three functional profiles identified through cluster analysis. For instance, OGs classified as Collaborative Leaders perform consistently high across all innovation functions and report the highest levels of success in achieving or exceeding their objectives (83.3%). In contrast, Emerging Explorers show lower engagement in intermediary roles and more modest outcomes (50%), while Moderate Innovators fall in between. This confirms a heterogeneous, context-dependent influence of intermediary functions rather than a uniform one.

These findings highlight the functional diversity of OGs within the EIP-AGRI programme, positioning them as a hybrid category of knowledge communities. As networks, OGs foster direct collaboration among stakeholders and support the co-creation and dissemination of innovations. As intermediaries, they facilitate connections and provide support services, catalysing the innovation process both within and beyond the group. This research illustrates the variety of functions and strategic orientations among Spanish OGs and supports the need for differentiated policy tools adapted to their operational realities.

These findings are particularly relevant in the context of the EIP-AGRI framework and its articulation through the EU Rural Development Programme (2014-2020) and the new CAP Strategic Plans. The diversity of intermediary profiles identified suggests that innovation support measures should be adapted to the specific capacities and needs of each OG type. This includes reinforcing targeted capacity-building for less mature groups (e.g., Emerging Explorers), simplifying administrative procedures to support Moderate Innovators, and incentivising collaborative practices among well-performing consortia. Therefore, rural innovation policies should adopt a function-oriented approach that complements the current project-based funding schemes with long-term strategies for strengthening multi-actor partnerships.

Regarding RQ2, the facilitating factors for providing innovative solutions vary significantly between groups. For OGs acting as Collaborative Leaders, selecting partners with qualified personnel is crucial from the outset. External experts play a pivotal role in helping OGs achieve ambitious innovation goals, particularly for Emerging Explorers. In contrast, Moderate Innovators prioritise reducing the costs of innovative solutions and facilitating administrative procedures.

Developing innovative initiatives that effectively address complex challenges requires the support of knowledge communities tailored to the unique characteristics and needs of different types of innovation groups. This recognises the different capacities and improvement areas of each cluster. The success of innovation programmes hinges on policymakers' ability to recognise and accommodate beneficiaries' varied interests, ensuring inclusivity and adaptability to diverse needs. Farm advisors and innovation agents should be ready to recognise and respond to the diverse interests and functions of participant groups within the same innovation programme.

In the context of the EU's new programming period for the Common Agricultural Policy and National Strategic Plans, these findings provide valuable guidance for fostering collaborative and efficient environments. Tailoring strategies to the strengths and weaknesses of each OG cluster can enhance synergies and knowledge

exchange, maximising innovation benefits. Policies should support collaboration, especially in catalyst groups.

Rural innovation policies should be flexible and adaptive, tailored to address the specific roles and functions identified within OGs. For Collaborative Leader OGs, ongoing support is crucial to maintain a holistic approach. OGs in the Moderate Innovators cluster require additional resources to manage costs and streamline administrative processes effectively. Emerging Explorer OGs would benefit from strategies that emphasise early consortium building and the incorporation of external experts to bolster innovation capabilities.

One potential limitation of this study is the response rate of 16.4%. Although this figure aligns with accepted standards in organisational research using online surveys (Baruch & Holtom, 2008), it may limit the generalisability of the findings. While the diversity of OGs represented and their alignment with regional distribution patterns provides some reassurance, future research should aim to confirm these behavioural profiles using larger and more representative samples.

This study's main limitations are its geographic scope and qualitative methods. Future research could employ quantitative approaches such as partial least squares structural equation modelling (PLS-SEM) to provide quantitative validation of necessary conditions and causal relationships. Exploring the nuances of innovation intermediaries in different contexts would also be valuable.

Acknowledgements

The authors acknowledge the support offered by the Ministerio de Ciencia e Innovacion (MCIN) and the Agencia Estatal de Investigacion (AEI) of the Spanish Government. This paper is part of the Project PID2023-150150OA-C32, funded by MICIU/AEI/10.13039/501100011033 and 'ERDF/EU'.

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Stakeholder mapping and engagement in living labs for co-designing nature-based solutions in sustainable land and water management

ALESSANDRA SCARDIGNO*, LORENZO LABELLARTE*, ZEIN KALLAS**, GEORGIOS MANEAS***, ABDALLAH ZAGHLOUL****, AHMED ELSHENAWY****, FARDOUS ZARIF****, HUSSIEN MOHAMED****, CHIARA CESERACCIU*****, PIER PAOLO ROGGERO******, SAID WAHBI*******, MOHAMED AIT-EL-MOKHTAR*******, JAVIER PÉREZ-ROMERO********, MONGI BEN ZAIED*********, FETHI ABDELLI*********

DOI: 10.30682/nm2505d
JEL codes: Q16, Q18, Q24, Q25

Abstract

The Living Lab approach is gaining popularity to promote the co-design of innovative nature-based solutions (NBSs) to improve the resilience of endangered Mediterranean dryland socio-ecological systems and to restore degraded ecosystems in lands arid and hyper-arid. However, the socio-ecological complexity of the rural and agricultural contexts of the Mediterranean presents specific potential and constraints that have been considered by six LLs in the context of the SALAM-MED PRIMA project. Identifying and engaging relevant stakeholders is a crucial first step. This ensures that all relevant voices are heard and that the solutions address the needs and concerns of the community. Since the stakeholder mapping phase and then in the co-design of the NBS, the LLs have been designed as spaces to generate lasting learning processes and tailored methodological approaches have been adopted to empower local stakeholders and support the scaling-out of NBS.

Keywords: *Living Labs, Nature-Based Solutions, Mediterranean drylands, Stakeholder mapping and analysis, Co-design, Socio-ecological systems*

* CIHEAM Bari, International Center for Advanced Agronomic Studies, Mediterranean Agronomic Institute of Bari, Italy.
** CREDA.
*** Navarino Environmental Observatory, Messinia, Greece; Research Centre for Atmospheric Physics and Climatology, Academy of Athens, Athens, Greece.
**** Desert Research Center, El Mataryia, Cairo, Egypt.
***** Desertification Research Centre (NRD), University of Sassari, Italy; University School for Advanced Studies IUSS Pavia, Italy.
****** Desertification Research Centre (NRD) & Department of Agricultural Sciences, University of Sassari, Italy.
******* Laboratory of Agro-Food, Biotechnologies, and Valorization of Plant Bioresources (AGROBIOVAL), Department of Biology, Faculty of Science Semlalia, Cadi Ayyad University, Marrakesh, Morocco.
******** Research Group in Forest Science and Technology (Re-ForeST), Universitat Politecnica de Valencia, Spain.
********* Laboratory of Eremology and Combating Desertification, Institut des Régions Arides (IRA), Tunisia.
Corresponding author: scardigno@iamb.it

1. Introduction

Nature-Based Solutions (NBSs) are innovative actions that, either inspired or supported by nature (EC, 2015), offer systemic responses to the challenges of sustainable development. Increasingly relevant in EU policies, NBS are promoted to achieve multiple goals and incorporate multiple economic, environmental, and social benefits and costs by influencing the well-being of different stakeholders.

The innovative nature of many NBSs increases the difficulty of designing, adapting and simulating them and requires further vision efforts to outline the solution in different future scenarios and according to different perspectives. Previous research demonstrates that the higher the number of services and stakeholder groups targeted, the lower the capacity to maximize the delivery of each service and simultaneously fulfill the specific needs of all stakeholders (Coletta *et al*., 2021; Lupp *et al*., 2021). The socio-ecological complexity of Mediterranean rural and agricultural contexts presents specific potential and constraints for adopting and adapting the LL approach and reveals further difficulties for a real and effective bottom-up approach (Yousefi and Ewert, 2023; Zingraff-Hamed *et al*., 2020). In this context, this work aims to provide answers to the following research questions: Which stakeholders are or should be part of a co-design and implementation of NBS? What systematic method of stakeholder mapping can support the process and be replicated?

Which approach/methodological tools can support the process of understanding the different perspectives, developing a collective view of the challenges, and identifying potential innovation pathways? Could a shared framework for evaluation facilitate a more inclusive and long-lasting potential innovation pathways?

2. Material and methods

2.1. *LL experience in SALAM-MED Project*

"Sustainable Approaches to Land and water Management in Mediterranean Drylands" is a Research & Innovation Actions project funded under the PRIMA 2021 program section 1. The project started in April 2022 and will have a duration of 3 years. SALAM-MED builds upon an interdisciplinary network of research organisations, Non-Governmental Organizations (NGOs), Small and Medium Enterprises and international organizations, with long-standing collaborative activities across the MED. The consortium is composed of a multidisciplinary team of 15 partners from 8 Mediterranean countries.

SALAM-MED aims at co-designing, testing, validating, and implementing an array of advanced technologies and management NBSs to improve the hydrological ecosystem services of MED dryland socio-ecological systems. They include water harvesting technologies – crop cultivation in wadi rivers (Egypt) and subsurface water retention in pastoral argan forests (Morocco) –, managed aquifer recharge to enhance the groundwater capacity of rechargeable aquifers (Tunisia), management of native forests and silvo-pastoral systems (Spain, Morocco, Italy), and integrated management of olive groves (Greece), plant phenotyping and symbiotic plant promoting microbial consortia to increase plant water use efficiency, drought resilience, and productivity (Italy, Egypt, Morocco).

SALAM-MED promotes co-innovation through six Living Labs (LLs) where innovative NBSs are co-designed through an inclusive social learning process to integrate traditional and scientific knowledge. The participatory process strengthens the resilience of rural communities by creating new business opportunities particularly for youth and women while the scaling out of SALAM-MED outcomes will be enabled through different actions and strategies: vegetation/hydrological/system dynamics modelling and climate change impact assessment scenarios; extended cost-benefit analysis; capacity building and science-policy interface actions.

Despite being different in terms of context and focus, all SALAM-MED LLs present the key five characteristics identified by the ENoLL – European Network on Living Labs – (Garcia Robles, 2015) and widely cited academic sources: multi-method approach, multi-stakeholder participation; active user engagement; real-life setting; co-creation.

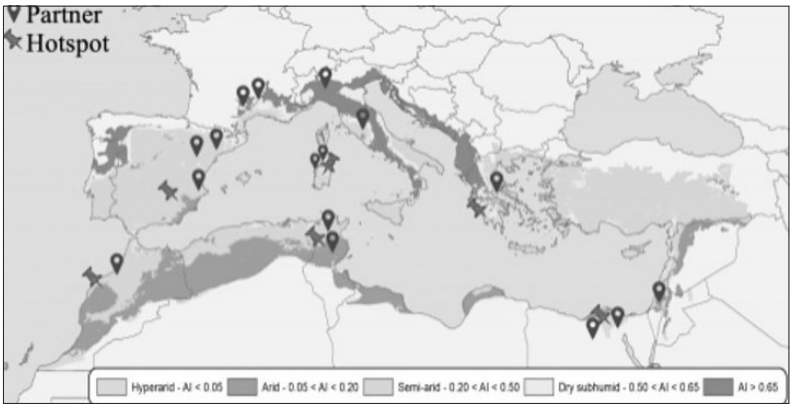


Figure 1 - Living Lab of SALAM-MED.

An extended framework, especially in agricultural or broader real-world implementations, often introduces orchestration as a sixth characteristic reflecting the LL's role as a coordinator of the innovation ecosystem (Schuurman *et al*., 2025).

2.2. *Stakeholders' mapping and analysis*

The proposed methodology has been applied in all the six LLs between September 2022 and April 2023. It includes identifying and defining individuals or groups of individuals who are directly or indirectly affected by the NBS, their role and their relationships; identification, determination, and analysis of one's interests, power, and level of influence on the project itself. The stakeholders' mapping consists of the three main phases: identification, analysis, and prioritizing.

Once the decision-maker and stakeholders' landscape are mapped, in-depth semi-structured interviews have been conducted with the Key-representative individuals amongst the decision-makers to analyze factors affecting the adoption decision and to deepen insight into the adoption processes.

In our research, we adopted a multi-phase participatory approach that combined both quantitative and qualitative methods. The initial identification phase involved a top-down screening based on existing literature and previous studies, followed by snowball sampling to include additional relevant stakeholders. For the prioritization step, stakeholders were assessed using four criteria – capacity, willingness, influence, and necessity – and ranked through the Analytical Hierarchy Process (AHP) to ensure balanced representation across the Quadruple Helix dimensions.

We then conducted open, semi-structured interviews with key representatives to validate priorities, explore perceptions, and collaboratively define the baseline scenario. By setting the state of the art of traditional knowledge, current practices, available research, and technologies, it also allows us to set the scenario which will be considered as the baseline in the monitoring and evaluation of SALAM-MED output and impacts. Interviews offered flexibility to capture diverse viewpoints and were complemented by contextual analyses.

Although we did not formally organize Focus Groups or World Café sessions, the Living Labs themselves served as interactive co-creation spaces. Within these labs, stakeholders participated in workshops and iterative discussions to refine priorities and co-design solutions.

2.2. *Identification of the potential stakeholders*

The first step in stakeholder mapping is the preliminary identification of relevant stakeholders. A clear and concise description of the project or initiative is essential at this stage, as it facilitates the identification process by defining the necessary characteristics and types of stakeholders involved.

Stakeholders should have clearly defined roles throughout their engagement. Therefore, a prioritization exercise is required to assess their relevance and determine their expected level of involvement. Identifying stakeholder roles is particularly important, as some actors may hold

greater influence or play more critical roles in the co-design process than others.

For the identification of the stakeholders, an initial stakeholder screening is used as a top-down approach since it is less time- and resource-consuming. This initial approach is based on a literature review and previously conducted studies to collect data on potentially related stakeholders to the project. In a second step, a bottom-up approach is usually used by means of a snowball-sampling where researchers ask stakeholders (from the top-down identified list) to nominate other stakeholders as potential interested in the project (Clausen *et al*., 2020).

An initial identification of the stakeholders has been performed taking into account: the stakeholders who have a direct relation with the project – direct stakeholders; the stakeholders who do not have a direct relation with the project – Indirect stakeholders; the stakeholders who support the success of the project – supporting stakeholders; the stakeholders who hinder the successful implementation of the project – competitor stakeholders.

Indicatively, the initial list of stakeholders may include: national or international organizations, regional or local administrators, agencies and authorities (national and international), research and innovation agencies (national and Europeans), universities, research centers, think thanks and institutions, NGOs, consumers, consultancy firms, Investors, national standardization bodies, national associations and European association (farming, food, consumers, forester, retailers), media, citizens and others.

For data protection reasons, the detailed list of stakeholders is not publicly available, although it has been compiled and used internally for the purposes of stakeholder engagement and analysis.

Therefore, stakeholders were classified into four dimensions – government, citizens, academia, and industry – according to the Quadruple Helix model (Carayannis *et al*., 2009), which frames the innovation and development process in a collaborative, dynamic, and multilayered context. This typological framework is consistent with the Quadruple Helix and Quintuple Helix innovation models, which extend the traditional Triple Helix model of innovation to address the complexities inherent in multi-stakeholder environments within sustainable land and water management initiatives. The Quadruple Helix framework emphasises the importance of socio-cultural actors and processes in innovation, aiming to align with public needs and ensure the social acceptance of new technologies and practices (Da Penha *et al*., 2024; Roman *et al*., 2020; Van Horne & Dutot, 2016). The Quintuple Helix model introduces an additional dimension, the natural environment, emphasising the importance of ecological preservation and the sustainable use of natural resources as central to innovation (Carayannis & Cambpbell, 2022).

The aim is to create knowledge- and needs-based solutions to complex social problems, promoting efficiency, responsibility, and social innovation. A balanced representativeness of each dimension has been ensured.

2.2.2. *Analysis of the potential stakeholders*

After the step of the stakeholders' identification, stakeholders have been analysed and their characteristics and profiles have been assessed. Different stakeholders may have completely different levels of interest and influence towards the project. Nevertheless, the stakeholders should represent a mix of perspectives, experiences and roles related to the project. The proposed approach aims at the qualitative assessment of specific stakeholders' components such as their degree of expertise, their willingness for participation and the overall impact, which is expected to be triggered by their involvement.

The evaluation is based on four specific criteria: i) capacity: evaluate the resource capacity of each stakeholder taking into consideration their knowledge, expertise and technical capabilities; ii) willingness: evaluate stakeholders' availability and willingness for participation; iii) influence: evaluate the number and the quality of stakeholders' connections, which can influence all the involved parties; iv) necessity: evaluate stakeholders' necessity for inclusion.

All the above criteria have been first assessed by the researcher (case study leader) in each case study to identify the weight of each criterion and to better adapt the weight of each criterion for the specificity of each Mediterranean region analysed.

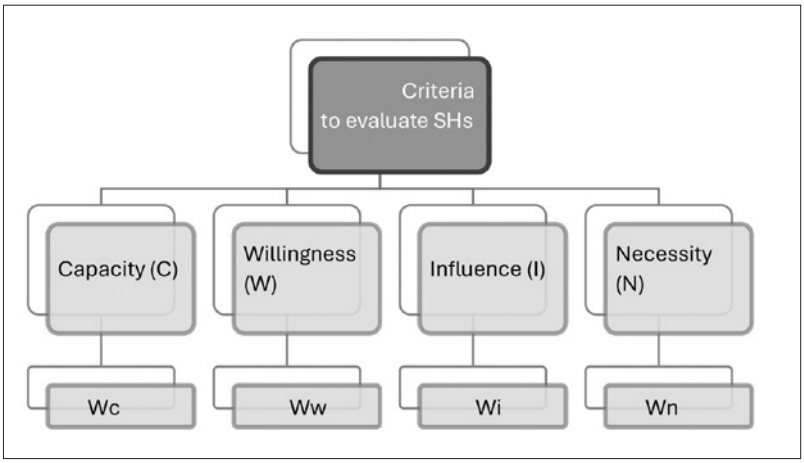


Figure 2 - The Analytical Hierarchical Process.

The prioritization of the criterion has been assessed through the Analytical Hierarchical Process (AHP) technique (Saaty, 1980). The AHP is a multi-criteria decision-supporting method in discrete environments that allows eliciting weights (w) (i.e., priorities) for elements or criteria that will be used to assess stakeholders. The priorities (w), also known as relative importance, are estimated for the criterion (Cn) where n is the number of the main categories. In our case, 4 main categories are identified: capacity, willingness, influence, necessity. A hierarchy then is created with the criterion to be assessed:

To implement the AHP, a question must be formulated (in our case, answered by the researchers) asking subjects to rate the criteria in pairwise comparisons. The researcher must then indicate which of the two elements is considered important for evaluating stakeholders, using a nine-point scale to measure the importance of this importance through verbal judgment.

2.2.3. *Prioritizing of potential stakeholders*

Once the criteria are analyzed, the next step of the stakeholders' mapping is the prioritization process which aims at the scoring (prioritization) of the identified stakeholders that should lead to identifying between 12-16 stakeholders which will represent the core members of LL.

Prioritization has been carried out in 2 different steps: the first one is based on pairwise comparing the Stakeholders type to identify the relative importance of the different categories for the project/innovations; the second one is based on comparing, for each type, the different stakeholders. In this step, and for stakeholders and types, the total score (priority) assigned to a stakeholder "*k*" (total number of stakeholder/Stakeholder category is K) will be estimated using the AHP, by evaluating jointly all stakeholders within the same type based on the 4 criteria mentioned before (capacity, willingness, influence and necessity). The number of pairwise comparisons to be made will depend on the total number of stakeholders identified. The initial outcomes of the stakeholder prioritization process required further adjustments. Specifically, some stakeholders have low scores, mainly due to their limited capacities in terms of knowledge and resources; yet, they have a considerable impact on the system of interest through their farming practices. After the interview process, we recalculated the mapping after the interview to ensure a correct ranking by co-designing the selection of the members in the LL.

2.3. *From the Mind Map to the Causal Loop Diagram: design thinking for co-creation*

SALAM-MED Living Labs are designed as learning systems for co-creation, i.e. the collaborative development of new concepts, solutions, products and/or services together with stakeholders. After the stakeholder mapping and analysis (Scardigno *et al*., 2022), a theory of change was identified to map out future innovation pathways and role of the different actors involved.

The co-creation process is structured within the framework of design thinking as a method to practically and creatively address complex and undefined problems, following a systemic perspective to appreciate multiple viewpoints, and incorporating a reflective monitoring approach. Among the several tools available in co-creation processes – spray diagrams; scenario-ing exercises, (Ison *et al*., 2014; Rickards *et al*., 2014), pathways approach (Wise *et al*., 2014; Cradock-Henry *et al*., 2021) – we focus on the co-development of Causal Loop Diagrams (CLDs) (Lane, 2008; Morecroft, 1982). CLDs are used to describe and analyse perspectives from different stakeholders; to develop a collective view of the challenges and identify potential solutions and innovation pathways; to create a common understanding within each LL and a common framework for evaluation within and across the LLs (Tiller *et al*., 2021). Moreover, CLDs provide links between variables that can be later transformed to quantified System Dynamics Models (SDM) for scenario analysis and for decision-support-making (Maneas, 2023).

Following an iterative process (Tiller *et al*., 2021), a first LL event was organised to provide the space for discussions among researchers and stakeholders, with the aim to grasp the main bio-geo-physical and socio-economic settings – and their connections – into a participatory mind map (MM). The process provided the base for a common understanding among the different stakeholders, while the generated MMs provided the graphical representation of the context-specific challenges.

After the workshop, the MMs were digitized by using the VenSim simulation software, and they were further processed to translate case specific social-ecological components into ecosystem services (Maes *et al*., 2020; Díaz *et al*., 2015). The aim of this exercise was twofold: to provide a common language across the different countries, thus allow comparisons between the case studies; and to allow the integration of socio-ecological metrics, and their interconnections with the suggested NBSs at a case study level. The last step of this process was to transform the MMs into CLDs by adding signs (plus or minus) to denote the nature of interaction between the variables.

During the second LL event, the generated CLDs were presented and discussed with stakeholders who were asked to validate their structure, by providing feedback on the nature of interaction between the variables, and their applicability in exploring business opportunities aligned with soil, water and biodiversity conservation objectives.
To evaluate the effectiveness of the CLDs as a tool/methodology/approach for co-designing NBSs in rural context, a short questionnaire was administered to LL managers. For each of the following questions:

1) Has CLD allowed the combination of different stakeholders' points of view on the main challenges of the current situation, on the representation of the dynamics of the system and on the priorities?

2) Does the CLD Loop Diagram allow you to properly include the ecosystem services in the narrative of the system?

3) Do you think that CLD could be useful to design the NBS and evaluate their impact on the system?

They were asked to replay by selecting values from 1 to 5, where 1 stands for "not at all", and 5 "very much".

3. Results and Discussion

3.1.1. *Identification of the potential stakeholders*

The mapping of seven LL systems across six different countries in the Mediterranean arid zones resulted in the identification of 11 primary stakeholder typologies, contextually adapted to the specific requirements of each case study (Table 1).

Table 1 delineates a comprehensive typology of stakeholders, formulated through iterative stakeholder mapping processes. This classification includes traditional value chain actors (producers, transformers, companies) and extends to encompass enabling actors (consultancy, agencies & institutions, public administration) as well as knowledge actors (education & research, partnerships), thereby reflecting the multifaceted nature of NBS co-creation within Mediterranean contexts.

Table 1 - Typologies of potential stakeholders.

Type	*Stakeholder*
Producers	Producers & Farmers
	Producers' Associations or Cooperatives
Transformers	HORECA
	Industry
Companies	International Private Company
	National Private Company
Consumers	Consumer's Associations
	Individual Consumers/ Citizens
Consultancy	Consultancy firms
	Marketing Consultancy
	Technical & Specialized Consultancy
Agencies & Institutions	International Organizations
	Public Agencies/Institutions
Public Administration	Local Public Administration
	Regional Public Administration
Education & Research	Institutions and centres for education
	Research centres, think thanks & institutions
	Universities
Partnerships	National or local associations
	NGOs
	Public-Private Partnerships
Investors	
Tourism Sector	

3.1.2 *Analysis and Prioritization of Potential Stakeholders*

To analyse the stakeholders identified in previous phases and to define a composition of the Living Lab suitable for the co-design process, a weight was assigned to the four selected criteria – capacity (CAP), willingness (WIL), influence (INF), and necessity (NEC) – reflecting the importance in the specific context of each Living Lab, as illustrated in Section 2.

Figure 3 demonstrates significant variations in the weighting of these criteria across the six LLs, underscoring the contextual differences in governance structures, resource availability, and stakeholder environments. Although the influence of context on co-creation processes is not extensively explored in the existing literature, Soini et al. (2023) argue that variations in the "real life context" in which LLs operate, encompassing ecological-physical, socio-economic, institutional, and research contexts, affect the co-creation processes of NBS in rural areas.

Figure 3 - Criteria's weight in the 6 countries.

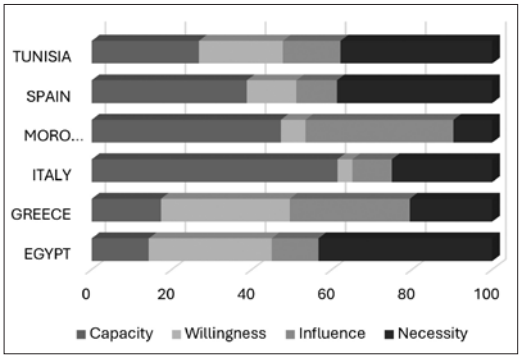
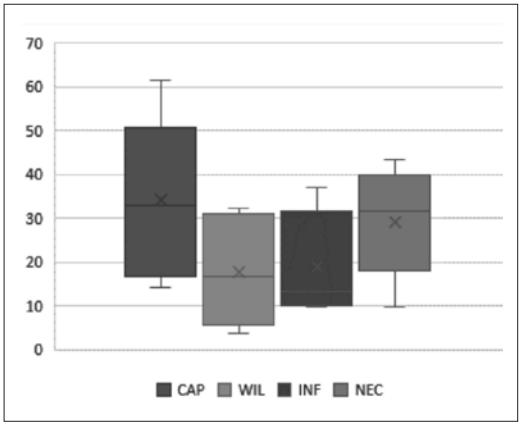


Figure 4 - Criteria's weight distribution.



The cross-country comparison also reveals distinct patterns in how stakeholders are prioritised. The box plot analysis (Figure 4) shows that the capacity criterion has the greatest variability, ranging from 15% to 50% across countries. This suggests significant differences in the relative importance of stakeholders' resource availability, including their knowledge, expertise and technical capabilities. Conversely, willingness and influence criteria show lower median values (17.7% and 18.8% respectively), indicating similar levels of importance for stakeholder motivation to participate and power dynamics across Mediterranean contexts.

3.1.3. *Comparative analysis of stakeholder maps across Living Labs*

Table 2 reveals striking differences in stakeholder ecosystem composition across the LLs, with several notable patterns emerging from the comparative analysis. Tunisia and Morocco show high representation of public agencies and regional public administration, with 70.86% and 44.56% respectively, reflecting centralised governance structures common in North African water management systems. This contrasts sharply with Spain's more distributed stakeholder composition, where no single category exceeds 19%, suggesting different approaches to multi-stakeholder governance in NBS implementation. The academic sector demonstrates remarkable variation, from minimal representation in Morocco with only 2.56% university participation to significant presence in Tunisia at 31.18% and Spain at 15-18%. This pattern suggests different innovation system maturity levels and knowledge transfer mechanisms across Mediterranean countries, with implications for the science-practice interface in NBS co-design processes. Civil society stakeholders are notably under-represented in Italy, Morocco, and Tunisia, with consumer associations and individual citizens showing minimal or zero representation. This gap contrasts with established participatory governance literature and suggests potential barriers to inclusive NBS co-design processes that warrant further investigation. Private sector engagement shows distinct geographical clustering, with Spanish Living Labs demonstrating balanced private company participation ranging from 8-12%, while North African Living Labs show minimal private sector involvement, potentially reflecting different economic development stages and market structures that influence NBS implementation strategies.

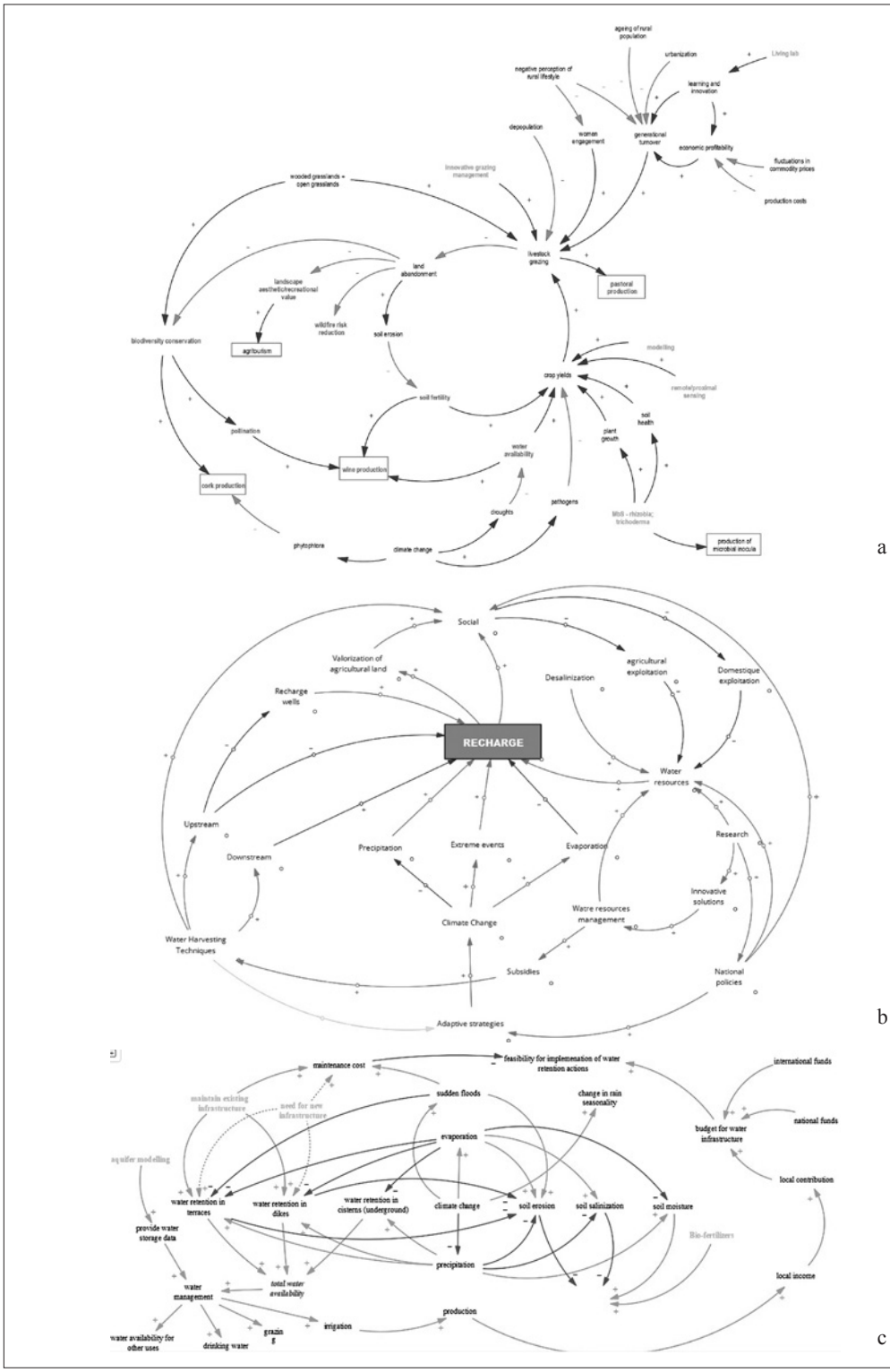
The stakeholder map's development followed the AHP process, yet it was dynamic, adapting to emerging priorities and perspectives from the participatory process. The preliminary results of the pair-wise comparison and prioritisation exercise were modified based on insights gathered from semi-structured interviews with local stakeholders. The comparison between ex-ante and ex-post weights reveals significant learning effects and adaptive processes throughout the LL implementation. The most pronounced change was observed in the Italian LL, where the representation of producers and farmers increased from 18.88% to 34.32%, nearly doubling their prioritisation weight. This shift indicates increasing recognition of the central role of farmers in NBS implementation and aligns with recent literature on farmer-led innovation systems (Eidt *et al*., 2020; Ensor & De Bruin, 2022). In Tunisia, there was remarkable consistency between ex-ante and ex-post assessments, with minimal changes across stakeholder categories, which may indicate either well-calibrated initial assessments or potential rigidity in stakeholder engagement approaches that warrants further investigation. In Greece, nuanced adjustments were observed, particularly with research institutions decreasing from 23.14% to 19.28% and producers' associations from 17.97% to 16.96%. These changes suggest iterative learning about optimal stakeholder balance for sustainability initiatives in olive oil production. These dynamic adjustments highlight the value of adaptive stakeholder mapping that respond to emerging insights and changing contextual conditions during NBS implementation processes.

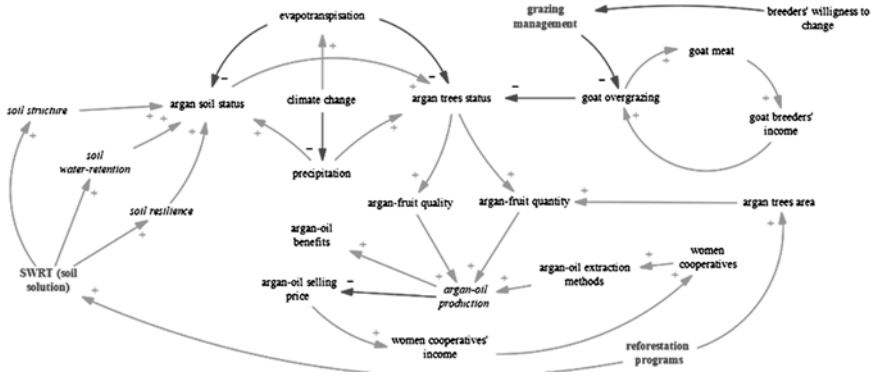
The Italian LL revealed initial under-representation of academia, highlighting perceived disconnection between scholarly research and practical knowledge within the local context. As the project advanced, academic institutions, especially universities and research agencies, were increasingly acknowledged for their capacity to close knowledge gaps and enhance innovation and sustainability outcomes. Results from the Tunisian LL highlight the central role of regional authorities (public administration) in water governance, with these institutions possessing comprehensive technical, organizational, institutional, and coordination capacities. Regional authorities supervise the work of operators (national agencies, regional associations, etc.), maintain alliances and influence with all institutional categories (research, private, civil society, etc.), and hold primary responsibility for the region's water sector management. The Greece LL highlighted the fundamental role of local olive oil producers and administrative bodies in adopt-

Table 2 - The potential stakeholders' list.

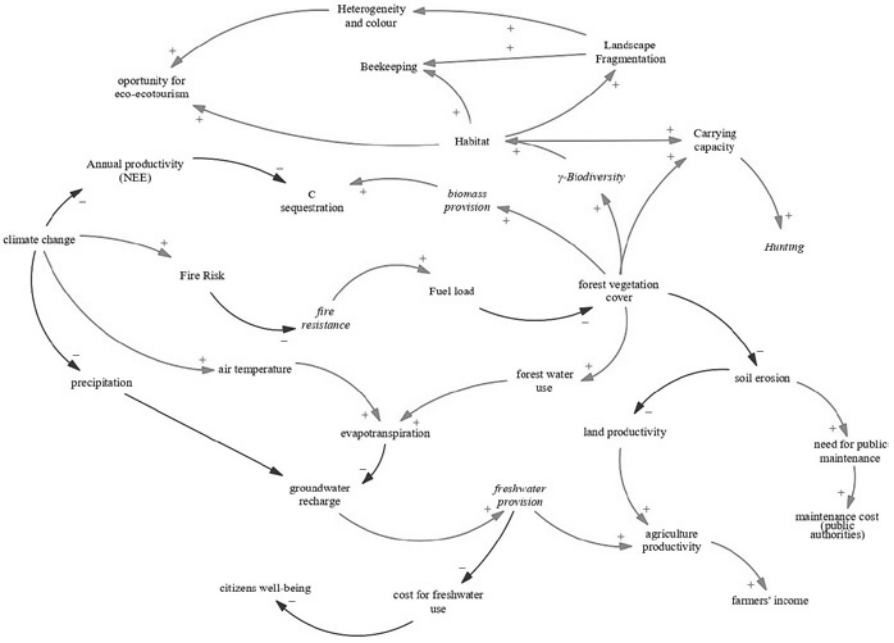
Type	*Stakeholder*	*Spain- La Calderona*		*Spain-Ayora-La Hunde*		*Tunisia*		*Morocco*		*Italy*		*Greece*		*Egypt*	
		Ex ante	*Ex post*	*Ex ante*	*Ex post*	*Ex ante*	*Ex post*	*Ex ante*	*Ex post*	*Ex ante*	*Ex post*	*Ex ante*	*Ex post*	*Ex ante*	*Ex post*
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
Producers	Producers & Farmers					4,18	4,18	18,79	18,79	18,88	34,32	20,82	19,82		
	Producers' Associations or Cooperatives							3,72	3,72			17,97	16,96		
Transformers	HORECA											1,16	2,16		
	Industry									59,07	46,33	1,58	2,57	4,13	6,00
Companies	International Private Company	8,77	4.23	8,30	3.90										
	National Private Company	12,60	10.41	11,92	9.60	3,64	3,64								
Consumers	Consumer's Associations	3,14	4.66	2,97	4.30			1,14	1,14						
	Individual Consumers/ Citizens													22,20	15,00
Consultancy	Consultancy firms											4,82	5,82		
	Marketing Consultancy			5,39	7.80							3,50	3,50		
	Technical & Specialized Consultancy											6,64	8,64		
Agencies & Institutions	International Organizations													14,43	8,00
	Public Agencies/Institutions	7,79	6.62	7,37	6.10	9,95	9,95	70,86	70,86	7,46	5,52				
Public Administration	Local Public Administration	12,69	13.23	12,01	12.20	2,02	2,02	1,94	1,94			17,97	16,85	8,56	12,50
	Regional Public Administration	13,40	18.87	12,67	17.40	44,56	44,56			3,63	2,81				
Education & Research	Institutions and centres for education	2,67	4.66	2,53	4.30									8,72	8,72
	Research centres, think thanks & institutions	8,46	9.44	8,01	8.70	0,93	0,93			7,26	6,00	23,14	19,28	13,01	15,25
	Universities	18,06	15.08	17,09	13.90	31,18	31,18	2,56	2,56		1,20			7,28	7,28
Partnerships	National or local associations	7,26	9.44	6,87	8.70	3,54	3,54							9,10	10,00
	NGOs	5,14	3.36	4,87	3.10					1,47	1,66			4,82	9,50
	Public-Private Partnerships									1,47	1,66				
Investors									0,99						7,75
Tourism										0.76	0,76	1,50	4.40		
TOTAL		100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00

Figure 5 - CLD of a) Italian b) Tunisian C) Egyptian d) Moroccan e) Spanish f) of Greek LL.

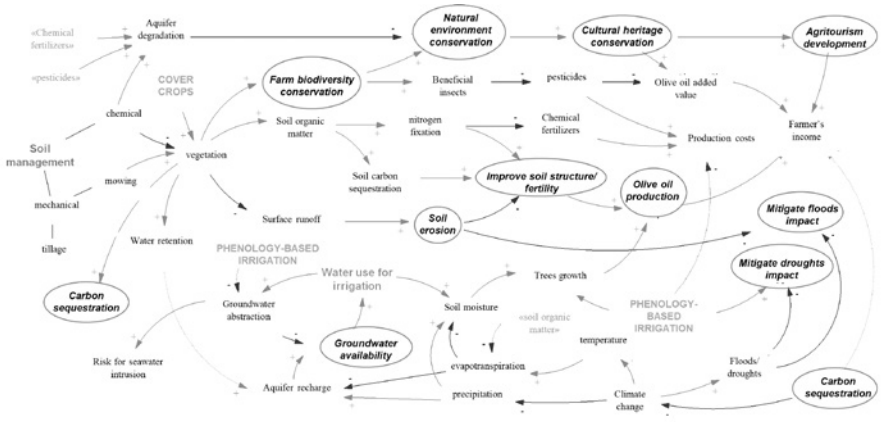



evapotranspiration
grazing management
breeders' willigness to change
goat meat
soil structure
argan soil status
climate change
argan trees status
goat overgrazing
goat breeders' income
soil water-retention
precipitation
soil resilience
argan-fruit quality
argan-fruit quantity
argan trees area
argan-oil benefits
women cooperatives
argan-oil extraction methods
SWRT (soil solution)
argan-oil selling price
argan-oil production
women cooperatives' income
reforestation programs

d


Heterogeneity and colour
Landscape Fragmentation
Beekeeping
oportunity for eco-ecotourism
Habitat
Carrying capacity
Annual productivity (NEE)
C sequestration
biomass provision
γ-Biodiversity
Hunting
climate change
Fire Risk
Fuel load
forest vegetation cover
fire resistance
precipitation
air temperature
forest water use
soil erosion
evapotranspiration
land productivity
need for public maintenance
groundwater recharge
freshwater provision
maintenance cost (public authorities)
agriculture productivity
citizens well-being
cost for freshwater use
farmers' income

e


«Chemical fertilizers»
Aquifer degradation
Natural environment conservation
Cultural heritage conservation
Agritourism development
«pesticides»
COVER CROPS
Farm biodiversity conservation
Beneficial insects
pesticides
Olive oil added value
chemical
Soil organic matter
nitrogen fixation
Chemical fertilizers
Farmer's income
Soil management
vegetation
Production costs
Soil carbon sequestration
Improve soil structure/ fertility
Olive oil production
mowing
mechanical
Surface runoff
Soil erosion
Mitigate floods impact
tillage
Water retention
PHENOLOGY-BASED IRRIGATION
Water use for irrigation
Trees growth
Mitigate droughts impact
Carbon sequestration
Groundwater abstraction
Soil moisture
«soil organic matter»
PHENOLOGY-BASED IRRIGATION
temperature
Groundwater availability
Risk for seawater intrusion
evapotranspiration
Floods/ droughts
Aquifer recharge
precipitation
Climate change
Carbon sequestration

f

ing sustainable farming practices, while emphasizing the importance of research institutions in in providing evidence-based recommendations in relation to suggested NBS (phenology-based irrigation, cover crops). This producer-research nexus aligns with agricultural innovation system literature while demonstrating context-specific adaptation mechanisms that emerge through participatory co-design processes (Prajapati *et al*., 2025; Soini *et al*., 2023).

The comparative analysis reveals several critical implications for NBS co-design and broader stakeholder engagement. Variations among LLs indicate that standardised stakeholder engagement strategies may not be adequate for addressing complex socio-environmental challenges. Instead, it is crucial to employ context-sensitive frameworks that account for local governance structures and LL maturity to facilitate effective multi-stakeholder collaboration. Furthermore, the differences between ex-ante and ex-post evaluations highlight the importance of iterative, learning-oriented stakeholder mapping that can adapt to emerging insights and changing contexts throughout LL implementation (Reed *et al*., 2009; Zingraff-Hamed *et al*., 2020).

3.1.4. *Development of CLDs and system analysis for Co-design*

Seven LL workshops were held from February to June 2023, engaging representatives from all four quadruple helix dimensions identified through the stakeholder mapping process

This methodological approach represents a systematic progression from stakeholder identification and prioritisation to active, collaborative knowledge creation and NBS co-design, through the development of six CLDs (Figure 5), which synthesise the complexity of each socio-ecological system as initially depicted in the mind maps.

This section synthesises the six CLDs developed across the LLs. We first provide concise case-by-case summaries, followed by a comparative table that reports dominant risks, ecosystem services, the principal NBSs or leverage points, and the expected effects (Table 3). We also provide a cross-case analysis highlighting convergences and context-specific differences that condition NBS adoption and performance. The six CLDs (Figure 5) provide an overview of the complex interdependencies within each LL's socio-ecological context, as well as the implemented practical solutions. The CLDs illustrate multiple relationship types among variables, including positive relationships, such as soil fertility enhancing olive oil production, negative relationships, such as reduced precipitation decreasing groundwater recharge, negative-to-positive relationships, such as reduced aquifer degradation promoting environmental conservation, and positive-to-negative relationships such as increased evapotranspiration reducing groundwater recharge. The visual representation facilitated stakeholders' understanding of the system's complexity, which would be difficult to articulate through traditional linear planning approaches.

The comparative analysis across LLs reveals significant differences in the perception of system complexity and the conceptualisation of environmental challenges by stakeholders. The number of variables incorporated in the CLDs varies considerably, ranging from 21 to 47, reflecting diverse stakeholder perceptions and priorities within their socio-ecological systems. The Italian LL, with 47 variables, demonstrates the highest complexity, suggesting a higher level of system awareness and more extensive stakeholder participation. Conversely, the Tunisian LL, with 21 variables, indicates a more focused problem-framing and potential constraints in stakeholder engagement processes. The variation in relationship mapping further enriches the analysis. Positive relationships range from 24 to 41 across LLs, while negative relationships span from 7 to 18, indicating different conceptual approaches to understanding system dynamics and feedback mechanisms. The nature of the variables is also different, as they were systematically categorised into "determinant variables" that drive system behaviour, "affected variables" that respond to system changes, "impacts" conceptualised through ecosystem services frameworks, and "strategies/actions" representing potentially adoptable NBS. This categorisation extends systems thinking approaches (Haraldsson, 2004; Meadows, 2008) and builds upon participatory systems dynamics methodologies

Table 3 - Dominant risks, Ecosystem Services, NBS and expected effects at a LL scale.

Case study	*Dominant risks / system focus*	*Key Ecosystem services addressed*	*NBS / leverage points*	*Expected effects (from NBS)*
Italy	Rural depopulation; land abandonment; fuel accumulation; soil erosion; loss of landscape value	Biodiversity conservation; wildfire risk reduction; soil conservation; agritourism; wine and livestock productivity	Sustainable silvo-pastoral & forest management; biotechnological innovation (plant phenotyping; microbial consortia)	Maintain functional grazing (open grasslands), lower fuel load, reduced erosion; higher infiltration & soil organic matter; stabilised yields and profitability; improved biodiversity and cultural value
Tunisia	Groundwater stress: declining rainfall, increasing evaporation; rising water demand	Groundwater recharge; water provision; soil conservation; food provision; social well-being	Managed aquifer recharge & recharge wells; adaptive strategies; governance enablers (policy, management, subsidies)	Higher recharge & seasonal reliability; reduced drawdown and pumping costs; lower dependence on desalination; improved agricultural performance and land value
Egypt	Rainfall variability and land degradation in wadi cultivation systems	Water regulation/ provision (total water availability); soil fertility; food provision	Rehabilitate/ expand harvesting & retention works; aquifer modelling; bio-fertilisers to rebuild soil function	Increased reliable supply; reduced conveyance losses; improved water-use efficiency via healthier soils; more stable yields and higher water productivity
Morocco	Overgrazing & vegetation loss in pastoral argan forests; erosion & runoff; limited infiltration/soil moisture	Water retention/ recharge; soil stabilisation; biodiversity; fodder provision; carbon sequestration	Grazing management (rest/rotation/stocking control); SWRT (subsurface water retention); reforestation/ assisted regeneration	Vegetation recovery; reduced erosion; higher infiltration/soil moisture; restored forest/pastoral services; better fodder and household incomes
Spain	Climate-driven fire risk via fuel accumulation; post-fire erosion and water-service decline	Soil fertility; biodiversity; carbon sequestration; recreation; fire regulation	Fuel-load management (thinning/strategic removal/prescribed burning); post-fire soil & cover recovery; landscape heterogeneity planning; water-sensitive forest management	Lower fire probability and severity; protected soils; improved recharge and freshwater provision; preserved carbon and biodiversity; reduced public maintenance costs; gains in eco-tourism
Greece	Over-irrigation → aquifer stress/ salinisation risk; soil degradation; biodiversity loss	Carbon sequestration; biodiversity conservation; soil structure/fertility; drought/flood effect mitigation; water regulation; agro-tourism, cultural heritage	Phenology based irrigation; agri-ecological vegetation management (cover crops, reduced tillage);	Lower pumping and salinity risk; higher soil moisture & infiltration; reduced erosion; improved pollination; stabilised olive yields & oil quality; reduced input costs

specifically applied to NBS design (Coletta *et al*., 2021). It is worth noting that some CLDs enabled documentation of socioeconomic factors, while others faced constraints in capturing these essential system components. This pattern reflects variations in stakeholders' understanding of the situation, diverse cultural approaches to integrating socioeconomic factors into environmental contexts, and potential limitations in the facilitation processes designed to integrate a broad spectrum of perspectives. The Italian and Greek LLs demonstrate more comprehensive socioeconomic integration, possibly reflecting established participatory governance traditions and higher stakeholder engagement experience in these contexts.

Italy – The CLD is centred on a socio-demographic and economic spiral – ageing popula-

tion, urbanisation, and low profitability – that weakens generational turnover and women's engagement, reduces grazing, and drives land abandonment. Abandonment increases fuel loads and soil erosion, degrading biodiversity and cultural services. Innovative grazing management, soil-health practices, and monitoring/biotech enablers support yields and profitability, stabilising the rural system.

Tunisia – Recharge is the pivotal node. Climate-driven precipitation variability, evaporation, and rising demand cause persistent water stress. Managed aquifer recharge, water harvesting, and adaptive strategies—enabled by policy and management—shift the system from depletion to reliability with knock-on benefits for agriculture and social outcomes.

Egypt – Resilience hinges on dual levers: (i) rehabilitating and siting new harvesting/retention works to raise total water availability, and (ii) restoring soil fertility (bio-fertilisers) to translate water into stable production. Aquifer modelling improves the payoff of investments and reduces losses.

Morocco – A grazing-vegetation-infiltration loop dominates. Overgrazing reduces cover, increases erosion and runoff, and constrains regeneration. Rotational/resting schemes, subsurface water retention and reforestation flip the system toward recovery, improving fodder, biodiversity, and local incomes.

Spain – Climate-amplified fire risk is central: higher temperatures and reduced precipitation increase fuel load and fire probability, with hydro-erosive externalities after burns. Fuel-load management and post-fire soil/cover recovery protect soils and water services while preserving carbon, biodiversity, and cultural values.

Greece – In olive-grove systems, over-irrigation and intensive inputs stress aquifers and degrade soils and biodiversity. Smart irrigation, and improved soil management (cover crops) reduce pumping, build soil water storage, stabilise yields and oil quality, and strengthen cultural/heritage values.

When the six CLDs are read side-by-side, buffering hydrology and building soil organic matter appear as recurrent leverage points that could strengthen resilience and sustainability across contexts (Table 3). The diagrams indicate that hydrological feedbacks are particularly prominent in Tunisia, Egypt, and Greece, whereas soil–vegetation interactions are more strongly emphasised in Italy and Morocco (e.g., reduced overgrazing/erosion, higher infiltration) and Spain centres on fuel-load–wildfire dynamics. Biodiversity recovery is repeatedly positioned as an amplifier that could reinforce soil protection, pollination (notably in Greece), and habitat conservation (Italy, Spain), thereby supporting more stable production. Recharge and water-use efficiency may be the most effective entry points where hydrological stress dominates (Tunisia, Egypt; and aquifer protection in Greece); fuel-load management may offer the clearest lever in Spain; moderating grazing pressure appears central in Morocco; and integrated land-use management with targeted innovation seems pertinent in Italy. The ecosystem-service emphasis also seems to vary by region: North African LLs foreground water/soil-linked provisioning and regulating services, whereas Southern European LLs additionally highlight cultural services and ties to high-value value chains (wine, olive-oil)—patterns that could inform how incentives for sustainability are framed.

The governance nodes in the CLDs indicate that feasibility may depend on context: public administrations are prominent in Tunisia (water) and Spain (forest/fire), cooperatives/farmers are central in Morocco and Greece, Italy shows mixed public–private roles, and in Egypt the adoption pathway appears to hinge on incentives, extension, and demonstration. Gender/youth elements suggest uneven burdens (e.g., water-related time costs, fire-related employment volatility) but also targeted opportunities (women's cooperatives in Morocco; youth engagement in digital irrigation/soil monitoring and quality-oriented chains in Greece/Italy).

Feedback from LL managers regarding the CLD methodology provides empirical validation for systems thinking approaches in environmental contexts involving multiple stakeholders. As illustrated in Figure 6, all six responding LLs unanimously concurred that CLDs facilitated the integration of diverse stakeholder perspectives on key challenges, system dynamics, and priority setting. In the discussions that followed,

Figure 6 - Answers of Living Labs to the first question.

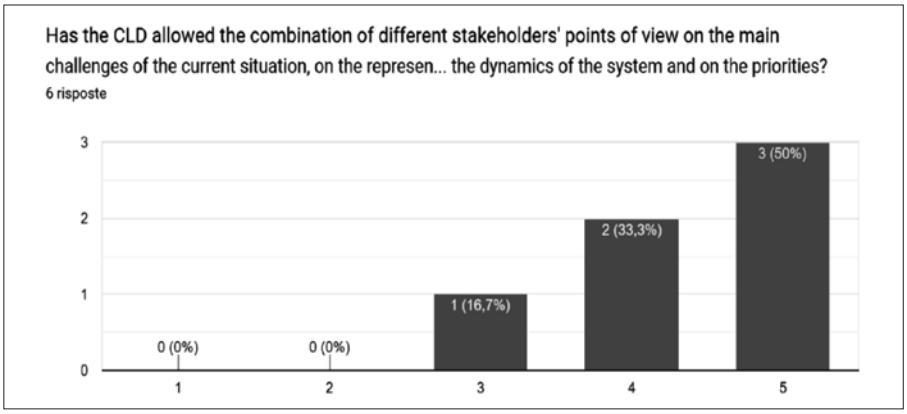


Figure 7 - Answers of Living Labs to the second question.

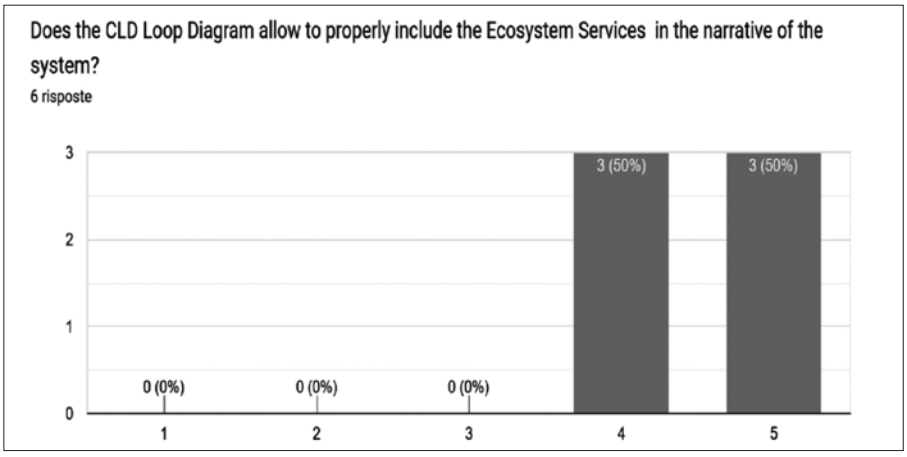
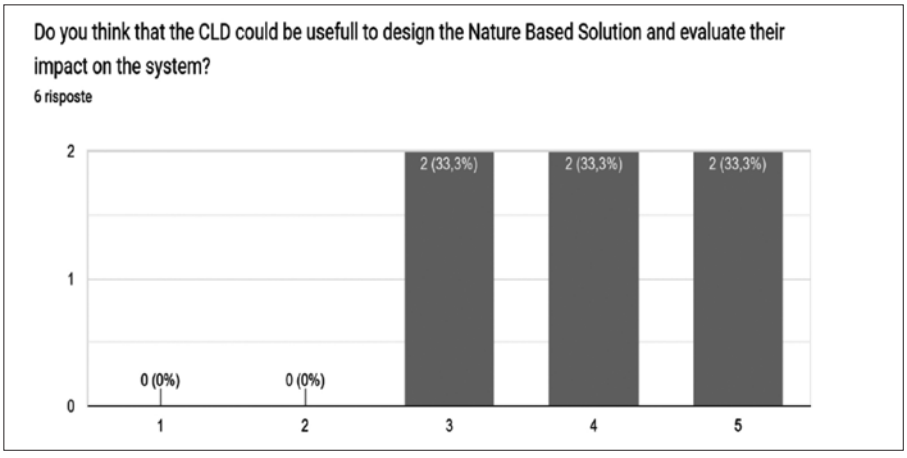


Figure 8 - Answers of Living Labs to the third question.



participants reported that putting reinforcing and balancing loops on a single map reduced disagreement about causes versus symptoms and created a shared language for discussing complex drivers (e.g., groundwater dynamics, soil fertility, biomass/fuel load, grazing pressure). The diagrams also helped stakeholders converge on priority leverage points within each Living Lab. Taken together, responses support the view that CLDs function effectively as boundary objects, improving mutual understanding and the legitimacy of agreed priorities. A few groups noted that common ground was easier to reach where socio-economic nodes (costs, incentives, labour/time burdens) were visible on the map—underscoring the value of integrating these variables in future iterations.

Figure 7 reveals consensus among LLs that CLDs enabled appropriate inclusion of ecosystem services in system narratives, representing a significant methodological advancement given documented difficulties in creating a shared vision about the existence and the relevance of ecosystem services in some contexts (García-Llorente *et al*., 2020; Lamarque *et al*., 2011). This contributes to addressing the well-documented challenges of divergent stakeholder perspectives alongside the discrepancies between scientific and local knowledge (García-Nieto *et al*., 2015).

Making ecosystem services explicit – especially groundwater recharge, soil conservation/erosion control, and biodiversity regulation (including pollination), and, in European sites, cultural services (recreation, heritage, landscape identity) – shifted discussion from single outputs to co-benefits and trade-offs. Stakeholders could trace how management choices propagate through ecosystem services to sectoral outcomes (e.g., soil protection → yield stability/quality for wine and olive-oil) and where short-term extraction may conflict with long-term regulation. Feedback suggests keeping a clear ecosystem services legend and using short, concrete ecosystem services → outcome chains (one-two steps) to support non-technical participants.

According to Figure 8, stakeholders consider the CLDs useful for designing NBSs and for anticipating and evaluating system-wide effects. The diagrams helped identify where to act (e.g., recharge and water-use efficiency under hydrological stress; fuel-load reduction in fire-prone forests; moderated grazing and soil-organic-matter build-up in pastoral systems), agree how to sequence measures (fuel management before reforestation; grazing controls before regeneration; irrigation scheduling and ground cover before varietal/biotechnological shifts), and define impact pathways and indicators aligned with feedbacks – hydrology (aquifer levels/drawdown, on-farm efficiency), soils (SOM, infiltration, erosion), biodiversity (indicator taxa, pollination), and production (yield/quality).

Figure 8 captures strong positive endorsement across all LLs regarding CLD potential for NBS design and impact evaluation, with stakeholders recognising the methodology's capacity to visualise cross-sectoral and socio-ecological interactions, alongside system impacts of proposed interventions.

Overall, stakeholder responses across Figures 6-8 show that the CLDs improved common understanding, brought ES into routine decision-making, and provided a workable scaffold for co-designing NBS, their sequencing, and their evaluation. Developed iteratively between the SALAM-MED research team and LL stakeholders, the CLDs integrated scientific expertise with local perspectives and practical knowledge. At the same time, two limitations emerged: (i) uneven representation of socio-economic variables that shape adoption, and (ii) dependence on facilitation quality and visual clarity to ensure inclusive participation. Addressing these through richer socio-economic nodes, standardised legends, and feedback-aligned monitoring could further strengthen the role of CLDs as living tools for co-creation and adaptive implementation.

4. Conclusions

"Systematic methods to identify the relevant stakeholders seem to be crucial to a) enable higher planning efficiency and b) reduce bottlenecks and time needed for planning, deciding, and implementing NBS. Future studies should also focus on the role of policy on the stakeholder constellation to co-create NBS." (Zingraff-Hamed A. *et al*. 2020).

The experience from the SALAM MED project demonstrates that it is essential to maintain a balanced selection of representatives from societal organizations, public bodies, the private sector, and scientific experts for stakeholder identification. This approach ensures the representativeness of all dimensions of the quadruple helix and promotes an open-minded consideration of potential stakeholders, acknowledging the innovative character of NBSs, which may introduce new markets, technologies, regulations, and legislation within socio-ecological systems.

The composition of the LLs facilitated an environment in which all participants felt at ease articulating their ideas, concerns, suggestions, and solutions. Most stakeholders expressed shared challenges and concerns, which facilitated harmonious discussions devoid of conflict. Nonetheless, the living lab occasionally comprises a diverse array of stakeholders, and their understanding of the interdependencies among seemingly independent activities and processes is limited. The analysis revealed the differing influence and adaptability of stakeholders. In the Italian LL, certain stakeholders, including vine growers, cork producers, and dairy factory proprietors, exhibited considerable resilience to economic, climatic, and ecological challenges. In contrast, shepherds, beef cattle farmers, and sheep breeders were regarded as less influential and adaptable due to restricted access to knowledge and resources. Nonetheless, livestock farmers are essential to the sustainability of the system, underscoring the necessity to bolster and enhance their capabilities.

Additionally, interviews indicated a widespread underestimation of the ecosystem services provided by socio-ecological processes, with numerous stakeholders neglecting the critical connections among economic productivity, ecosystem resilience, and socio-cultural values. Agriculture and forest management are regarded as separate economic activities rather than integral components of broader sustainability efforts. In such instances, stakeholders' perceptions of the connections between economic productivity, ecosystem resilience, and the socio-cultural importance of landscapes could worsen conflicts and hinder the creation of new learning environments to identify collaborative actions or practical solutions. This insight highlighted the necessity of expanding the stakeholder map to more accurately represent the complex nature of various socio-ecological systems and to effectively capture the interactions among economic performance, environmental health, and community socio-cultural dynamics, thus fostering a more comprehensive approach to sustainability.

The project emphasizes the significance of inclusivity in stakeholder engagement, especially regarding the participation of women and youth. By intentionally incorporating these frequently marginalized groups, the project enhances its depth through varied perspectives while promoting increased community engagement and empowerment. This inclusivity enriches the stakeholder map and, consequently, the overall research, guaranteeing that the results are both scientifically rigorous and socially equitable, accurately representing the community's complete demographic range. However, challenges arose when engaging women and communicating with illiterate stakeholders in the rural region. To surmount these challenges, particular strategies have been proposed and will be evaluated. This finding contributes to the existing participatory systems modelling literature by underscoring the importance of incorporating local knowledge, which is frequently neglected in traditional modelling, into the NBS planning process (Hemmerling *et al*., 2019). Finally, an essential aspect to consider is the flexibility of the stakeholder mapping process, which may result in ongoing adjustments to the chosen stakeholders. It is essential to retain a core group of stakeholders from each of the four dimensions of the quadruple helix, who are committed to the entire process and receptive to exploring new concepts and reassessing challenging issues. For instance, regarding policy makers, who may alter during the LL process, it is more prudent to concentrate on lower-level administrative stakeholders rather than higher-level elected officials.

Concerning the CLD participatory approach selected for the solution's design, its iterative

nature – involving systematic integration of research team expertise with stakeholder input – enabled the incorporation of different scientific expertise as well as stakeholder perspectives, perceptions and knowledge. This integration addresses criticisms of environmental modelling that depend exclusively on expert input, while also avoiding the limitations associated with unstructured stakeholder consultations (Gray *et al*., 2017; Krueger *et al*., 2012). The CLD methodology makes several contributions to the literature and practice of participatory environmental management. The approach empirically supports the efficacy of visual systems mapping tools in integrating diverse types of knowledge, addressing challenges in the integration of science and practice identified in environmental governance literature (Ceseracciu *et al*., 2025). By operationalising quadruple helix innovation principles in socio-environmental contexts, the methodology creates structured spaces for multi-stakeholder knowledge integration and collaborative problem-framing, advancing beyond consultation to achieve co-creation (Carayannis & Campbell, 2009; van Bruggen *et al*., 2019). Despite its complexity, it has yielded noteworthy outcomes in establishing a collective conceptual vision of the system and clarifying the interconnections and operations of its processes. It facilitated the identification of priority intervention areas and the establishment of new social learning environments. Enhanced social capacity and entrepreneurial prospects enable local communities to undertake effective initiatives for the restoration of land and water resources, as well as for bolstering the resilience of dryland zone ecosystems.

The findings contribute to the growing body of literature on participatory systems modelling by demonstrating the role of CLDs for NBS co-design (Coletta *et al*., 2021). This approach advances beyond traditional stakeholder engagement methods by generating tangible outputs that stakeholders can reference and modify during implementation, thereby facilitating adaptive management principles crucial for complex socio-ecological challenges that require ongoing adjustment in response to new insights and changing conditions.

However, the methodology revealed important limitations that warrant consideration for future applications and theoretical development, mainly related to its suitability to promote a smooth interaction with all stakeholders. Some stakeholders experienced challenges with the visual complexity of CLDs, particularly when these included numerous variables and feedback mechanisms. This underscores the need for effective facilitation approaches that address different levels of systems thinking expertise among stakeholder groups.

A more comprehensive assessment of the used methodology could be achieved through a deeper analysis of challenges related to the engagement of all stakeholders, and the importance of community ownership over processes, while a set of KPIs should offer a more objective analysis of the impacts. It could be also useful to explore the potentialities of the Quintuple Helix Model (Carayannis *et al*., 2012) to more explicitly consider into a transdisciplinary framework the interrelation among knowledge, know-how and the natural environment system recognized as a pivotal "component of and for knowledge production and innovation". As the project progresses, it will also be valuable to conduct a retrospective analysis of how the identified stakeholders interact, collaborate, engage, and interconnect throughout the entire lifecycle of a co-creation process. Additional research into this collaborative effort could yield insights into developing stakeholder engagement strategies and improving process design, ensuring the appropriate stakeholders are involved in NBS co-design initiatives at each LL.

Acknowledgements

This research has been funded by the SALAM-MED project (Sustainable Approaches to LAnd and water Management in MEditerranean Drylands) financed by the PRIMA (Partnership for Research and Innovation in the Mediterranean Area) program under Grant Agreement n° 2123. PRIMA program is an Art. 185 European Partnership supported and funded under Horizon 2020, the European Union's Framework Programme for Research and Innovation.

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Profiling tourist movements in rural areas with wine protected designations of origin: Analyzing tourist spending & accommodation patterns

JESÚS BARREAL PERNAS*, PILAR GAGO DE SANTOS**, JULIO VENA OYA***

DOI: 10.30682/nm2505e
JEL codes: C33, Q18

Abstract

This paper aims to analyse Spain's inbound tourism in low-populated areas (under 5000 inhabitants) within its wine-protected regions. Based on data retrieved from 2015 to 2023 from the national survey on tourism expenditure (EGATUR) and employing a Latent Class Model research method, we will segment Spain's inbound tourism (in terms of their expenditure, motivations and accommodation patterns) into four classes from the most profligate to the thriftiest while consuming tourism services in Spain's regions less populated, where the international demand is lower than Spain's average international demand for tourism services. The paper includes a statistical analysis (Wilcoxon and Lenven's tests) of the economic patterns of each class, concluding that it is essential to encourage Europeans to come to these destinations to improve the rural economy and their long-term sustainability.

Keywords*: Depopulated areas, Tourism demand diversification, Spain's wine-protected areas, Inbound tourism, Sustainable tourism, Latent class model.*

1. Introduction

Spain is a world leader in tourism production, a top destination for international demand, and the EU's most competitive and sustainable tourism industry since 2015 (Gago de Santos, 2022, WTTC, 2023; WEF, 2024). However, like other major European destinations[1], it presents several deep challenges regarding sustainability due to the extreme concentration of its international demand on the coastline[2] and significant urban destinations like Madrid, Barcelona, Granada, or Malaga (the capital of Málaga province). Tourism seasonality is also

* Complutense University of Madrid and University of Santiago de Compostela, Spain.
** Complutense University of Madrid, Spain.
*** University of Jaén, Spain.
Corresponding author: jvena@ujaen.es

[1] Particularly France, the United Kingdom, Germany and Italy though even more, smaller countries such as Croatia, Greece, Cyprus, Malta or Austria; to name the ones more overwhelmed by international demand at the peak season.

[2] Catalonia, Balearic Islands, Canary Islands, Andalusia, Valencia and Madrid account for over 90% of Spain 's international demand (Frontur, 2023).

quite pressing, particularly in the third quarter (Barreal *et al*., 2023a).

Concentration in space and time of international demand is a significant concern for Spain's tourism management (García-Buades *et al*., 2022). In this scenario, boosting international demand in less populated areas would bring plenty of benefits at different economic levels. For example, at the macroeconomic level, it would alleviate the pressure borne by the regions already suffering from congestion (Mihalic and Kuščer, 2021). On the other, at the microeconomic level, it would bring socioeconomic benefits[3] to those regions and people that make up the so-called "emptied Spain[4]", alluding to the territory being emptied of people (particularly young people) due to the massive exodus to the cities (Barreal *et al*., 2023b).

In recent years, but particularly since the surge of international demand in the aftermath of the Covid-19 pandemic crisis, Spain's tourism planning authorities have faced one of its most profound challenges in deviating some of its international demand to less saturated territories (Donaire *et al*., 2021). In such areas, other types of tourism services, such as rural tourism, ecotourism, agrotourism, wine tourism and gastronomy, among others, are being offered and remain still with great demand potential (Belanche *et al*., 2021). Thus, given the importance of international tourism in Spain and how it can represent an essential flow of financial resources and employment for rural areas, this research is relevant to the Spanish economy.

The impact of wine Protected Designations of Origin (PDO) in Spain is the largest compared to other agro-alimentary sectors because it implies a gross economic impact in 2022 of about 4.313 million euros (M€) and the remaining 2.417 M€ (including all types of protections and all products) (MAPA, 2023a; MAPA 2023b). Also, the economic impact of international markets is quite different; for the wine PDOs, it implies next to 41% of the total, and for the remaining product, it is slightly more than 17%. It underlines the robust brand that wine-protected labels have in international markets. It is also noteworthy because Spain has one of the highest wine consumption rates in the world. It is one opportunity to attract tourists to lower-density areas by taking advantage of the powerful international brand that provides the wine PDO for these destinations.

In short, our study aims to analyse Spain's inbound tourism from 2015 to 2023 in depopulated areas within wine-protected areas to understand their behavioral patterns concerning the activities they carry out, type of accommodation, and daily spending to help these regions attract a more desirable tourist profile. Our results show that the market of international tourists in these wine designations of origin is heterogeneous, reaching up to 4 different segments and identifying a series of strategies for each of these segments that can help the managers of these destinations to identify the most optimal tourist profile according to their nationality, expenditure, length of stay or travel motivations. It contributes to fill the gap in the current literature by providing a statistical method that could help depopulated areas with PDO to adapt their offerings by better understanding the international tourist demand and addressing socio-demographic issues.

The paper follows the structure below. It starts with a brief literature review and the research questions that the paper should address. The following section will describe the research methods and present the database that should support the response to the previous hypothesis. The latter sections will present the results and their implications for the topic as a previous step to depict the main paper conclusions.

2. Literature review

2.1. *An overview of wine tourism in depopulated rural areas—Wine tourism as a tool to soften seasonality*

Enotourism embraces visits to wine cellars, vineyards, wine tasting and wine festivals, among

[3] Employment and income, mostly.

[4] In Spanish this phenomenon has been coined as "España vaciada".

other wine-related experiences (Damijanić *et al*., 2016). Getz (2000) considered wine tourism from three different perspectives: "a form of consumer behaviour", "a strategy for destinations to develop" and "a marketing opportunity for wineries to sell directly to their customers and educate them on wine culture". Mitchell and Hall (2003) reckoned that seasonal tourism demand is one key reason for developing wine tourism regions, given the potential of enotourism to develop tourism flows during the non-peak season. Their study in New Zealand showed evidence of wine tourists' preference for late summer and fall seasons. So, this would open a win-win situation for host communities and the country's travel and tourism industry as a whole. In Spain, international wine demand is still far from its potential (Jannes & Barreal, 2024) and exploring ways to foster it will, on the one hand, help to alleviate the international demand pressure, particularly in the third quarter of the year and on the other, diversify the tourism offer. Along the same lines, other studies have focused on other types of tourism related to the Mediterranean basin, such as oleotourism (Vena-Oya and Parrilla-González, 2024). This type of gastronomic tourism has been identified as another driver of international tourist influx to these areas, as has been confirmed in various studies (Vena-Oya and Parrilla-González, 2024). It is an important factor in tourist satisfaction with these areas (Murgado-Armenteros *et al*., 2025) and generates certain income streams towards these regions (Parrilla *et al*., 2024).

In this sense, tourism sustainability embraces social, economic, and environmental dimensions (Blancas *et al*., 2010). Particularly from the social dimension, touristification and the excess of tourism carrying capacity in top international destinations have brought concerns in host communities before 2019 (Zelenka & Kacetti, 2014; Peeters *et al*., 2018; Milano *et al*., 2019). On the other hand, other host communities not suffering so strongly from the perception of over-tourism in their territory, which is more typical of cultural and coastal destinations (Vena-Oya *et al*., 2022), seek to attract tourists to obtain new and diversified sources of income to alleviate the effects of the seasonality of their principal activity, eminently agricultural in rural environments (Mercadé-Melé *et al*., 2018). Besides, these regions in Spain are facing serious issues such as depopulation (Vilar *et al*., 2017), income seasonality (Mercadé-Melé *et al*., 2018) or hardship in attracting the most profitable tourist segments to their territory (Barreal *et al*., 2023b). Among those destinations that seek to attract tourists away from overcrowded destinations, providing a slow and sustainable tourism experience (Li *et al*., 2024), we are witnessing a rapid boom in wine tourism in the main wine-producing countries (Sellers-Rubio *et al*., 2024). Moreover, wine tourism and food pairing may act as a contributor to tourist destination sustainability and competitiveness (Serra *et al*., 2021; Marco-Lajara *et al*., 2024). In this scenario, Spain shows a competitive advantage as the world's second most visited destination as well as one of the leading wine producers with a large number of protected designations of origin for wine (PDO), considered as a significant indicator of quality in wine production and as a differentiating factor in attracting the attention of international tourists (Tahar *et al*., 2021; Sellers-Rubio *et al*., 2024).

2.2. *Tourism in wine-producing regions*

The study of tourism in wine-producing regions has recently aroused the curiosity of the scientific community (Damijanić *et al*., 2016). This interest is partly due to the enormous potential these producing regions have in attracting tourists to areas that traditionally have not been top-rated destinations. (Gurgu & Fîntîneru, 2023), This allows the promotion of the destination and local produce (Gómez-Carmona *et al*., 2023), which can result in extra income beyond the tourism activity itself. Thus, recent literature has focused on the wine tourism experience itself, trying to analyse the emotions it arouses. (Wang *et al*., 2024), the experience lived in these destinations (Sellers-Rubio *et al*., 2024) or the motivations that lead a tourist to visit these destinations (Vorobiova *et al*., 2020; Santorinaios *et al*., 2023). Other authors have focused on more traditional topics, such as the profitability of these tourists over others with different motivations (Stone, 2023), on the opportunities that the attraction of international tourists to these

regions can bring to rural areas (Jannes & Barreal, 2024) or on the relationship between the sale of other non-wine products by tourists visiting these destinations (Yang *et al*., 2023). On the other hand, besides spending, another factor of vital importance for tourist destinations is the length of time tourists stay. Some authors have conducted studies on this topic; however, these focused more on regions not so specialised in wine production (De Simone *et al*., 2024) or on other types of products, such as EVOO-producing regions (Barreal *et al*., 2023b). Thus, bearing in mind these three key factors in the generation of sustainable tourism (motivations, spending and stay length), segmentation is a vital tool for analysing the most interesting tourist profiles for wine-producing regions (Murgado-Armenteros *et al*., 2021; Barreal *et al*., 2023b). Other attempts to segment the tourists visiting these regions have been found in the literature; however, they focus on those exclusively engaged in wine-related activities and not on the tourists who used to visit these wine-producing regions. (Cho *et al*., 2017; Szolnoki, 2018; Santos *et al*., 2020; Gómez-Carmona *et al*., 2023).

Moreover, another essential factor in analysing tourism demand is the type of accommodation tourists prefer in a destination. Recent studies have shown how these preferences have changed in the wake of the COVID-19 pandemic, especially regarding the choice of international tourists, who increasingly opt for individual rather than shared accommodations (such as Airbnb) (Ye *et al*., 2023). Other works segment tourists based on what they are willing to pay for accommodation, the length of stay and their principal motivation in the destination in urban tourism (Liu *et al*., 2015). If we focus on tourism in rural areas, Frías-Pérez *et al*. (2021) also found differences in preferences between resident and non-resident tourists visiting national parks, concluding that non-residents opted for more sustainable options such as apartments or campsites, especially in high season. Finally, other authors such as Nutsugbodo *et al*. (2022) found that other sociodemographic factors such as age, sex or income level could also influence the choice of accommodation type. All in all, this paper aims to analyse the profile of tourists visiting wine PDOs regions based on their motivations, spending profile and length of stay, for which the following research questions are formulated:

RQ1: Depending on the main motivations, are there differences in tourists' behaviour in Spain's low-populated wine PDO areas?

RQ2: Are there distinguishable accommodation patterns among international tourists in depopulated areas of Spanish wine PDO?

RQ3: What role do accommodation types play in increasing the daily revenue of this tourist market in the area?

3. Methodology & data - research methods

In the early stages of wine tourism research in the 1990s, most of the data were collected at the wine cellar, which may be well suited to measure wine consumer satisfaction but not so well suited for determining the latent demand that may exist within a given target market (Getz & Brown, 2006). That is why in this paper we employ data provided by EGATUR (INE, 2024a), Spain's national survey to account for international tourism spending, in order to offer responses of the international demand while traveling to highly depopulated areas within wine protected areas. The questionnaire is implemented when the tourist departs from Spain, and it includes questions related to their socioeconomic characteristics, the activities enjoyed during the stay, and the payments made in origin and in the country (INE, 2024b), among others. As in the survey, there is a question which provides data about what the principal destination during their visit was. Therefore, the paper will only use the data provided by the tourist that affirms their principal destination was in a Spanish wine PDO, which council population is lower than 5.000 inhabitants in 2023 (INE, 2024c). EGATUR, managed by INE started in October 2015, so the analysis initiates the database at this point and finishes the same month for 2023. Considering only the respondents who declare a principal destination to Spanish wine PDOs with low-populated councils, the final database has 13.499 questionnaires, representing a risk of

Table 1 - Summary variables implemented in clustering.

Variable	*Level Definition*	*Rate*
Nationality	Lv.1: Benelux	16,36%
	Lv.2: UK	17,31%
	Lv.3: Germany	20,70%
	Lv.4: France	21,10%
	Lv.5: Others	24,54%
Season	Lv.1: Winter	19,14%
	Lv.2: Spring	23,73%
	Lv.3: Summer	36,00%
	Lv.4: Autumn	21,13%
Visitors	Lv.1: Alone	28,63%
	Lv.2: Couple	40,07%
	Lv.3: Group	31,30%
Daily Activities. Expenditures	Lv.1: Lower than 4,05€ (Q1)	25,00%
	Lv.2: From 4,05€ to 8,84€ (Q2)	25,00%
	Lv.3: From 8,84€ to 17,27€ (Q3)	25,00%
	Lv.4: Upper to 17,27	25,00%
Daily Shopping Expenditures	Lv.1: None Expenditure (Q1)	43,07%
	Lv.2: Until 1.64€ (Q2)	6,93%
	Lv.3: From 1.64€ to 6,16€ (Q3)	24,99%
	Lv.4: Upper to 6,16€	25,00%

Variable	*Level Definition*	*Rate*
Main Motivation	Lv.1: Cultural & Leisure	34,34%
	Lv.2: Sun and Beach	39,36%
	Lv.3: Family visit	15,57%
	Lv.4: Others	10,73%
Sports	No	70,01%
	Yes	29,99%
Shows	No	93,50%
	Yes	6,50%
Party	No	81,22%
	Yes	18,78%
Shopping	No	46,88%
	Yes	53,12%
Museum	No	74,06%
	Yes	25,94%
City Tour	No	34,84%
	Yes	65,16%
Beach	No	35,83%
	Yes	64,17%
Gastronomy	No	81,77%
	Yes	18,23%

error of 1,11% with a confidence level of 99% (p=q=0,5).

Some different statistical techniques should be required to answer the research questions. Then, to solve the RQ1, the paper proposes segmentation by following the Linzer and Lewis (2011) methodology. These authors propose a Latent Class Model (LCM) with covariates, which first develops a clustering outcome by considering a set of factors. Later, they perform a logistic regression to analyse how some exogenous variables could condition the class membership. They also propose a double-check to set the number of clusters the model should calculate, first considering the AKAIKE and Log-Likelihood ratio parsimony and later analysing if the groups or class are significant enough to be included in the model. The ratios should find the number of clusters where introducing one more does not imply a considerable ratio reduction/increment. On the other hand, the different clusters should be big enough to be representative and be coherent with the data and literature.

The analysis will consider the principal motivation to visit Spain, the origin, travel companions, the visit season, and the daily expenditure on activities and shopping (clothing, jewelry, typical products, or souvenirs) to implement the clustering. It aims to describe the socioeconomic and touristic profile; however, the paper will also contemplate their activities, such as those related to sports, shows, parties, shopping, city tours, beach enjoyment or gastronomy. Table 1 describes all these factorial variables by indicating their levels and representation in the database. The outcome highlights, for example, that around 75% of questionnaires are from four countries and more than 70% visit Spain accompanied. Following the activities, the responses note that most tourists get to know cities, go to the beach, and go shopping; however, a remarkable 18% declare that they enjoy gastronomy activi-

Table 2 - Covariates summary considering complete EGATUR survey and study sample.

		Hotel	*Rental Accom.*	*Other Market Accom*	*Owned dwellings*	*Family & Friends Accom.*	*Other non-Market Accom.*
Accommodation	*Research Sample*	32,73%	10,15%	9,46%	18,52%	26,42%	2,73%
	EGATUR database	54,88%	6,25%	3,41%	9,23%	24,87%	1,36%
		Min	*Q1*	*Q2*	*Mean*	*Q3*	*Max*
Stay Length (in days)	*Research Sample*	1	5	7	11,59	14	180
	EGATUR database	1	4	7	9,80	10	300

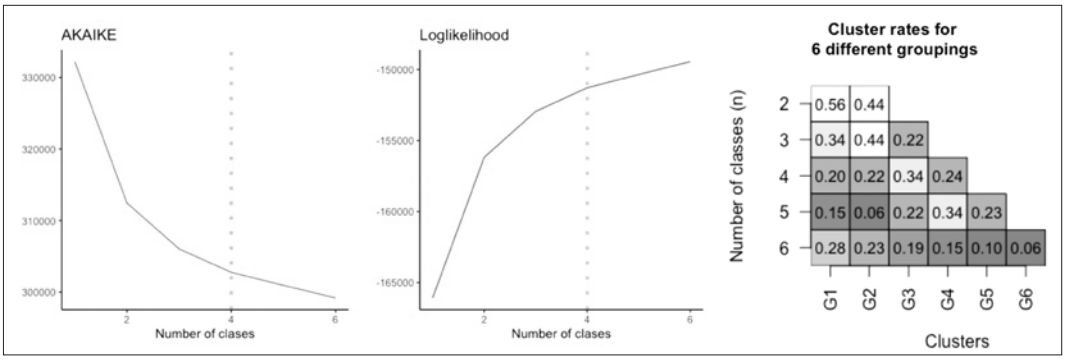
ties, and 25% visit museums. The results present lower values than the national data for the same study period, with the respective rates of 20,32% and 36,16%. The lack of identification of gastronomic activities could be the main reason for this lower value; as Gil and Barreal (2024) suggested, international tourists may not identify some activities as gastronomic even though they really enjoyed them during their visit. It highlights the importance of developing specific programs to promote the characteristics of gastronomic activities among international visitors.

The EGATUR database provides monetary data at current prices, which should be constant to aggregate in quartiles and compare the values between periods. Therefore, the pre-analysis processing considers the Consumer Price Index (CPI) based on 2021 to convert current prices into constant with the same temporal scope (INE, 2024d).

The modelisation employs a logistic regression after the clustering analysis to determine how the class membership could fluctuate considering two exogenous variables: the stay length (in days) and accommodation choice. The model also considers the cross-effect of these two variables. This point is vital to solving the RQ2 because of the relevance of regression coefficients and forecasting different stay lengths according to each type, which could help better understand how the segment representation could change if the accommodations are modified. It is a novelty in the accommodation sector derived from the model's capability to help regional and rural managers adapt their offerings according to their market position targets. Table 2 summarises the covariates according to the current study sample and EGATUR database and it depicts differences between accommodations and stay length. The whole questionnaire shows a strong influence of hotels, in which half of the respondents declare they will use these accommodations; meanwhile, for the study area, it drops to a third. The stay length is, on average, lower for the entire database than the study sample.

The last step involves analysing significant differences and comparing variance between clusters to solve the RQ2 and RQ3. The stay length and expenditures are the variables implemented to learn more about cluster differences and how they could change if public and market policy focused on one group instead of the others. The first involves an ANalysis Of VAriance (ANOVA) (Chambers *et al*., 1992)., which considers the null hypothesis (Ho) that cluster means are equal. The alternative hypothesis (H1) proposes that at least one is unequal. The variable should be normally distributed, so the Jarque-Bera test should be run to confirm or reject it (Jarque and Bera, 1987). In case of rejection, the analysis will consider a non-parametric analysis denominated Kruskal-Wallis test to know if at least one group differs from the others. Previous tes is general, so, in case of rejecting the null hypothesis, then the analysis should perform the Wilcoxon rank sum test with continuity correction, which lets cluster paired analysis and identify the groups with different patterns (Wilcoxon, 1945; R Core Team, 2022). The test to compare the variance ratio will expand the analysis. It allows us to compare two variances between groups (σclassi/

Figure 1 - AKAIKE and Log-Likelihood ratio and classes relevance in the function of the number of clusters implemented.



σclassj for all i=/=j) by analysing whether the variances are similar or different. The F test could be applied; however, it is sensitive under non-normal variable distribution, and its confidence intervals are not robust. So, if the data present this characteristic, the research will employ Levene's Test (Fox and Weisberg, 2019). That is, a variance ratio analysis is performed in which if the variances are equal (Ho), the ratio is one and otherwise, it will be different (H1), being less than 1 when σclassi>σclassj and greater otherwise (Yanagida, 2024).

4. Results

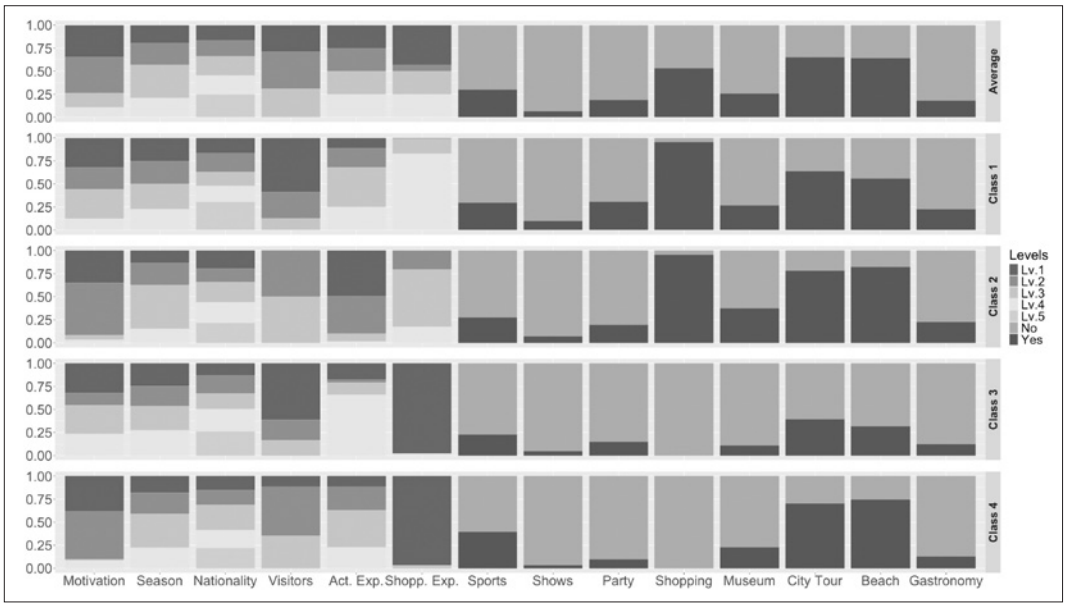
The analysis shows that the best number of samples to use in the segmentation is four. This is supported by the fact that it is the point where the AKAIKE statistic is reduced the most and where the Log Likelihood increases the most, in addition to offering groups or classes of considerable volume and with a qualitative analysis that allows describing the classes with tourist relevance. Following Figure 1, if the number of segments is increased, then the statistics do not improve as much as in the case of the increase from three to four, and some groups are tiny.

Applying the segmentation with four classes, their characteristics are obtained following the factors implemented to get them. The first row summarises the distributions for the total sample for each variable. This is arranged to facilitate the understanding and differentiation of each segment for the overall market. Each of the following classes can be classified according to their characteristics:

- *Class 1. Consumerist traveller (22,68%):* Lone low-season tourist who spends much more on shopping than the rest, coming mainly from the United Kingdom[5] plus other markets not considered main markets for Spain. In terms of activities, he/she mostly does shop, while the remaining activities are below the average of the sample.
- *Class 2. High peak season cultural and shopper traveler (32,94%):* These are mainly cultural tourists who visit accompanied during the high season (summertime). Their spending on shopping is high, though low in activities, which are mainly urban tourism, museums, and sun and sea tourism.
- *Class 3. Selective solitary European traveler (20,43%):* A *lone visitor from Germany* or other countries visiting during the fall-winter season who spends a lot on activities but nothing on shopping but does activities, so in the ones he does, he/she ends up spending a great deal of money.
- *Class 4. Active summer travelers (23,95%):* French travelers or from other major tourist-sending countries who travel in summer accompanied and do not spend money on shopping but on activities, especially sports, visits to cities or the beach.

[5] The United Kingdom is Spain's largest source market for inbound tourism.

Figure 2 - Class classification by factorial clustering variables.



We can thus answer the first of our research questions, which asked whether there were differences in the motivations of international tourists visiting the wine PDOs. Thus, we see how these differences are indeed evident between the different classes, where the first class, mainly British, are much more interested in shopping activities than the others. On the other hand, we find tourists whose main motivation is urban-cultural in Class 2, who prefer to visit these destinations in high season. The third class, called "solitary tourists" are mainly Germans who prefer to travel in the cold season and perform different activities related to the destination itself, showing less interest than the previous classes in shopping. Finally, the fourth class is mainly composed of French tourists, mostly motivated by a more active tourism.

Moving to the other RQs, in this segmentation, the average length of stay was 13.09 nights in Class 1, the highest of the four classes. In turn, and respectively, the averages of 12.61, 9.07 and 10.89 nights were recorded. Almeida *et al*. (2021) suggest that the impact of distance and the first country visit has significant implications on stay length; so, rural areas do not have fast and accessible connectivity and provoke that international tourists should spend more time to arrive than other destinations, implying a higher cost opportunity that only more extensive stays could palliate. The data also shows that more than 90% of each group is the first country visit, so previous arguments could explain why rural areas record higher lengths than the national average. Thus, Class 1 has more extended stays than the rest and has more accentuated shopping patterns, making it a very interesting class on which to focus the sale of local products. By contrast, it is observed that this result can be deviated by 16.20 nights, while for the rest, this deviation is smaller (11.46, 12.17 and 10.31, respectively). To better understand the relevance of each class, we can observe which is more interesting, taking into account the daily expenditure; thus, the one that spends the most on average is Class 3 (97.21€), followed by Class 1 (85.70€), 4 (68.34€) and 2 (45.40€). This implies that Class 3 is the most interesting in terms of strengthening the economic flows derived from international tourism.

Following Nutsugbodo *et al*. (2022), the relevance of socioeconomic variables such as gender, age, or income on the identified groups is analyzed. In this regard, Pearson's Chi-squared test is applied to examine whether there is a dependency between these factors. As shown

Table 3 - Proportion of socioeconomic descriptors by class.

	Class 1	*Class 2*	*Class 3*	*Class 4*	*Pearson's Chi-squared test*
Age					
Less than 24	34,51%	24,42%	21,99%	19,08%	p-value: < 0.001
From 25 to 44	22,64%	32,75%	20,82%	23,79%	
From 45 to 64	20,93%	34,72%	20,20%	24,15%	
More than 65	18,76%	36,43%	18,80%	26,01%	
Gender					
Man	19,62%	34,07%	21,76%	24,54%	p-value: < 0.001
Woman	25,24%	33,17%	18,31%	23,28%	
Income					
High	22,54%	33,18%	20,21%	24,06%	p-value: < 0.001
High/mid	19,96%	37,50%	18,28%	24,27%	
Mid	22,68%	32,89%	20,60%	23,83%	
Mid/low	24,37%	22,64%	28,30%	24,69%	

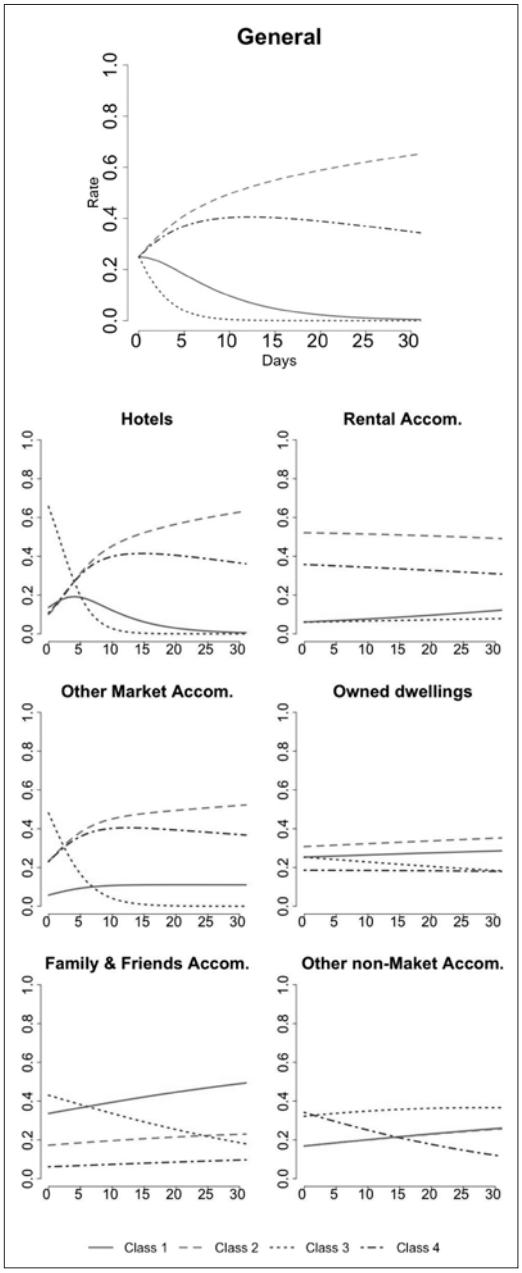
in Table 3, there is evidence of dependency between the obtained classes and the selected socioeconomic variables. The p-values are less than 0.001, indicating statistically significant associations between the variables and classes. There is a clear trend showing that younger individuals are overrepresented in Class 1, while older individuals, especially those over 65, are more concentrated in Class 2. In gender terms, the men are more represented in Class 2 and Class 3, whereas women are more represented in Class 1. Finally, high/mid income are predominantly in Class 2, whereas those with mid/low income are most represented in Class 3.

Once the classes had been identified, a logistic regression was applied to obtain the elasticities of the exogenous variables and determine the percentage of each class according to these variables. The results of the regression can be consulted in Appendix 1. From these results, the forecast of each class according to the type of stay and its duration has been made, as shown in Figure 3. With this, it is observed that Class 2 will grow as the length of stay increases, a similar case to that of Class 4, but once the ten days are passed, it begins to decrease. Class 3 is only present in very short stays; it disappears from the market when it exceeds five days. A similar situation occurs with Class 1, although its gradual decrease is more prolonged.

On the other hand, when types of establishments are broken down, we observe that rental accommodation and owned dwellings are the most inelastic establishments for the length of stay. While in hotels and other market accommodations, the composition of demand is susceptible to short stays and less to extended stays. Regarding the remaining accommodations, we find that there are sustained patterns of changes as the stay evolves, but not with a very high sensitivity. This is very useful for studying how the market evolves in response to changes in the average length of stay at a global level or by type of accommodation, but it does not indicate whether, in this analysis, there are significant differences within the sample that would allow us to know whether stays are longer or shorter depending on the class and/or type of establishment.

Table 3 summarises the stays for each class and analyses whether there are significant differences between accommodations in Table 4, showing that there are, in general terms, with a very high level of confidence, except between Class 1 and 4, which drops considerably. However, it is still significant for p-values above 0.2%. The analy-

Figure 3 - Cluster membership rates depending on the accommodation and stay length (x-axis).



sis considers the Wilcoxon statistic because all data present a non-normal distribution according to Jarque-Bera test results. This means that there may be no difference in length of stay between these two classes, so attracting any of these two classes may not result in any change in length of stay. On the other hand, the shift from Class 3 to 4 significantly increases the average length of stay.

The analysis can also be replicated to study the differences in stays between establishments within each class. Thus, hotel stays are shorter than in vacation rental accommodations or owned housing. This can be framed in terms of the cost since it is the most expensive on average among all the options considered. Out of the other options, the difference between other market and non-market accommodations is positive when Class 3 is studied and negative when Class 4 is studied, with no significant differences detected for the rest of the classes.

Class 2 and 1 generally have more extended average stays, while Class 1 and 3 have the highest daily expenditures. Therefore, it seems essential to promote the segment of spenders because they are a segment that will guarantee higher occupancies or to encourage the class group of solitary Europeans who are very selective in their activities if what is sought is to promote daily spending. Note that the analysis does not consider the variable dispersion in the class, so if its variability is high, it will imply that it is a class with more uncertainty in income guarantees. As the data is non-normal distributed, the paper considers Leven's test to know if variances between classes could be equal. In global terms, the analysis shows that Class 1 and 2 present the highest stay length however, the variance analysis indicates that Class 1 presents more highly significant variability than Class 2. Daily and total expenditure is higher in Class 1 and 4, but the first oscillates much more than the second.

In an analysis by type of accommodation, it is observed that the hotels in Class 2 and 4 present many days of stay but with low daily expenditure, while the remaining ones are the opposite. However, Class 3 shows much more relevant variability in daily spending than Class 1, while it is the opposite regarding stay and total expenditure. In total terms, Class 1 and 4 are those that spend the most, but if the volatility of both is analysed, it is much higher in Class 1. This means that group 4 seems to be the most desirable in this type of accommodation as it presents higher occupations and less variability in income.

Table 3 - Average terms of stay length, daily expenditure and total expenditure by class and accommodation type.

		Class 1	*Class 2*	*Class 3*	*Class 4*
General	Stay Length	13,09	12,61	9,08	10,89
	Daily Expenditure	85,70	45,40	97,21	68,34
	Total Expenditure	890,56	481,20	606,70	647,10
Hotel	Stay Length	6,20	9,08	3,70	8,56
	Daily Expenditure	139,15	62,10	158,98	85,52
	Total Expenditure	882,35	540,90	573,75	713,60
Rental Accom.	Stay Length	20,45	11,53	13,36	11,23
	Daily Expenditure	116,92	45,80	129,01	65,70
	Total Expenditure	1796,21	471,06	1167,70	653,05
Other Market Accom.	Stay Length	12,56	12,78	4,45	11,35
	Daily Expenditure	111,03	48,68	127,15	67,48
	Total Expenditure	1094,46	543,82	525,58	702,26
Owned dwellings	Stay Length	20,22	20,69	15,54	18,17
	Daily Expenditure	66,18	27,69	76,72	36,10
	Total Expenditure	1088,95	504,74	778,62	580,30
Family & Friends Accom.	Stay Length	12,57	12,02	9,04	12,98
	Daily Expenditure	66,22	26,68	69,66	33,22
	Total Expenditure	726,17	291,80	517,03	406,89
Other non-Market Accom.	Stay Length	9,97	11,67	9,14	5,69
	Daily Expenditure	78,89	30,14	88,69	54,82
	Total Expenditure	677,23	300,15	551,47	265,57

Table 4 - Class comparisons using the Wilcoxon rank sum test with continuity correction.

	1-2	*1-3*	*1-4*	*2-3*	*2-4*	*3-4*
General	> 0,001	> 0,001	0,002	> 0,001	> 0,001	> 0,001
Hotel	> 0,001	> 0,001	> 0,001	> 0,001	> 0,001	> 0,001
Rental Accom.	0,404	1,000	1,000	0,012	0,006	0,534
Other Market Accom.	0,001	> 0,001	0,082	> 0,001	> 0,001	> 0,001
Owned dwellings	> 0,001	> 0,001	0,313	> 0,001	0,001	> 0,001
Family & Friends Accom.	0,001	> 0,001	0,012	> 0,001	0,649	> 0,001
Other non-Market Accom.	0,044	0,432	0,216	0,003	> 0,001	0,735

In rental accommodations, Class 1 presents the highest total expenditure; however, it has the most significant and elevated variance ratio compared to the remaining groups. So, if the market is focused on this group, they should provide more resources to withstand the possible economic fluctuations. For the owned dwelling, the stay length is higher in Class 1 and 2; however, the expenditures are higher in Class 1 and 3. In variance terms, in the first case, the variance analysis shows a significant and positive difference for Class 1, and in the latter, the variance is more considerable to Class 1 than 3 for total expenditure but the opposite for daily.

Thus, and taking into account the different analyses performed above, we can answer RQ2 (Dif-

Table 5 - Variance ratio and Levene`s test coefficient signification codes.

		1-2	*1-3*	*1-4*	*2-3*	*2-4*	*3-4*
General	Stay Length	1,41***	1,33***	1,57***	0,94.	1,11***	1,18***
	Daily Expenditure	2,07***	0,87***	1,58***	0,42***	0,76***	1,82***
	Total Expenditure	2,41***	1,69***	1,79***	0,70***	0,74***	1,06*
Hotel	Stay Length	1,17	2,04***	1,12	1,74***	0,96	0,55***
	Daily Expenditure	2,05***	0,74***	1,46***	0,36***	0,71***	1,97***
	Total Expenditure	2,86***	2,13***	1,84***	0,74***	0,64***	0,87
Rental Accom.	Stay Length	4,27***	1,94**	3,03***	0,46***	0,71*	1,56***
	Daily Expenditure	1,84***	0,66	1,34**	0,36***	0,73***	2,03***
	Total Expenditure	6,94***	2,51**	3,71***	0,36***	0,53***	1,48**
Other Market Accom.	Stay Length	1,48***	4,96***	1,52***	3,34***	1,02	0,31***
	Daily Expenditure	1,50**	0,93.	1,73.	0,62***	1,15**	1,86***
	Total Expenditure	1,22***	2,28***	1,27***	1,87	1,04**	0,56*
Owned dwellings	Stay Length	1,17**	1,22**	1,26***	1,04	1,08	1,04
	Daily Expenditure	2,97***	0,57***	2,09***	0,19***	0,70***	3,66***
	Total Expenditure	2,66***	1,52***	1,98***	0,57***	0,75*	1,31***
Family & Friends Accom.	Stay Length	1,39***	1,25***	1,13*	0,89	0,81*	0,91*
	Daily Expenditure	4,18***	1,30	3,73***	0,31***	0,89*	2,87***
	Total Expenditure	3,23***	1,44***	1,97***	0,45***	0,61***	1,37*
Other non-Market Accom.	Stay Length	1,49	1,01	2,57***	0,68	1,73***	2,55***
	Daily Expenditure	2,76***	0,56**	1,38.	0,20***	0,50***	2,47***
	Total Expenditure	3,86***	1,13	3,39***	0,29***	0,88	3,01***

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

ferences in accommodation patterns) and RQ3 (accommodation patterns + daily revenue). First of all, different accommodation patterns are observed between classes (RQ2). While, in general, Classes 1 and 3 are the most attractive in terms of expenditure, it is Classes 1 and 2 that have the longest overall length of stay. Looking at the different types of accommodation, the most profitable type, or in other words, the one that represents the highest average daily expenditure, would undoubtedly be the hotel, especially for those classes of British (1) and German (3) tourists.

On the other hand, if what is sought is to retain the tourist in the destination, rental accommodation would be the most recommendable option for the different classes. Returning to daily profitability (RQ3), it is undoubtedly (see Table 3) the option of staying with friends and family that is the least recommendable, as it does not seem to transfer the saved lodging expenses to other activities (Vena-Oya *et al*., 2022). In general, and in response to research questions 2 and 3, different patterns of behavior can be observed in terms of spending and days of stay based on the types of accommodation for the different classes found. Thus, in a strategy of daily profitability, Class 3 (Germans) would be the most interesting in a strategy more focused on the rotation of tourists, while Class 1 (British) would be the most advisable in a strategy of renting and obtaining income in the longer term.

5. Discussion & conclusion

Prior studies have tried to segment the tourist visiting a wine-producing destination based on their motivations, spending or length of stay (e.g. Szolnoki, 2018; Santos *et al*., 2020; Gó-

mez-Carmona *et al*., 2023); however, one of the main contributions of this paper is that it focuses on international tourists visiting these regions, not just wine tourists. In addition, many of those studies focused on data from tourists who engaged in wine tourism (surveys in wineries and restaurants, among others), so the present study expands the analysis to those who do not consider that they travel to consume wine tourism. Thus, at the academic level, it is observed how, through segmentation, Destination Management Officers (DMOs) can focus their attention on the different tourist profiles, trying to better adapt the offer to their expectations and demands, thus trying to generate stable income flows from tourism in areas traditionally excluded from tourism activity (Barreal *et al*., 2023b). On the other hand, the study of the behavior of tourists visiting destinations whose main activity is not tourism has been studied in depth. Thus, differences have been observed in terms of spending profile, average stay and motivations, as suggested by different authors on the heterogeneity of these markets and the possibilities of obtaining higher income that their correct identification entails (Hristov and Zehrer, 2019; Sigala, 2020).

In terms of accommodation, our study data shows that, generally speaking, in Spain, on average, almost 55% of inbound tourists prefer staying at hotels, but in our research sample, barely 33% of the inbound tourists in those destinations choose a hotel for their accommodation. As far as rental accommodations are concerned, in our research sample, almost 10% of the sample chose to rent accommodation, a share higher than in Spain's general database (around 6%). In our sample, other non-market accommodation[6] options have almost the same share (10%) as rental accommodation. This share is much more relevant in our sample than Spain's average accommodation preference dataset (3,5%). Finally, we also state that in these less populated regions, owned dwellings by non-residents and their stays in family and friends accommodations are much more relevant than in Spain's general sample (see Table 2), moreover, taking into account the higher daily expenditure, this option does not seem to shift expenses to other activities (Vena-Oya *et al*., 2022).

Taking into account, therefore the profiles found, a series of contributions are made at the management level of these destinations. Firstly, it is observed that it is the segments of tourists who travel mainly alone (1 and 3) that show the highest spending profile. These tourists prefer to travel in times of low tourist demand, which is highly attractive in order to minimise tourist seasonality and the problems that this entails (Barreal *et al*., 2023a). Tailoring activity packages according to their profile (mainly an active tourist who wants to do as many activities as possible in the destination) will be key to attracting their attention. On the other hand, tourists in segments 2 and 4 have a lower spending profile than the previous ones, they do prefer to travel during high season and reveal different motivations. While tourists in the second segment prefer cultural tourism activities, those in the fourth segment are more active, and managers must adapt to these profiles as well. Taking this into account, from a sustainability perspective it seems reasonable for tourism planners to promote the demand of groups 1 and 3 who show a higher spending rate and a tool to soften tourism seasonality.

On the other hand, DMOs should also focus on a differentiation strategy, based on their main strength (being wine PDOs) and on the motivations for wine presented by different segments of the population (mainly middle-aged and older). These strategies should follow an approach based on sustainability and environmental protection, an element that makes these destinations unique, but should also look at the other dimensions of sustainability (Blancas *et al*., 2010), such as economic and social, trying to attract profiles that wish to engage in slower tourism and with higher spending profiles, which corresponds to segments 1 and 3. Furthermore, with regard to the economic sustainability of these destinations, DMOs can take into consideration the segments found in order to establish the most appropriate strate-

[6] Campings, hostels, rural lodgings.

gies for their destination, taking into account the range of activities of the destination. Thus, a high profitability strategy in a destination that wishes to attract tourists for a short period of time would be to focus on Class 3 or German solitary tourists, while for a tourist retention strategy, where the priority is to obtain income by increasing the length of stay, Classes 1, 2 and 4 would be the most recommendable. Thus, the key would be to focus on different segments and offer fully adapted seasonal packages to them, for which this type of work can help destinations to make decisions in this regard (Barreal *et al*., 2023b).

This paper contributes to the existing literature by analysing low-populated areas with some protected primary production, using data from international wine tourists who are not typically engaged with these regions. It builds upon the methodology proposed by Jannes and Barreal (2024) by focusing specifically on low-population areas and placing an emphasis on stay length and accommodation. Additionally, this study extends the work of Vidal-Matzanke and Vidal-González (2022) as well as Ramos-Ruiz *et al*. (2024) to include Protected Designations of Origin (PDO) areas. The tourism implications affect various economic sectors and can help mitigate depopulation trends. The paper also complements the research of López-Sanz *et al*. (2021) by presenting a methodology aimed at balancing tourism offerings with demands in low-populated areas, thereby enabling sustainable development that conserves cultural heritage and the environmental resources.

This research has a number of limitations. Firstly, it focuses on a single destination such as Spain. Despite being one of the world's main wine producers and inbound tourism receiver and exporter, it would be interesting to analyse and compare to other markets such as France and Italy in Europe, the United States in America and Australia in the Asia-Pacific region. Secondly, the data was from international tourist who declared the areas as the primary destination and did not consider their country moving to other places or destinations. The tourist movement analysis requires a separate study to determine how the internal country distance is spent in national routings and its effect on accommodation choice and expenditure patterns. Third, the paper does not involve specific activities linked to the wine PDO; it only includes gastronomic activities, but sometimes the proper visitor does not clearly identify this activity and only associates them with visiting a wine cellar or Michelin restaurant when the gastronomic experience involves more local cultural assets than that.

Following previous limitations, future research should seek to compare and define the different international behaviours between rural and urban areas, including the comparison between rural areas without any specific agro-gastronomic protection and those with it. Furthermore, revealing more about different international patterns between areas could enrich the literature, and it could also be an important argument for producing public and private programs to expand this tourism niche in areas with lower economic development.

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Appendix 1

Table 6 - Latent Class Model model with covariates outcome.

Fit for four latent classes:

1/2	*Coefficient*	*Std. Error*	*t value*	*Pr(>|t|)*
Stay length	0,163	0,011	15,553	0,000***
Hotel	-0,313	0,105	-2,995	0,003**
Rental Accom.	2,150	0,161	13,361	0,000***
Other Market Accom.	1,388	0,164	8,469	0,000***
Owned dwellings	0,195	0,087	2,238	0,025*
Family & Friends Accom.	-0,667	0,093	-7,178	0,000***
Other non-Market Accom.	-0,443	0,336	-1,317	0,188
Stay Lenght * Rental Accom.	-0,188	0,013	-14,800	0,000***
Stay Lenght * Other Market Accom.	-0,158	0,013	-11,886	0,000***
Stay Lenght * Owned dwellings	-0,163	0,011	-15,104	0,000***
Stay Lenght * Family & Friends Accom.	-0,167	0,012	-14,175	0,000***
Stay Lenght * Other non-Market Accom.	-0,164	0,023	-6,991	0,000***

1/3	*Coefficient*	*Std. Error*	*t value*	*Pr(>|t|)*
Stay lenght	-0,308	0,024	-12,695	>0,001***
Hotel	1,573	0,125	12,551	>0,001***
Rental Accom.	0,118	0,212	0,558	0,577
Other Market Accom.	2,120	0,273	7,766	0,000***
Owned dwellings	0,050	0,088	0,563	0,574
Family & Friends Accom.	0,247	0,065	3,793	0,000***
Other non-Market Accom.	0,649	0,206	3,145	0,002**
Stay Lenght * Rental Accom.	0,294	0,025	11,533	0,000***
Stay Lenght * Other Market Accom.	-0,006	0,049	-0,114	0,909
Stay Lenght * Owned dwellings	0,294	0,024	12,014	0,000***
Stay Lenght * Family & Friends Accom.	0,268	0,024	10,934	0,000***
Stay Lenght * Other non-Market Accom.	0,298	0,027	11,154	0,000***

1/3	*Coefficient*	*Std. Error*	*t value*	*Pr(>|t|)*
Stay lenght	0,143	0,011	13,251	0,000***
Hotel	-0,233	0,103	-2,270	0,023*
Rental Accom.	1,773	0,148	11,978	0,000***
Other Market Accom.	1,385	0,160	8,657	0,000***
Owned dwellings	-0,309	0,100	-3,087	0,002**
Family & Friends Accom.	-1,701	0,129	-13,200	0,000***
Other non-Market Accom.	0,708	0,245	2,887	0,004**
Stay Lenght * Rental Accom.	-0,170	0,012	-14,198	0,000***
Stay Lenght * Other Market Accom.	-0,149	0,014	-10,907	0,000***
Stay Lenght * Owned dwellings	-0,148	0,011	-13,144	0,000***
Stay Lenght * Family & Friends Accom.	-0,140	0,013	-11,001	0,000***
Stay Lenght * Other non-Market Accom.	-0,192	0,027	-7,092	0,000***

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Olive oil price prediction with machine learning algorithms

ISABEL RAMOS GALÁN*, JUAN J. CUBILLAS**,
RUTH M. CÓRDOBA***, LIDIA M. ORTEGA****

DOI: 10.30682/nm2505f
JEL codes: C45, Q11

Abstract

The main objective of this study is to develop a machine learning model to accurately predict the price at origin of Extra Virgin Olive Oil (EVOO) in Jaén (South Spain), addressing the growing importance of price prediction in the food sector. The methodology used integrates an exhaustive set of predictor variables obtained from official sources between 2011 and 2024. These variables range from historical base price, seasonal factors and production costs, to climatic conditions, economic indicators, global oil production, and early prediction of olive crop production. Several regression algorithms are applied and compared, including Linear Regression, SVM, Neural Networks, Random Forest, Gradient Boosting and K-Nearest Neighbors. The results highlight that ensemble models, particularly Gradient Boosting and Random Forest, show superior predictive ability and are more effective in capturing the complex non-linear relationships and market inflections that affect the price of EVOO. Crossvalidation confirms that the use of the multivariate ensemble consistently improves accuracy over using the base price alone, validating the relevance of the selected attributes and their ability to reflect market dynamics. A pattern of price behaviour is detected that is significantly influenced by weather conditions, crop production, energy costs, speculation and global markets, factors that the ensemble models manage to model effectively.

Keywords*: Extra virgin olive oil, Machine learning, Regression algorithms, Multi-source data, Price prediction.*

1. Introduction

The economic growth and development of regions and countries is usually measured by macroeconomic indicators, which are deeply intertwined with food industry and consumption. Changes in these macroeconomic indicators can directly or indirectly impact the entire food supply chain, from agricultural production and processing to retail and consumption. This makes that fluctuations in food prices can detrimentally impact both price stability and the purchasing power of individuals (Borrallo *et al*., 2023). Additionally, these price changes can influence macroeconomic indicators via the inflation pathway (FAO *et al*., 2025). Consequently, it can be argued that food prices are important not only for societies and individuals, but also for nations

* Department of Cartographic, Geodetic and Photogrammetry Engineering, University of Jaén, Jaén, Spain.
** Department of Information and Communication Technologies applied to Education, International University of La Rioja, Logroño, Spain.
*** PhD Student in the Information and Communication Technologies Doctoral Program, University of Jaén, Spain.
**** Department of Computer Science, University of Jaén, Jaén, Spain.
Corresponding author: miramos@ujaen.es

and economies as a whole (Talat Ulussever *et al*., 2023). Lately, the global community has been contending with a sequence of crises, encompassing the COVID-19 pandemic, the Russia-Ukraine conflict and the climate change that have profoundly disrupted global prices of fuel and food (Breslin *et al*., 2023).

The ability to predict food prices, as well as other consumer goods, is one of the most ambitious objectives sought by global and local economies. Fluctuations in prices can impact inflation rates, trade balances, and the overall economic stability of countries. Particularly, food plays a key role in numerous aspects affecting economics and society. Predicting food prices helps stabilize markets by allowing producers, distributors, and consumers to make informed decisions. It assists in reducing price fluctuations, to supply the food chain efficiently and adjust demand and production. Governments can formulate the policies that best suite the trade, subsidies, food security while ensuring access to affordable food. In this framework, forecasting helps to mitigate the impact of food crises and assists in distribution planning during emergencies. From the consumer's point of view, forecasts allow individuals to plan their budgets and anticipate potential changes in food prices.

Predictive Models (PM), a specific application within Machine Learning (ML), have emerged as powerful tools to anticipate price and economic behavior, drawing on historical data, algorithms, and statistical theory to learn patterns and make predictions (García-Miralles, 2023). Forecasting is widely applied within the realm of commodity prices. Food prices are usually directly related to agricultural production and market behavior, and are influenced by factors such as weather and climate conditions, global trade, energy and pesticide prices, government policies, natural disasters, international conflicts, market trends, and speculation. The latter, speculation, in the EVOO market involves buying or selling the product for the sole purpose of profiting from future price fluctuations, with no interest in its production or consumption, a practice that can cause market instability. This speculation is driven by various variables, such as weather conditions (droughts or frosts), rising production costs (energy and fertilizers), international conflicts, government policies, changes in consumer trends, low stock levels, prediction of crop production, and the influence of large operators or pressure groups that can manipulate the market. For example, in the Spanish olive oil sector, recent research has shown that large supermarket chains deliberately keep retail EVOO prices low by absorbing cost increases as a strategy to attract customers; as a result, consumer prices often do not fully reflect the fluctuations occurring at origin (García-Agulló *et al*., 2025).

This study introduces an innovative methodology based on predictive models to forecast the price behavior of Extra Virgin Olive Oil (EVOO) at origin, with a particular focus on the Jaén market. While previous research has explored price prediction for this commodity, few studies have approached the issue from a multivariable perspective that comprehensively incorporates the key determinants of the price index. The proposed framework integrates a broad set of factors, including historical prices, climate conditions, production forecasts, economic indicators, and global market data, to overcome the limitations of earlier approaches and provide a more accurate and practical tool for decision-making across the olive oil value chain.

In summary, the study develops a machine learning model capable of accurately estimating EVOO prices in Jaén, using official data collected between 2011 and 2024. The methodology involves applying and comparing several regression algorithms, including Linear Regression, Support Vector Machines (SVM), Neural Networks, Random Forest, Gradient Boosting, and K-Nearest Neighbors, implemented through Oracle Data Mining. This multivariate approach incorporates diverse inputs beyond historical pricing, enabling the model to capture complex, nonlinear market dynamics. The results demonstrate that ensemble methods—particularly Gradient Boosting and Random Forest—outperform other algorithms by more effectively reflecting market shifts and intricate price behaviors.

In this paper we develop the methodology based on ML techniques for olive oil price prediction. Section 2 goes into the state of the art on those studies that also make forecasts on food

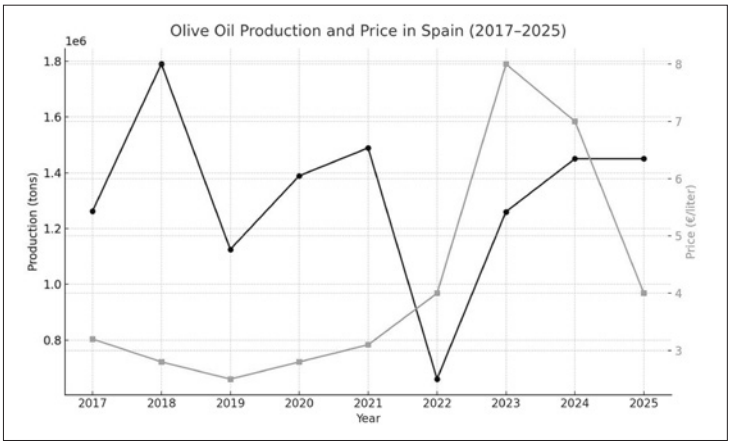


Figure 1 - Relationship between EVOO price (in Euro) and EVOO production in Spain (in Tons).

Data source: POOLred: Olive oil price information system at source [Database]. https://www.poolred.com

prices, including vegetable fats. Section 3 describes the process developed, which consists of a first phase of data acquisition and preparation, and a second phase in which data are integrated into the training model and different ML algorithms are applied to evaluate how good each one is at predicting the price of EVOO in Spain. Section 4 describes and discusses the results obtained, and, finally, Section 5 concludes the article with the conclusions.

2. State of the art

Generally, the price of food is directly related to crop production and the behavior of markets. Specifying, these factors are weather and climate behaviors, global trade of commodities, market trends and speculation, energy and phytosanitary prices, government policies, and even natural disasters or international conflicts (García-Moral *et al*., 2025; Monge, 2024).

By means of algorithms and statistical theory, Predictive Models (PM) use historical data and known results to learn patterns and make decisions or predictions without explicit programming. Similarly, Machine Learning techniques are widely used to predict the price of various types of foods including food prices (Sharma *et al*., 2023; Murugesan & Radha, 2023; Talat Ulussever *et al*., 2023; Gastli *et al*., 2021). Many of these studies focus on staple foods that have a major influence on the markets. For instance, the price of cereals in general have been affected by many different circumstances (Wang *et al*., 2023; Murugesan, Radha, 2023; Zelingher & Makowski, 2022). The rice prices particularly impact in the Asian continent (Hasan *et al*., 2020; Imran *et al*., 2022). However, the price of cereals should not be studied in isolation, given their fundamental role in the food chain, which is particularly evident in sectors such as meat production (Chuluunsaikhan *et al*., 2020; Guo *et al*., 2021; Suaza-Medina *et al*., 2023). Likewise, the study of price forecasting within the vegetable sector is also essential due to similar reasons (Domingo *et al*., 2023; Paul *et al*., 2023; Mishra, 2021).

Similar to what happens with cereals, the price of edible fats such as palm, soybean, sunflower or olive oils has international repercussions (Valiyaveettil *et al*., 2023). The first two have a greater impact on Asia, while the latter two are consumed more in Europe (Kanchymalay *et al*., 2017; Sarmidi *et al*., 2022). Over the last three years, the price of edible oils has risen and fallen significantly, particularly as regards olive and sunflower oils, the most consumed in Europe.

In the particular case of olive oil, the causes have been varied. Weather conditions that directly affect to the drop in production in two consecutive campaigns are pointed to as the most plausible (D'Adamo *et al*., 2019; García-Moral & Moral-Pajares, 2025). In addition to this, the energy costs, the speculation and low stock levels (Cabello, 2022; Abid & Kaffel, 2018; Fousekis, 2022), as well as the Russo-Ukrainian war has led to distortions in the market (Theo-

fanus & Tremma, 2024). Consumer behavior is also changing towards healthier fats that may affect the demand for specific types of edible oils, in particular, the extra virgin olive oil (EVOO) is considered the healthiest among the various types of olive oil (García-Moral & Moral-Pajares, 2025; Ballco & Gracia, 2020; Theofanus & Tremma, 2024; D'Adamo *et al*., 2019). This suggests that the consumer is willing to pay an additional premium price for olive oil with functional properties (Zanchini *et al*., 2022, Salazar-Ordoñez *et al*., 2021). According to the Eurostat[1] reports, the statistical office of the European Union (EU), food prices have been continuously rising from January 2021, highlighting olive oil with an increase of 75%. In the last 2024-25 campaign, however, the significant increase in production has lowered prices to almost those of the previous three years. This has undoubtedly destabilized the market, especially in Spain, the largest producer of olive oil in Europe (and also worldwide). In Figure 1 we observe the behavior how the drop in production directly affects to the increase of prices.

Therefore, a crucial element in determining future prices is on the one hand to determine the historical series of prices and on the other hand, to study those variables that may affect the production of the next harvest. Literature review consider weather and climatic conditions when being crucial for estimating food prices (Sharma *et al*., 2023; Wang *et al*., 2023; Imran *et al*., 2022; Ju *et al*., 2021; Gastli *et al*., 2021; García-Moral & Moral-Pajares, 2025; Cabello, 2022). In the particular case of olive crops, additional factors such as pollen levels and flowering stage play a role in crop production (Orlandi *et al*., 2017; Cabello, 2022), and even lobbying and speculation (Cabello, 2022; Abid & Kaffel, 2018). However, other variables that could also affect prices, such as the price Variables such as energy costs and fertilizers are rarely studied (Talat Ulussever *et al*., 2023), which may also be affected by international conflicts (Valiyaveettil *et al*., 2023; Theofanus & Tremma, 2024).

Olive oil price prediction has already been studied in the literature using soft computing techniques (Rivera *et al*., 2011). However, the emergence of machine and deep learning techniques are currently the most widely used. Most of these methodologies use regression, the supervised learning technique used to understand the relationship between one dependent variable (olive oil price) and one or more independent variables (historical price series, weather, fuel prices, etc.). Neuronal networks are mostly considered deep learning techniques, and they are widely used to predict food price for its capability of approximating a function describing the relationship between input and output data (olive oil price). We find the different classifications of this technique for forecasting olive oil and other food prices in the literature, including the Artificial Neural Networks (ANN) (Abid & Kaffel, 2018; Paul *et al*., 2023), Convolutional Neural Networks (CNN) (Sharma *et al*., 2023; Wang *et al*., 2023; Gastli *et al*., 2021) or Recurrent Neural Networks (RNN) such as Long ShortTerm Memory (LSTM) (Wang *et al*., 2023; Paul *et al*., 2023; Manogna & Mishra, 2021; Chuluunsaikhan *et al*., 2020; Gastli *et al*., 2021; Cabello, 2022), Multi-Layer Perceptron (MLP) (Talat Ulussever *et al*., 2023) or Nonlinear Auto-Regressive Neural Network (NAR-NN) (Xu *et al*., 2023).

Classical ML models have also been widely used on the purpose of olive oil and other edible fats. The techniques used are also varied, such as Support Vector Machines (SVM) (Talat Ulussever *et al*., 2023; Kanchymalay *et al*., 2017), AutoRegressive Integrated Moving Average (ARIMA) (Mishra, 2021) or Random Forest (RF) (Cabello, 2022; D'Adamo *et al*., 2019).

As stated above, there are several works focused on advancing the price olive oil, due to the repercussions for farmers and consumers, especially in the Mediterranean area. However, as far as we know, there is limited existing research, including the studies mentioned above, that delves into forecasting all those variables that really influence olive oil price index. Drawing from the literature on forecasting commodity prices, we address this research gap by conducting a forecast

[1] https://ec.europa.eu/eurostat.

analysis centered on the price of extra virgin olive oil, which are considered the highest quality olive fat and is also the most expensive.

In this work we develop a ML approach considering all those variables analyzed in the literature revised in this section. We include the temporal series of prices of olive oil from the most relevant markets in Spain (most of them in Andalusia), as well as international markets. The rest of vegetable fats such as sunflower oil prices are also considered. Additional variables correspond to energy prices, in particular fuel prices and, especially important, weather factors such as drought, which has undoubtedly been a determining factor in the harvests of the last two years. This dataset is the input (independent variables) to the analysis module integrated into the Oracle Data Mining software, in which several algorithms are checked to approximate as much as possible the function describing the relationship between input data and EVOO price in origin.

3. Methodology

3.1. *Data preparation*

3.1.1. *Data acquisition*

This initial phase is primarily concerned with the acquisition of quality data, focusing on official web services, a reliable and structured source of information that can provide a solid basis for the training of our models. Before starting the extraction, it is crucial to define precisely the variables that will be relevant for our model. These variables must be directly related to the causes that influence the price of extra virgin olive oil (EVOO). This is a complex indicator that reflects the interaction of multiple factors, both economic and agronomic in nature. It is also important to have historical data for a wide range of years. In this case, we have information from 2011 to 2024. The variables that influence the EVOO price considered are detailed below.

- *Base prize*. This is the price of EVOO in the month before the time in which the price forecast is calculated. It is obtained from the Olive oil prices website of the European Union of the Directorate-General for Agricultural and Rural Development. It is an API (Application Programming Interface) that provides weekly data for the different categories of olive oil, reaching the province. The download format is JSON (JavaScript Object Notation). In this study, the province of Jaen in Spain was taken as a reference[2].
- *Month*. Seasonality influences demand and supply. The values of all variables are considered for each of the twelve months.
- *Year*. As with the Month variable, the predictor values are considered for each month of the year for all years considered.
- *Diesel prize*. Both products, diesel and EVOO, are influenced by global economic factors such as oil prices, inflation, demand, and supply.
- Moreover, diesel is used in agricultural machinery for olive production, so an increase in its price could indirectly affect the production costs of EVOO and therefore its final price. The data are obtained from the Spanish Ministry of Ecological Transition and Demographic Challenge of the Spanish Government. They are detailed data on the average price of diesel in Spain, in CSV (Comma-Separated Values) or Excel format. They can be downloaded for different levels of spatial and temporal aggregation. In this study, the average value of the price of fuel in the province of Jaen was taken, grouped by month[3].
- *Accumulated rainfall*. The rainfall accumulated each month since the previous twenty-four months is considered. The reason for this grouping is because the accumulated rainfall in the previous 24 months influences the price of EVOO mainly because it affects the production, quality and production costs of olive oil. This influence extends beyond the immediate harvest, as olive trees have a biennial production cycle and previous rain-

[2] https://agridata.ec.europa.eu/extensions/DashboardOliveOil/OliveOilPrices.html.
[3] https://sedeaplicaciones.minetur.gob.es/shpcarburantes/.

fall determines whether the year will be a high or low production year. The Andalusian Agroclimatic Information Network (RIA) is a network of meteorological stations that provides information on the main variables throughout Andalusia. It consists of more than one hundred stations spread throughout Andalusia. Specifically, in the province of Jaen there are more than twenty stations[4].

- *Average level of reservoirs*. This has a significant influence on the price of EVOO because it is directly related to the availability of irrigation water, which impacts on the quantity and quality of olives produced. Low reservoirs, indicative of water scarcity, tend to result in smaller and lower quality harvests, leading to reduced supply and higher prices. Conversely, when reservoirs are full and irrigation is adequate, olive trees can produce more olives of better quality, leading to higher supply and lower prices. The Ministry for Ecological Transition and the Demographic Challenge of the Spanish government has available and open historical data on Spanish shipments. The data can be selected by dates and accumulated by days and months[5].
- *Consumer Price Index (CPI)*. It is an economic indicator that measures the variation over time in the prices of a basket of goods and services consumed by households. This index has a direct influence on the price of EVOO and vice versa. When the CPI increases, it means that prices of most products and services are rising. This generates inflationary pressure that is transmitted to all sectors of the economy, including agriculture. In addition, changes in the CPI also affect the purchasing power of consumers, which can influence demand and thus prices. Data about CPI have been extracted from Spanish National Statistics Institute (INE)[6].
- *World olive oil production*. The price of EVOO in Spain is strongly influenced by global olive oil prices due to the globalised nature of the market and Spain's dominant role as a producer and exporter of olive oil. Although the national market has its own particularities, the price of olive oil in Spain is not unaffected by the fluctuations that occur in other olive oil producing countries. The global olive oil market has reference prices that directly influence producers' decisions. Prices on international markets serve as a guide for local prices, as international consumers and buyers may choose to purchase olive oil from other producing countries if prices in Spain are higher. Ultimately, if global production increases or decreases, prices in Spain tend to adjust to these international dynamics, as Spain competes in both local and export markets. Data on world oil production have been obtained from the web service of the International Olive Oil Council (IOC), which is an intergovernmental organization that regulates the global market for olive oil and table olives[7].
- *World production of other types of oil*. These data have been acquired from FAOSTAT, a global database managed by the Food and Agriculture Organization of the United Nations (FAO), which provides access to comprehensive statistics related to agriculture, food, natural resources, and other key sectors around the world. Incorporating this information is critical due to the impact of global vegetable oil markets on domestic prices. FAO provides detailed statistics on the production, consumption, and trade of oils such as palm, sunflower, and soybean oils, which are substitutes for EVOO in many international markets. Fluctuations in the prices of these oils directly influence the demand and competitiveness of EVOO, especially in key export markets[8]. Inside this group, sunflower oil is the most influence of all types of oils. This variable is necessary

[4] https://www.juntadeandalucia.es/agriculturaypesca/ifapa/riaweb/web/.
[5] https://www.chguadalquivir.es/saih/DatosHistoricos.aspx.
[6] https://ine.es/consul/menu.do.
[7] https://www.internationaloliveoil.org.
[8] https://www.fao.org/faostat/en/#data.

due to the substitution effect, as consumers can switch between two products depending on their relative price, affecting the demand for EVOO. Furthermore, the oil market is interconnected, and fluctuations in the price of one oil can influence others due to the global supply and demand dynamics.

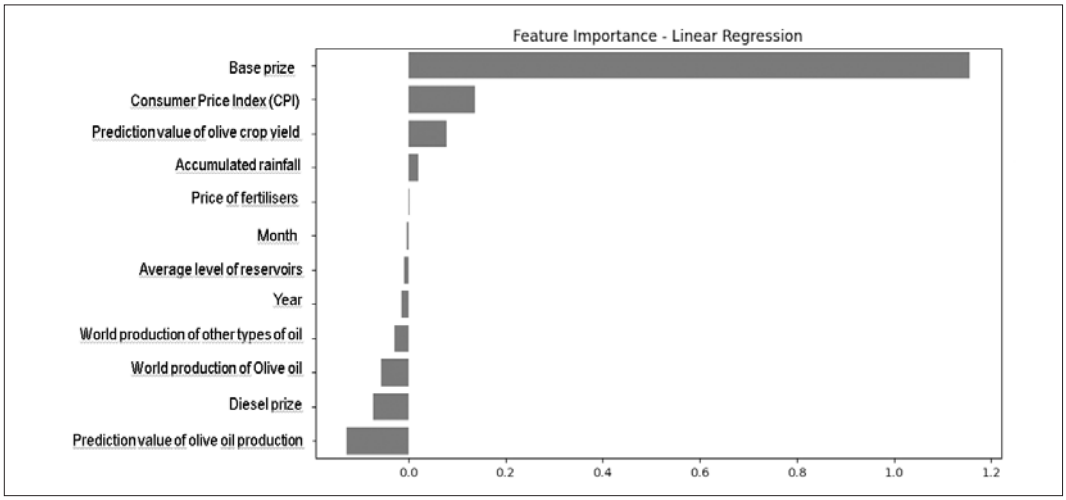
- *Early prediction value of olive crop production*. This is a key indicator that directly influences the supply of raw material for olive oil production. A high production suggests a greater availability of olives, which could reduce the price of EVOO due to a surplus on the market, while a low crop production may indicate shortages and put upward pressure on prices. In addition, higher yields can reduce production costs per unit of oil, as fixed costs (such as harvesting and processing) are spread over a larger quantity of product, which could translate into lower prices. Market actors (producers, distributors, investors) adjust their strategies according to these predictions: an early bumper harvest could reduce prices, while a low harvest could lead to speculation and price increases. This value is obtained from climatological variables and different vegetation indices obtained from satellite images (Ramos *et al*., 2025).
- *Early prediction value of olive oil production*. This variable provides an early estimate of the quantity of olive oil that will be available on the market, thus capturing the direct relationship between supply and price. An increase in anticipated production could indicate oversupply, which would tend to reduce prices, while a decrease in anticipated production could generate shortages and put upward pressure on prices. It is also useful to anticipate market expectations: economic actors, such as producers and distributors, adjust their strategies according to these predictions, which can lead to price movements even before production materialises. This input value is obtained following the workflow described in the article by Ramos *et al*., 2025.
- *Price of fertilisers*. This is a key variable in a predictive study of the price of EVOO due to its direct impact on production costs and crop yield. Fertilisers are an essential input in olive farming, and an increase in their price raises production costs, which can be passed on to the final price of EVOO. Furthermore, the proper use of fertilisers influences the health and productivity of olive trees; if prices are too high, farmers may reduce their use, negatively affecting crop yields and thus the supply of olives. This variable also acts as an economic indicator, reflecting global trends in commodity and energy markets, which can influence the olive oil sector. Including fertiliser prices allows the model to capture these dynamics and improve its accuracy. In Spain, official data on fertiliser prices can be obtained through the Ministry of Agriculture[9], Fisheries and Food (MAPA) and its Price and Market Information Service (SIPMA). MAPA publishes regular reports on the prices of agricultural inputs, including fertilisers, accessible on its statistics portal. The SIPMA provides detailed and regionalised information on fertiliser prices[10], which is useful for local or specific analyses.

Figure 2 shows the level of influence of the variables considered in the prediction of the EVOO price using a linear regression model. The most relevant variables include the base (historical) EVOO price, the olive harvest forecast and the consumer price index (CPI), which reflect the importance of price history, raw material supply and inflation. Climatic factors such as cumulative rainfall and reservoir levels also have a significant impact, as they affect the quality and quantity of the harvest. Other variables, such as the price of fertilisers, world production of other oils and the price of diesel, have a moderate influence, capturing production costs, competition with

[9] https://www.mapa.gob.es/es/agricultura/temas/medios-de-produccion/productos-fertilizantes/consulta-de-productos-fertilizantes-inscritos.

[10] http://www.mapa.es/es/estadistica/pags/medios/fertilizantes/ fertilizantes.htm.

Figure 2 - Feature Importance of variables in predicting EVOO price using Linear Regression.



other oils and logistical expenses. Overall, the figure highlights that the model considers both local factors (climate, costs) and global factors (world production, inflation), providing a comprehensive view of the dynamics affecting the price of EVOO.

3.1.2. *Data categorization*

Machine learning algorithms operate under mathematical and statistical assumptions that require data to be in specific formats, whether numerical, categorical or binary. Thus, it not only ensures compatibility with these assumptions, but also allows capturing non-linear relationships, reducing the risk of overfitting and improving the interpretability of the models. In addition, this process facilitates the identification and handling of outliers or missing data, which is essential to ensure the robustness and reproducibility of the findings. In this study the main groupings and normalisations include temporal aggregation (monthly, daily, cumulative), spatial selection (province of Jaen) and categorization by month to capture seasonality.

3.2. *Machine Learning algorithms*

Both linear and non-linear models have been selected in order to consider different types of relationships between attributes and target. As confirmed in the previous section, the variables considered have different influences on the target and even their seasonality is key in the predictive model.

3.2.1. *Linear regression*

This is a simple model that looks for the best linear relationship between the predictor variables and the target variable. It is characterized by being easy to implement and interpret, but assumes a linear relationship between the variables, which may not be true in complex problems. This type of model assumes that the price of EVOO changes in a constant manner with respect to changes in the independent variables or attributes. The relationship is represented by a linear equation, $EVOO = a_1x_1 + a_2x_2 + ... + a_nx_n + b$, where 'x' are the independent variables that affect the price, 'a' are the coefficients that indicate the contribution of each variable to the price, and 'b' is the independent term, which represents the price of EVOO when all the independent variables are zero. The main parameters of this model would be the coefficients (a_1, a_2, ..., a_n) and the independent term (b). Linear regression models are more suitable for numerical input variables, which have a linear relationship with the price of EVOO and which are ideally independent of each other.

3.3. *Support Vector Machines*

Support Vector Machines (SVM) is an algorithm that searches for the best hyperplane to separate classes of data, maximising the distance between the hyperplane and the nearest points (support vectors). For non-linear data, it uses the kernel to transform it to a space where it is separable. The hyperplane equation is w.x + b = 0, where 'w' is the vector of weights, 'x' the vector of features and 'b' the bias. The key parameters are the cost, which controls the penalty for classification errors, and the kernel, which defines the function for transforming the data. In this EVOO price prediction study, this algorithm offers a robust approach to prediction modelling, especially in this complex scenario with multi-source attributes and variable seasonality. Its ability to handle high-dimensional and non-linear data, through the kernel, allows it to capture the intricate relationships between factors such as crop production prediction, amount of rainfall and reservoir reserves, and economic indicators, highlighting the most influential data points in price determination. Moreover, SVM's flexibility to adjust regularisation allows balancing the model's accuracy with its generalisability, crucial to avoid over-fitting in data with seasonal patterns and unpredictable fluctuations. As there may be years of exceptionally high or low production, extreme weather events or abrupt changes in demand.

3.4. *Neural Networks*

Neural Networks (NN), unlike linear regression and SVM, excel in their ability to model complex non-linear relationships through multiple layers and activation functions. While linear regression assumes linear relationships and SVM searches for optimal hyperplanes, Neural Networks learn intricate patterns by adapting to diverse data, such as time series or categorical data. This flexibility makes them ideal for complex predictions, albeit with higher computational cost and lower interpretability. NN process multi-source attributes by adapting to the nature of each attribute. Continuous numerical attributes, such as Base prize, Diesel prize and CPI, are fed directly into the input layer, allowing the network to learn the linear and non-linear relationships inherent in their variations. On the other hand, categorical attributes such as 'Month' are transformed by encoding to represent each month as a binary vector, making it easier for the network to capture seasonal patterns. Temporal attributes, such as 'Accumulated rainfall' and 'Average level of reservoirs', can be processed through recurrent or convolutional layers to extract temporal trends and dependencies, crucial to reflect the cumulative influence on the EVOO price. The neural network adjusts the weights of its connections using the backpropagation algorithm to minimise the error between predictions and actual prices. This process allows the network to learn to weight the importance of each attribute according to its impact on the price of EVOO.

3.5. *Random Forest*

The Random Forest (RF) algorithm is a ML method that operates by constructing multiple decision trees, each trained on a random sample with replacement from the original dataset, thus introducing variability and robustness to the model. Numerical attributes, such as 'Base prize', 'Diesel prize' and 'CPI', are used in the splitting of tree nodes, where the algorithm determines the optimal thresholds to maximise the homogeneity of predictions within each branch. On the other hand, the categorical attribute 'Month' can be handled by labels, allowing the algorithm to capture seasonal patterns in the price of EVOO. Temporal attributes, such as 'Accumulated rainfall' and 'Average level of reservoirs', are processed to identify temporal trends and dependencies that influence the olive crop production. During the tree construction process, the random selection of attributes at each node ensures that each tree considers a different subset of predictors, increasing the diversity of the forest and reducing the risk of overfitting. Once the trees are constructed, the final prediction of the EVOO price is obtained by aggregating the individual predictions of each tree, typically by averaging the results for the regression.

3.6. *Gradient Boosting*

Gradient Boosting (GB) algorithm is a sequential ensemble learning method, builds a predictive model by combining multiple decision trees, where each successive tree focuses on correcting errors made by previous trees. Unlike Random Forest, which builds trees independently, Gradient Boosting operates iteratively, adjusting the model at each step to minimise a loss function. During the training process, Gradient Boosting assigns weights to each decision tree, weighting those that improve the model's accuracy. At each iteration, the algorithm calculates the gradient of the loss function with respect to the current model predictions and trains a new tree to predict this gradient, i.e. the residual errors. The final prediction of the EVOO price is obtained by the weighted sum of the predictions of all the trees in the sequence. It is important to note that Gradient Boosting tends to be more susceptible to overfitting than Random Forest and requires careful hyperparameter optimisation to avoid this problem.

3.7. *K-Nearest Neighbors*

K-Nearest Neighbors (KNN) algorithm addresses EVOO price prediction using an intuitive, non-parametric approach, focusing on data proximity. Initially, it stores the training set together with the corresponding EVOO prices. Given a new data point, KNN calculates the distance, typically Euclidean, between it and all training points, quantifying the similarity in the multidimensional space defined by the attributes. The normalisation of continuous numeric attributes and the coding of categorical attributes as 'Month' are crucial steps to ensure that all attributes contribute equally to the distance calculation. The selection of K nearest neighbours, where K is an adjustable hyperparameter, determines the dataset that directly influences the prediction. For regression, the EVOO price is predicted by averaging the prices of the K neighbours; for ranking, the majority vote is used. The choice of K is vital: a small value may generate noisy predictions, while a large one may excessively smooth the patterns. KNN, being non-parametric, adapts to complex relationships without functional assumptions, but its computational cost increases with data size, requiring distances to be calculated for each prediction.

4. Results and Discussion

4.1. *Comparison between algorithms*

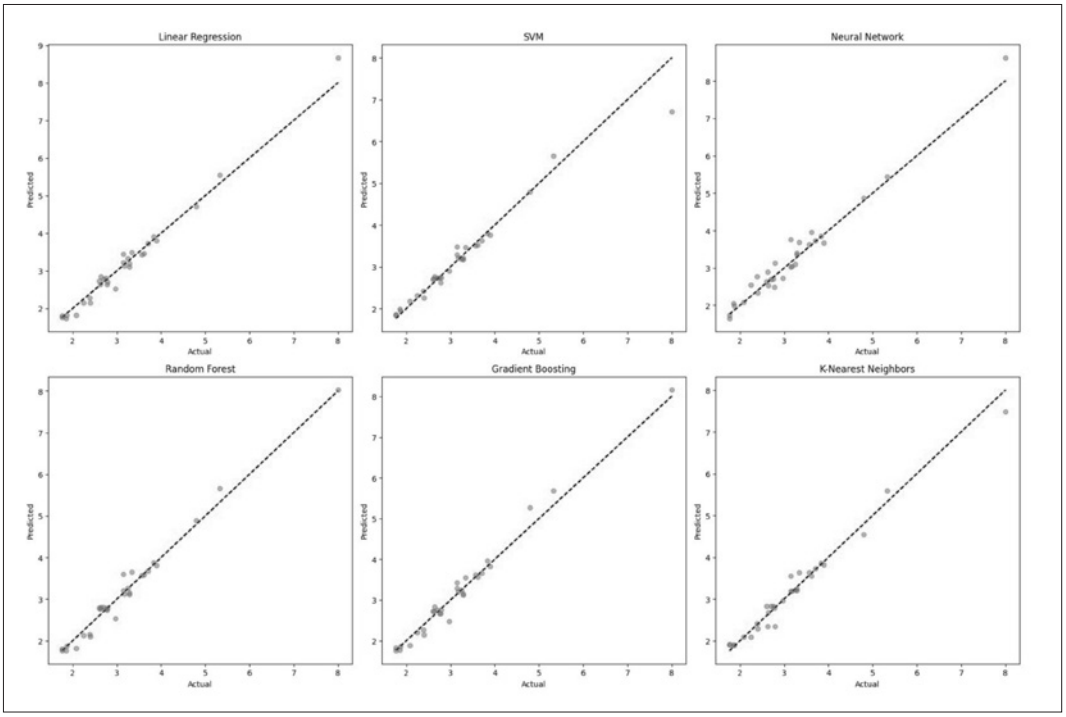
The attributes considered in this study have different weights on the target attribute and the relationship between them does not follow a linear pattern. The level of accuracy of each of the algorithms used in this study can be analysed from the scatter plot, Figure 3.

Comparing actual versus predicted extra virgin olive oil price values show significant variability in the accuracy of the different algorithms. Linear Regression and SVM models exhibit greater scatter of data points around the perfect prediction line, suggesting a reduced ability to capture the underlying relationships in the data. This could be due to the inability of these models to model complex non-linear relationships present in the dataset. In contrast, algorithms such as Random Forest, Gradient Boosting and K-Nearest Neighbours show a tighter clustering of points around the diagonal line, indicating higher accuracy in predictions. Gradient Boosting, in particular, stands out for its high accuracy, with data points very close to the perfect prediction line. This could be attributed to its ability to combine multiple weak models and correct errors iteratively. The Neural Network also shows good accuracy, although slightly lower than ensemble models such as Gradient Boosting and Random Forest. In terms of relative accuracy, Gradient Boosting has been found to be the most accurate algorithm, while Linear Regression and SVM show the lowest accuracy in this test set. However, scatter plots provide a first impression of the accuracy of the models, therefore, it is essential to calculate numerical metrics for an objective and rigorous assessment, avoiding the subjectivity of visual interpretation. The metrics used were as follows:

Mean Squared Error (MSE):

The MSE measures the average of the squares of the errors between the predicted values and the actual values. It provides a measure of the

Figure 3 - Scatterplots of Actual vs. Predicted Values per each algorithm.



magnitude of the errors, penalizing large errors quadratically.

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$$

where:

- n is the number of samples.
- y_i is the actual value of the i-th sample.
- $\hat{y}_i$ is the predicted value of the i-th sample.

Root Mean Squared Error (RMSE):

The RMSE measures the square root of the average of the squares of the errors between the predicted values and the actual values. This is a crucial metric for assessing the accuracy of the models. Specifically, the RMSE measures the square root of the average of the squares of the errors between predicted EVOO prices and actual prices. By reflecting the magnitude of the errors in the same units as the EVOO price (euros per kilogram), the RMSE facilitates the practical interpretation of the results.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

where:

- n is the number of samples.
- y_i is the actual value of the i-th sample.
- $\hat{y}_i$ is the predicted value of the i-th sample.

Mean Absolute Error (MAE):

The MAE measures the average of the absolute values of the errors between the predicted values and the actual values. It provides a measure of the magnitude of the errors, giving equal weight to all errors.

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

where:

- n is the number of samples.
- y_i is the actual value of the i-th sample.
- $\hat{y}_i$ is the predicted value of the i-th sample.

Mean Absolute Percentage Error (MAPE):

The MAPE becomes an essential metric. MAPE measures the average of the absolute values of the errors between predicted EVOO prices and actual prices, expressed as a percentage of actual prices. This metric provides a measure of

the relative error in the prediction of the EVOO price, which facilitates the comparison of the performance of models at different price scales.

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|y_i - \hat{y}_i|}{|y_i|}\right) \times 100$$

where:

- n is the number of samples.
- y_i is the actual value of the i-th sample.
- $\hat{y}_i$ is the predicted value of the i-th sample.

Coefficient of Determination (R^2):

The R^2 measures the proportion of the variance in the dependent variable that is predictable from the independent variables. It provides a measure of the goodness of fit of the model, indicating how well the model fits the data. An R^2 close to 1 indicates that the model captures a large proportion of the variability in the target, suggesting a good fit and a high predictive ability. Conversely, an R^2 close to 0 indicates that the model fails to explain the variability of the EVOO price.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

where:

- y_i is the actual value of the i-th sample.
- $\hat{y}_i$ is the predicted value of the i-th sample.
- $\bar{y}$ is the mean value of the actual values.

Explained Variance Score:

The Explained Variance measures the proportion of the variance in the dependent variable that is explained by the model. This is a measure of how well the model can reproduce the variability of the EVOO price data as influenced by the input variables considered. A score close to 1 indicates that the model explains a large proportion of the variance in the EVOO price, suggesting that the model effectively captures the market fluctuations and dynamics that influence prices. On the other hand, a score close to 0 suggests that the model does not adequately capture the factors influencing prices.

$$\text{Explained Variance Score} = 1 - \frac{\text{Var}(y_i - \hat{y}_i)}{\text{Var}(y_i)}$$

where:

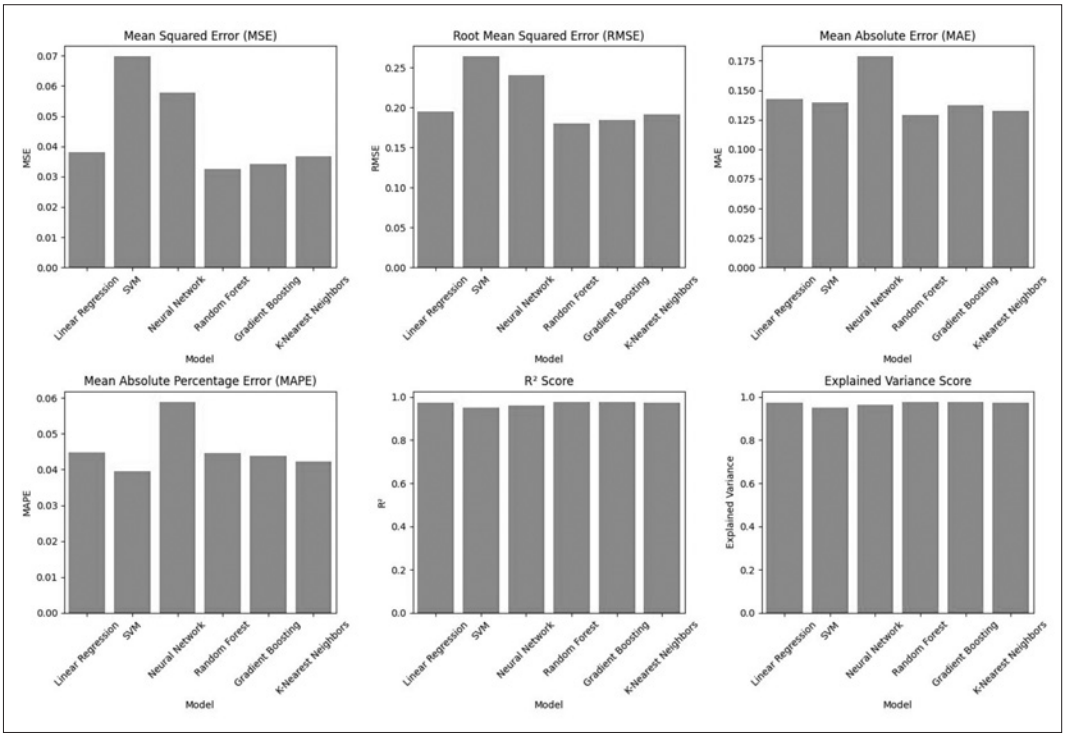
- y_i is the actual value of the i-th sample.
- $\hat{y}_i$ is the predicted value of the i-th sample.
- $\text{Var}(x)$ is the variance of x.

The analysis of the error and fit metrics for EVOO price prediction reflects the clear superiority of the Gradient Boosting and Random Forest models. These algorithms, with significantly lower values for MSE, RMSE, MAE and MAPE, demonstrate significantly higher predictive accuracy compared to SVM, Neural Network and Linear Regression, Figure 4. This difference highlights the ability of ensemble models to capture the complex interactions between predictor variables and the target attribute, a task in which linear and kernel-based models show limitations. The consistency between error and fit metrics reinforces the validity of these results. Although R^2 and Explained Variance indicate a good overall fit for all models, the slight advantage of Gradient Boosting and Random Forest underlines their ability to reproduce EVOO price variability more faithfully. This accuracy suggests that the selected input variables, ranging from climatic and economic factors to production data and market prices, are highly relevant and adequately reflect the dynamics of the EVOO market in Jaen. In particular, the high accuracy of Gradient Boosting and Random Forest, despite the complexity of this market, indicates that these models are able to accurately model price fluctuations influenced by diverse and potentially interdependent input variables. This implies that EVOO production, distribution, and marketing decisions in Jaen can benefit significantly from the application of these predictive models, allowing market actors to anticipate price fluctuations and make informed decisions.

4.2. *Validation of models*

The cross-validation method used in this study consists of assessing the quality and reliability of each EVOO price prediction model. To do this, a model is generated using data from all available years and months, except for the data corresponding to a specific period to be tested, such as a month per year. The information for that excluded period (the 'real' data) is then used to measure the precision of the model by com-

Figure 4 - Evaluation metrics for EVOO price prediction.



paring the predictions obtained with the actual values of the data for that period. This process is repeated iteratively for different periods excluded from the historical data set. Crossvalidation thus serves to test the model against data that it has not 'seen' during training, providing a more robust estimate of its generalizability and performance in real situations, and allowing the accuracy of the algorithms to be assessed before generating a final model with all the data available for training.

In this case, an annual retrospective cross-validation was performed for the period 2011-2024. The quantitative results of such validation are presented in Table 1, where the key metrics are reported: the Mean Squared Error (MSE), the Mean Absolute Error (MAE) and the coefficient of determination (R^2) for each individual year. The MSE and MAE values reveal a heterogeneous evolution in the model's accuracy. For example, in 2011 the model obtained an MSE of only 0.0029 and an MAE of 0.0350, reflecting high prediction fidelity. However, in years such as 2023 and 2021 a significant deterioration in performance is observed, with MSE values of 5.1380 and 0.5893 respectively, accompanied by high mean absolute errors (1.7571 and 0.7259), which evidences a lower capacity of the model to follow the real price dynamics in those years.

The R^2 coefficient, which measures the proportion of variance explained by the model, also reflects this inter-annual variability. While in 2013 ($R^2 = 0.7949$) and 2022 ($R^2 = 0.8200$) the model manages to adequately capture the structure of the data, in years such as 2023 and 2021 poor performance is observed, with negative R^2 (-4.4625 and -2.9491, respectively), indicating that the model predicts worse than a simple reference mean. This numerical analysis is complemented by a visual inspection in Figure 5, where the actual and predicted monthly time series for each year are compared. In high-performing years (e.g., 2013, 2017, 2022), the red prediction line accurately tracks the evolution of actual prices (blue line), with low monthly dispersion. In contrast, in problematic years such as 2023 and 2021, marked discrepancies are apparent, especially in the most volatile months, where the

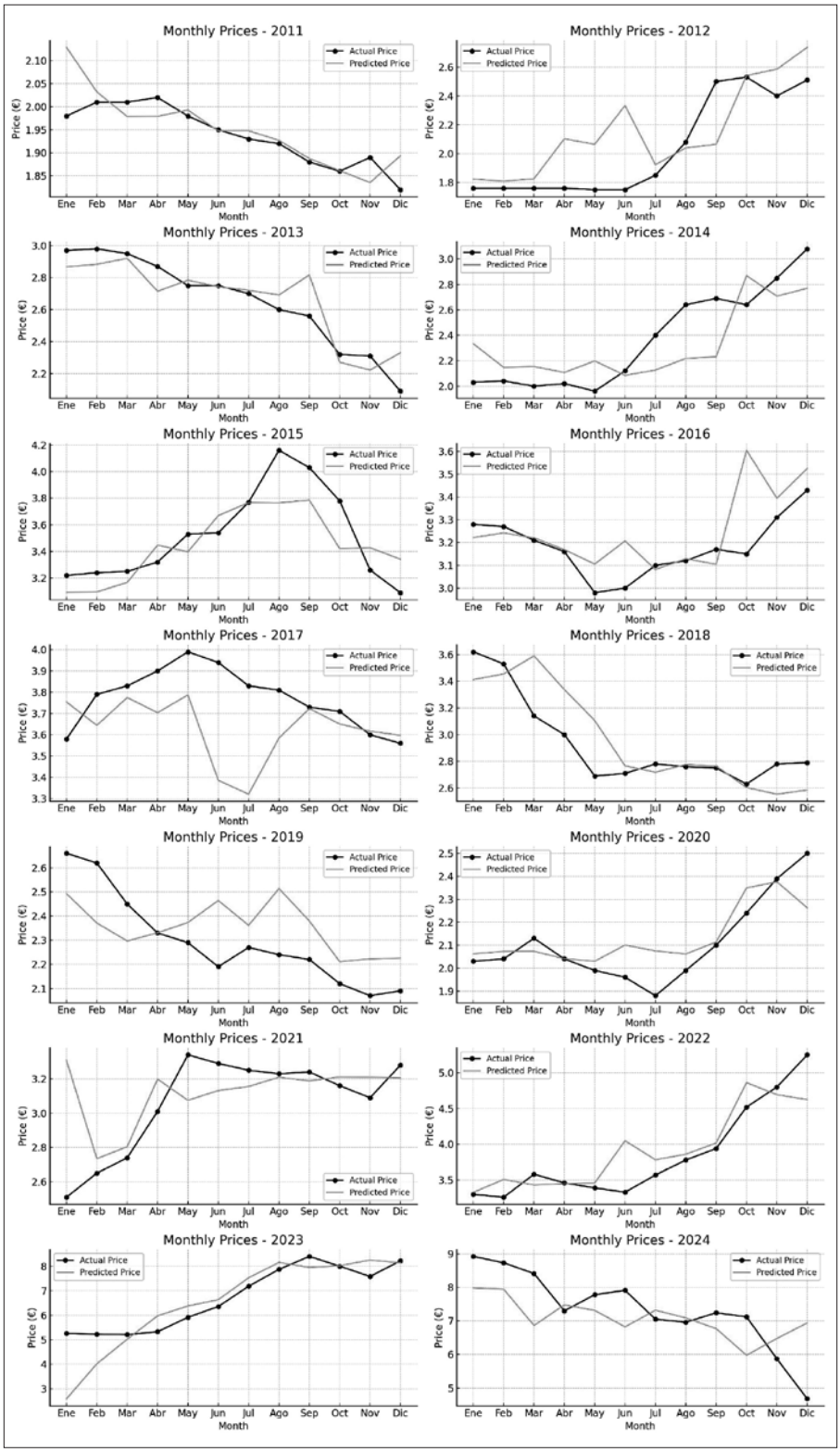


Figure 5 - Predictive capacity of the model in each year.

model systematically underestimates or overestimates price peaks. This suggests that, in such periods, the model fails to capture certain outlier events or structural changes in market price dynamics. The explanation for these variations may lie partly in the predictive attributes used. The predictors used have a strong economic and climatic component. Their influence is reasonable from an agronomic point of view: for example, diesel price directly affects production and transportation costs; reservoir levels and crop forecasts are closely related to product supply; CPI and fertilizer capture both inflationary pressure and input-dependent costs. However, these predictors, although relevant, may not have been sufficient to fully explain the variability in extreme years such as 2023, where the price of olive oil experienced abrupt growth due to causes possibly not reflected in the standard predictors, such as geopolitical crises, regulatory disruptions or severe weather events. In this sense, the limited explanatory capacity of the model in certain years can be attributed not so much to failures of the algorithm, but to the lack of key exogenous variables or to delays in incorporating such events in the data. Overall, the results in Table 1 and Figure 5 indicate that the model, based on structural agroeconomic predictors, achieves reasonable performance in most years.

Table 1 - Performance metrics by year.

Year	*MSE*	*MAE*	*R2*
2011	0.0029	0.0350	0.2674
2012	0.0708	0.1993	0.3568
2013	0.0157	0.0976	0.7949
2014	0.0688	0.2301	0.5140
2015	0.0442	0.1803	0.6024
2016	0.0597	0.2216	0.5786
2017	0.0600	0.1997	0.6225
2018	0.0536	0.2003	0.5817
2019	0.0509	0.1869	0.6231
2020	0.0464	0.1866	0.5324
2021	0.5893	0.7259	-2.9491
2022	0.1138	0.3076	0.8200
2023	5.1380	1.7571	-4.4625
2024	0.8872	0.8778	0.7390

4.3. *Performance assessment*

Finally, to complete the analysis of the goodness of fit of the model, the analysis requires the comparison of the oil price prediction results according to the inputs considered. As shown in Figure 2, the base price, which is the EVOO price in the month immediately before the month to be predicted, is by far the most influential variable. Therefore, it could be interpreted that adding the rest of the inputs does not improve or only vaguely improves the prediction. However, in Figure 6, it can be confirmed that the inclusion of the rest of the inputs already described in Section 3.1.1 allows capturing market inflections according to the time of the year. The use of multivariate ML approaches allows for a more robust and accurate prediction of the monthly EVOO price, especially in years of high volatility. The monthly graphical comparison validates the overall superiority of the enriched model, which should be adopted as a reference for operational predictive systems, especially in agricultural or agro-industrial contexts with multi-factor sensitivity.

Figure 7 shows a scatter plot between actual olive oil prices and the values predicted by the model, corresponding to the years 2011–2024. Each point represents a monthly value, and the dashed line in red indicates the perfect prediction, i.e., the ideal case in which the predicted value coincides exactly with the observed one. This visualization allows us to graphically evaluate the overall model fit and to detect possible error patterns or systematic biases. The point cloud is mostly aligned with the diagonal, indicating that the model has a reasonable ability to reproduce the observed values, especially in the price range between 2 and 4 €/kg, which corresponds to most of the historical data. This pattern suggests that the model has correctly captured the underlying structure of the olive oil market under normal conditions.

However, an increasing dispersion is observed as real prices increase, especially above 5 €/kg. At these extreme values, more frequent in recent years such as 2023 and 2024, the model tends to underestimate real prices, suggesting a loss

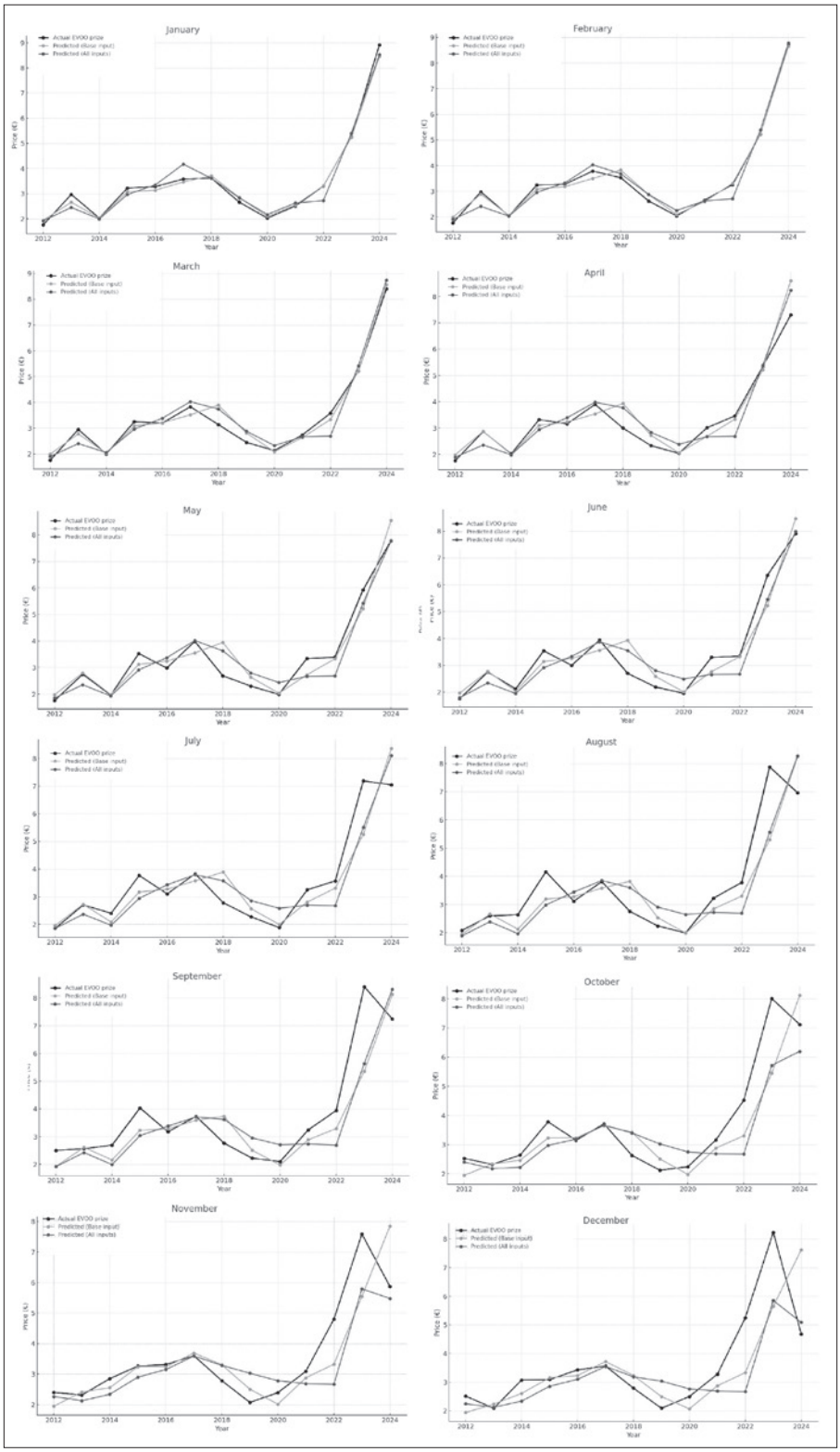
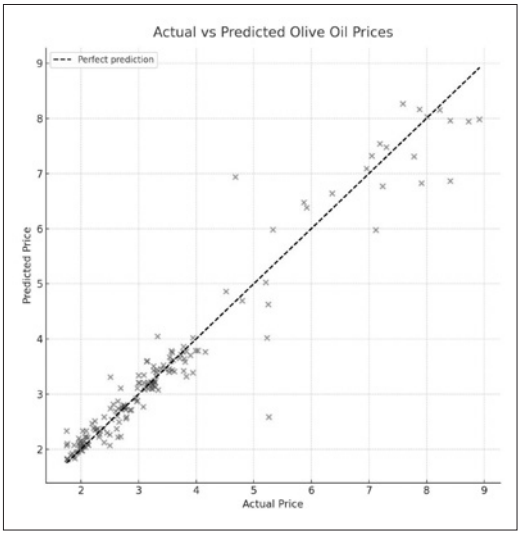


Figure 6 - Distribution of EVOO price and predicted values.

Figure 7 - Scatter plot of actual vs predicted olive oil prices (2011-2024).



of predictive ability in high volatility scenarios. This dispersion also suggests the possibility of a non-strictly linear relationship in these ranges, which may limit the performance of conventional linear models.

From a statistical perspective, the Pearson correlation coefficient between actual and predicted prices is $r = 0.969$, indicating a very strong and positive correlation. This result confirms that there is a robust linear association between the two variables. Furthermore, fitting a linear regression on the data produces a slope of 0.929 and an intercept of 0.228, implying that, on average, the model tends to slightly underestimate higher prices (the ideal slope would be 1). Nevertheless, the closeness of the slope to unity and the high value of r support the conclusion that the model is globally adequate.

5. Conclusions

The main objective of the study was to develop a machine learning (ML) model capable of accurately predicting the price of Extra Virgin Olive Oil (EVOO) in Jaén. This objective responds to the growing importance of price prediction in the food sector, given its impact on macroeconomic indicators and the entire supply chain. The methodology employed involved the construction of a model that integrates a diverse and comprehensive set of predictor variables. The results obtained, which show a high predictive capacity—particularly with certain algorithms—suggest that the goal of creating a reliable tool for EVOO price prediction, considering multiple influencing factors, has been largely achieved.

The appropriateness of the selected attributes and the ML models applied is a key factor in the predictive success of the study. The predictor variables included the historical EVOO base price, seasonal factors (month, year), production costs (diesel price, fertilizer price), weather conditions (cumulative rainfall, reservoir levels), economic indicators (Consumer Price Index, CPI), overall oil production (olive oil and others, such as sunflower oil), and early predictions of olive crop yield. The analysis of feature importance validated the relevance of variables such as base price, early prediction of crop production, and CPI, also highlighting the significant impact of climatic factors.

When comparing different ML algorithms (Linear Regression, SVM, Neural Networks, Random Forest, Gradient Boosting, KNN), ensemble methods such as Gradient Boosting and Random Forest showed superior accuracy. These algorithms demonstrated a better ability to capture the complex non-linear relationships between variables and EVOO price, outperforming simpler or kernel-based models.

The models have shown limited predictive power in extreme contexts, such as the years 2023 and 2024, where the models fail to capture disruptive events not reflected in the structural data. Although speculation is acknowledged as a factor that may influence market behavior, it was not included as a predictor in the model. This decision is based on methodological considerations: speculation lacks structured, quantifiable data that can be consistently incorporated into predictive modeling. Its inherently qualitative and volatile nature makes it difficult to operationalize within the framework of supervised learning. Nevertheless, its indirect effects may be partially captured through other variables such as historical price trends, stock levels, or economic indicators. Also noteworthy is the high dependence of these models on official

data, which may have time lags or limitations in spatial coverage, thereby affecting the effectiveness of the prediction.

The study has identified a complex pattern of behavior in EVOO pricing, determined by the interaction of the various factors considered. It is observed that weather conditions and crop production are highly influential causes of price variations, particularly in light of the notable decrease in production in recent years. Other factors such as energy costs, low stock levels, international conflicts, and global market dynamics, including the production of other vegetable oils, also contribute to market distortions. Seasonality affects supply and demand throughout the year, and the substitution effect linked to globalized markets influences Spanish prices. The multivariate model, particularly Gradient Boosting and Random Forest, is able to capture these market inflections, underlining that EVOO price behavior is dynamic and sensitive to the combined influence of local, seasonal, and global factors, especially in years of high volatility.

Acknowledgments

This research has been partially funded through the research projects HORIZON-MISS-2021-SOIL-02-03 and HORIZON-MISS-2023-SOIL-01, which are financed with the European Union's Horizon Europe research and innovation programme. We are also grateful for the support provided by the Ministry of Innovation and Science of the Government of Spain through the research projects PID2021-126339OB-I00, PID2022-137938OA-I00. Finally, our grateful to the Ministry for Ecological Transition and the Demographic Challenge of the Spanish Government (AEMET, Agencia Estatal de Meteorología).

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Quantification de la dégradation du paysage agricole et évaluation économique d'un aménagement approprié : cas du bassin versant Douimis (Tunisie)

SIHEM JEBARI*, SANA BOUGUERRA*, ALI CHEBIL*, LAMIA BAHLOUS**, SARRA TOUZI***

DOI: 10.30682/nm2505g
JEL codes: Q15, Q17

Abstract

In the context of climate change, soil erosion constitutes a significant threat to land conservation, water security, and ecosystem functioning. The study area covers Douimis catchment located in the northern part of Tunisia. The main objectives targeted, as well as the approaches considered in this present paper are 1- to assess the impact of climate change on soil loss based on RUSLE/GIS methodology, 2- to set an adaptation plan based on a participatory approach, then 3- to study its economic viability using Net Present Value (NPV) and Benefit-Cost Ratio (BCR) methods. The results showed that the basin is subject to a significant soil loss of 18 t/ha/year in the current situation. The impact of climate change has increased the erosion risk by 30% in 2050. This risk has been reduced by about 40% when introducing water and soil conservation measures. The economic analysis displayed that the Douimis Basin development plan constitutes an interesting investment opportunity that deserves the attention of local and national authorities in the search for funding. This shows the usefulness of investing in landscape management to prevent the degradation of natural resources.

Keywords: *Impact assessment, Climate change, Soil erosion, Adaptation, Development plan, Economic cost.*

1. Introduction

Pour assurer un développement durable, l'avenir d'un pays dépend de la gestion de ses ressources en eau et en sol (Hartmann *et al*., 2024). Ces deux ressources constituent la principale base des moyens de subsistance et du bien-être humains, y compris l'approvisionnement en nourriture, en eau douce et de multiples autres services écosystémiques (Bouguerra *et al*., 2024 ; Hou, 2023 ; Liu, 2024). En septembre 2015, un agenda comprenant 17 objectifs pour le développement durable (ODD) a été adopté par les dirigeants du monde (ONU, 2015). Ces objectifs visent à s'attaquer, entre autres, à des problèmes clés tels que le stress hydrique, la sécurité alimentaire la perte

* Institut National de Recherches en Génie Rural, Eaux et Forêts - INRGREF, Tunis, Tunisie.
** Société du Canal de Provence France (agence Tunisie), Tunis, Tunisie.
*** Le Partenariat Global pour l'Eau - Méditerranée (GWP-Med), Athens, Greece.
Corresponding author: bouguerra.sana@gmail.com

de biodiversité, la dégradation des terres et le changement climatique. En 2015, les parties de la Convention des Nations Unies sur la Lutte contre la Désertification (CNULCD) se sont appuyées sur les engagements des ODD, particulièrement l'objectif 15, pour formuler un plan de travail pluriannuel complet. Ce dernier vise à atteindre la neutralité carbone et la neutralité en matière de dégradation des terres en mentionnant les aspects suivants : « *Protéger, restaurer et promouvoir l'utilisation durable des écosystèmes terrestres, assurer la gestion durable des forêts et la lutte contre la désertification, arrêter voire inverser la dégradation des terres et mettre fin à la perte de biodiversité* ». En décembre 2015, un accord sur le climat a été conclu par les parties à la Convention-cadre des Nations Unies sur les changements climatiques (CCNUCC), cherchant à lutter contre la désertification, restaurer les terres et les sols dégradés, notamment les terres touchées par la sécheresse et les inondations, et s'efforcer de parvenir à un monde sans dégradation des sols d'ici 2030. Ces démarches arquent un moment important dans la résolution de ces défis interdépendants et soulignent également l'opportunité de les étudier plus en profondeur.

La dégradation des sols est un processus biologique, chimique et physique. Il peut s'agit de la perte de matière organique, de la baisse de la fertilité et de l'état structurel des sols, de l'érosion, de changements défavorables de la salinité, de l'acidité ou de l'alcalinité, et des effets de produits chimiques toxiques, de polluants ou d'inondations excessives (Roose, 2010 ; Ouvry, 2012). Actuellement, environ 33% des sols du monde sont modérément ou fortement dégradés. Quarante pour cent (40%) de ces sols dégradés se trouvent en Afrique et la plupart se trouvent dans des zones confrontées par la pauvreté et l'insécurité alimentaire. L'impact des dégradations des sols sur la sécurité alimentaire nécessite des actions stratégiques et immédiates (FAO, 2015 & 2016).

Par conséquent, les politiques de gestion des terres apparaissent comme un élément clé pour le développement durable. En même temps, le changement climatique présente d'autres défis, en particulier dans les pays arides où l'eau est déjà rare, les précipitations sont variables et les options de subsistance sont limitées. Plusieurs études ont souligné la nécessité d'examiner ensemble les problèmes de dégradation des terres sous les effets du changement climatique afin d'assurer la résilience à la fois des écosystèmes et de la population (Doulabian *et al*. 2021 ; Emadodin *et al.*, 2012).

L'érosion des sols était considérée comme le type de dégradation le plus grave qui menace la sécurité alimentaire et l'économie naturelle des régions, tant au niveau local que mondial (Nunes *et al.*, 2020). Elle est l'un des plus grands problèmes scientifiques du monde. Elle a diverses conséquences négatives, telles que la dégradation des terres, la diminution de la qualité de l'eau, la sédimentation des rivières et la destruction des routes (Kanianska *et al.*, 2024). Ainsi, l'érosion des sols causée par l'activité anthropique dans le bassin versant est un facteur clé de la sédimentation des barrages. Les sédiments sont transportés en aval par le réseau hydrographique, qui finissent par occuper les fonds des retenues d'eau (Irie *et al*., 2012).

Un modèle approprié d'érosion des sols peut être appliqué pour mesurer les niveaux d'érosion du sol d'une région spécifique. En effet, la modélisation de l'érosion peut être combinée à un outil spatial et statistique pour localiser et mesurer la perte en sol optimisant ainsi une planification environnementale (Bouguerra *et al*., 2021).

De nombreux modèles mathématiques catégorisés comme empiriques, conceptuels, basés sur la physique ou orientés vers les processus sont disponibles pour estimer l'érosion du sol à différentes échelles spatiales et temporelles. Parmi les plus connus figurent le Water Erosion Prediction Project (WEPP) (Morgan & Nearing, 2011) ou le modèle européen d'érosion du sol EUROSEM ; Morgan et al. (1998) ainsi que la mise à jour des approches empiriques existantes telles que l'équation universelle de perte de sol (USLE) (Wischmeier & Smith, 1965). Actuellement, l'USLE et l'USLE révisée (RUSLE) (Renard et al., 1997) sont de loin les modèles de prévision de l'érosion des sols les plus largement appliqués au niveau mondial et selon (Ghosal et Das Bhattacharya, 2020). Sur la base de son approche forfaitaire à l'échelle du bassin versant et de sa relative simplicité et robustesse, et parce qu'il

représente une approche standardisée. Elle est également considérée comme la méthode la plus efficace pour évaluer la perte de sol en l'absence de mesures. Les modèles les plus connus basés sur la technologie USLE/RUSLE sont le Soil and Water Assessment Tool (SWAT) (Arnold, 1998), l'AGricultural Non-Point Source Pollution Model (AGNPS) (Onstad, Bosch, & Anderson, 1989), le Water and Tillage Erosion and Sediment Model (Watem/Sedem) (Van Rompaey, 2001) et la Chinese Soil Loss Equation (Liu *et al*., 2002).

La Tunisie, comme tous les pays de la méditerranée, est confrontée à des défis environnementaux tels que l'érosion et les phénomènes extrêmes, à savoir les sécheresses et les inondations (Dhehibi *et al*., 2018). Ces phénomènes ont fréquemment touché le pays au cours des dernières décennies et la hausse des températures a conduit à une situation plus difficile (MARHP, 2022). A savoir, plus de 2.6 millions d'hectares (soit 17% du territoire) de sols, sont sensibles à très sensibles à l'érosion hydrique (DGACTA, 2017).

L'objectif principal de cet article est d'évaluer le niveau de dégradation des ressources en sol dans le contexte actuel et sous contrainte climatique. Plus encore, il aide à identifier les actions d'adaptation à préconiser en termes de gestion future de ces mêmes ressources, et évaluer la rentabilité économique de ces actions.

Les objectifs spécifiques sont particulièrement : (a) mettre en œuvre la méthode RUSLE/SIG (Equation Universelle de perte en sol combiné au système d'information géographique) en intégrant les données de télédétection, afin d'estimer la distribution spatiale de l'érosion des sols de l'ensemble de la zone d'étude, (b) étudier l'impact du changement climatique sur l'état de dégradation des terres (c) évaluer l'impact d'un plan d'aménagement pour prévenir les pertes en terres (c) évaluer la rentabilité économique de ce plan d'aménagement.

2. Matériels et méthodes

2.1. *Description de la zone d'étude*

Le bassin versant Douimis appartient à la délégation de Sejnane, gouvernorat de Bizerte. La population dans cette délégation est estimée à 20126 habitants (INS, 2024). Ce bassin, est l'un des affluents de l'unité hydrologique du lac Ichkeul, se situe au Nord Est de la Tunisie (Figure 1). Il couvre une superficie de 89,73 km^2. Il est drainé principalement par Oued Douimis.

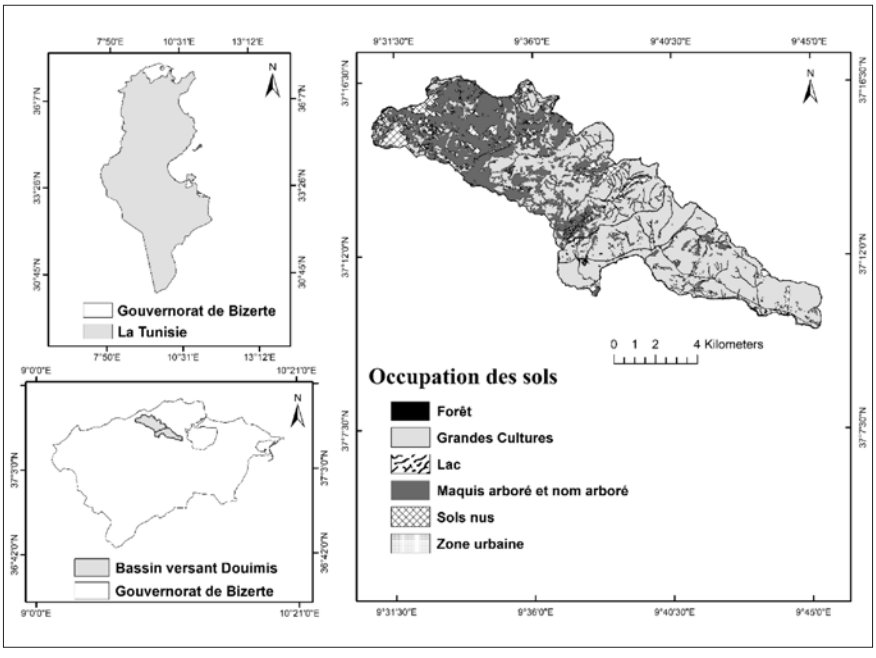
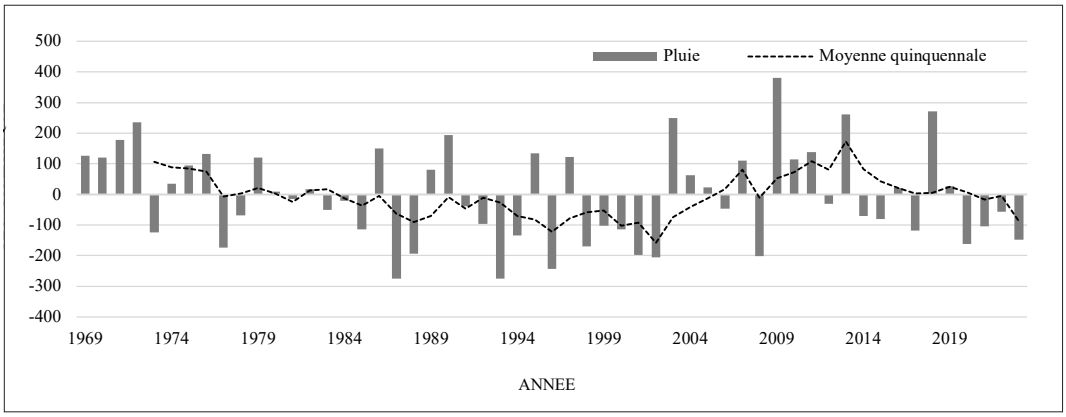


Figure 1 - Localisation et carte d'occupation des sols pour l'année 2023 du bassin versant Douimis.

Figure 2 - Anomalie de la pluie annuelle à la station Bizerte pour la période 1969-2023.



La zone d'étude est soumise à un climat tempéré, caractérisé par une période hivernale humide qui s'étale du mois d'Octobre au mois de février. Le climat est de type humide, alors qu'au cours des mois de Juin, Juillet et Août, le climat varie de sec à très sec. La température moyenne mensuelle de la région est estimée à 18,5 °C. La zone d'étude fait partie de l'étage bioclimatique subhumide, caractérisée par l'irrégularité de la pluviométrie, souvent avec une moyenne annuelle de 520 mm. Il s'agit donc d'un climat méditerranéen tempéré caractérisé par des étés chauds, des hivers doux et pluvieux (Figure 2).

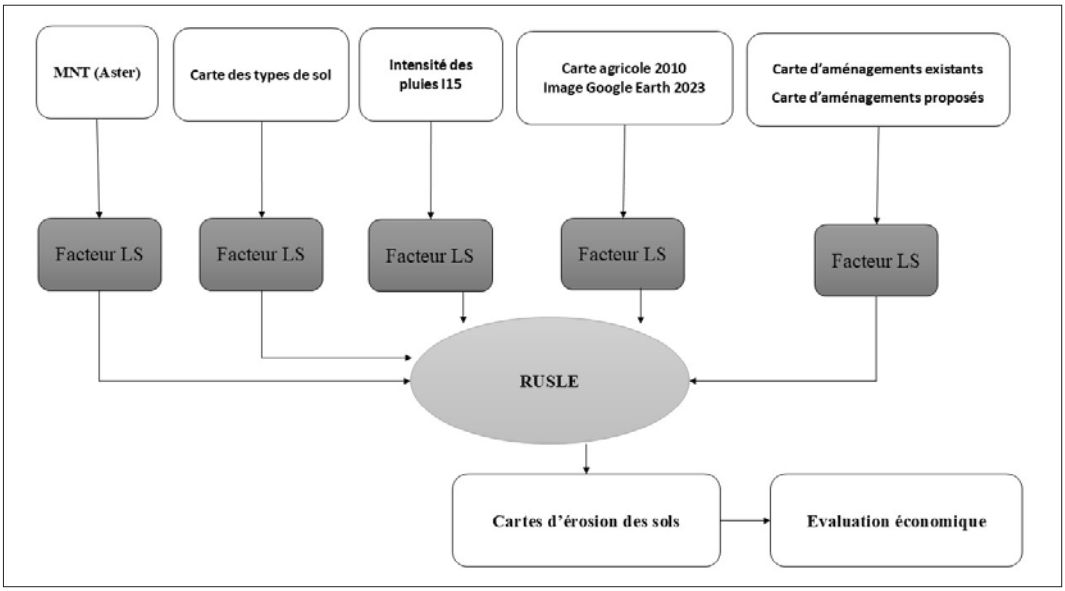
La Figure 2 montre que la région connait des périodes d'anomalies. En effet, on observe un écart par rapport à la moyenne positif, suivie de périodes d'anomalies négatives. Ces dernières sont marquées par un manque de précipitations par rapport à la moyenne historique. Ces constats sont à l'origine des situations de sécheresse, affectant l'approvisionnement en eau, les cultures agricoles, et les écosystèmes.

Ce travail est élaboré dans le cadre du programme panafricain «Eau, Climat et Développement pour l'Afrique (WACDEP)». Le programme avait pour objectif d'appuyer la planification des investissements d'adaptation au changement climatique à l'échelle territoriale en recourant aux connaissances et outils scientifiques les plus récentes et en adoptant un processus d'engagement inclusif des parties prenantes. La première étape a porté sur l'évaluation participative de la vulnérabilité au changement climatique qui a permis de décortiquer la sensibilité et la capacité d'adaptation des écosystèmes naturels et socio-économiques les plus vulnérables. Ceci a permis de discerner les paramètres sur lesquels il est possible d'agir pour réduire la vulnérabilité de ces écosystèmes et de proposer les solutions d'adaptation les plus appropriées. Une priorisation de ces solutions a été ensuite entreprise, octroyant aux aménagements de conservation des eaux et des sols une haute priorité. La quantification de la dégradation des terres sous contrainte de changement climatique pour une conception adéquate des aménagements à proposer a été essentielle. Les résultats de ce travail de quantification et de conception des aménagements ont été incorporés dans le plan d'aménagement intégré et participatif de gestion des ressources naturelles dans le bassin de Douimis (GWP-MED, 2017).

2.2. *Approche méthodologique*

La modélisation est un outil crucial pour analyser la dégradation des terres due au changement climatique et évaluer l'impact des plans d'aménagement proposés. En intégrant diverses données (climatiques, hydrologiques, pédologiques, etc.), elle permet de simuler des scénarios futurs et de comprendre les interactions complexes entre ces facteurs environnementaux. Cela aide à anticiper les effets des aménagements sur les écosystèmes et à évaluer l'efficacité des stratégies de conservation ou d'adaptation. Dans le présent travail,

Figure 3 - Diagramme décrivant la démarche méthodologique.



La modélisation des pertes en terres a été mise en œuvre doublement. En premier, pour l'évaluation de l'état de dégradation des sols dans le contexte actuel et en second, sous contrainte climatique. Une réflexion pour la recherche des outils et des points d'entrée pour l'évaluation de l'impact du changement climatique sur les ressources en sol. Les étapes de la mise en œuvre de l'approche RUSLE/SIG pour estimer les pertes en terres se résument dans la Figure 3.

Afin d'estimer les pertes en sol à l'échelle du bassin versant Doumis, l'Equation Universelle des Pertes Révisée (RUSLE) développée par Renard *et al*. (1997) a été utilisée. La modélisation de l'érosion hydrique sous contrainte climatique a été réalisée en premier temps en considérant l'analyse de la tendance (Jebari *et al*., 2010). Cette analyse a permis de traiter la série pluviographique régionale et caractériser le facteur de l'érosivité des pluies (R) sous l'impact du changement climatique. Cette démarche garde par ailleurs les autres paramètres constants. En deuxième temps, il a été procédé à l'établissement d'une carte d'occupation du sol relative à l'horizon 2050. Cette carte s'est basée sur l'étude d'adaptation des écosystèmes tunisiens (MARH, 2007). Une simulation combinée intégrant l'érosivité des pluies et la couverture des sols à l'horizon 2050 a été également établie pour analyser l'effet direct lié à la variation de la pluie et l'effet combiné rattaché au changement de l'occupation du sol.

Outre les simulations et l'évaluation de la sensibilité des terres à l'érosion hydrique en situation actuelle et sous contrainte climatique, l'outil modélisation permet dans la phase de planification, de traduire les orientations d'adaptation en actions d'aménagement. En effet, les composantes du plan d'aménagement et de gestion du paysage agricole ont été construites avec les parties prenantes en schéma d'aménagement. Cette démarche permet d'évaluer l'impact des actions d'adaptation préconisées sur l'état future de dégradation des sols.

2.2.1. *Description des données*

Le modèle numérique du terrain (TIN), la carte d'occupation des sols, les précipitations et les types des sols sont essentiels pour le modèle RUSLE. Les pluies journalières et pluviographiques [1969-2005] (15min) de la station Sidi Hmed et celles mensuelles [1969-2023] de la station de Bizerte au gouvernorat sont obtenues auprès du l'Institut National de la Météorologie (INM). La carte des sols en Tunisie (CRDS, 1979 ; échelle 1/200 000) a été obtenue par la

Direction Générale de l'Aménagement et de la Conservation des Terres Agricoles (DGACTA). La carte agricole considérée émane de la Direction Générale de la Forêt (DGF, 2010).

Le MNT de la zone d'étude présente une résolution spatiale de 30 m et est fourni par la Shuttle Radar Topography Mission (SRTM), ASTER GDEM (Version 2: http://gdex.cr.usgs.gov/gdex). Des images google earth de résolution 0.5 m pour l'année 2014 et 2023 ont été utilisées au sein de cette étude (September, 2024).

2.2.2. *Modélisation de l'érosion hydrique*

Il existe plusieurs modèles d'érosion des sols, plus ou moins complexes. L'un des modèles empiriques les plus utilisés pour évaluer l'érosion en nappe et en rigoles est l'USLE, développé par Wischmeier et Smith en 1965. L'USLE a été développé à l'origine, principalement, pour estimer l'érosion des sols dans les terres cultivées ou sur des terrains en pente douce.Il existe deux versions de ce modèle, à savoir, l'une révisée (RUSLE) et la seconde modifiée (MUSLE) (Renard, 1997).

Dans notre cas d'étude l'estimation des pertes en terres à l'échelle du bassin versant Douimis est réalisée à travers la version révisée de l'Equation Universelle des Pertes en Terres RUSLE couplée à un SIG. Cette approche permet d'établir une carte du risque érosif au niveau du bassin versant de Douimis et de connaître les quantités des pertes en sol (t/ha) pouvant être détachées annuellement pour chaque pixel d'un secteur donné. De ce fait, il est possible de localiser les zones de forte érosion hydrique nécessitant une intervention prioritaire. Selon le modèle de Wischmeier et Smith (1957), la perte en sol est une fonction multiplicative qui se présente comme suit :

$$A=R.K.L.S.C.P$$

Avec A, la perte en sol moyenne annuelle (t /ha) ; R, le facteur d'érosivité de la pluie (MJ. mm/ha. H) ; K, le facteur érodabilité du sol (t. h/MJ.mm) ; LS, le facteur topographique (adimensionnel) de la parcelle qui est représenté par la longueur de la pente et son degré, respectivement S et L ; C, le paramètre du couvert végétal (adimensionnel) et P, le facteur des pratiques antiérosives (adimensionnel)

L'érosivité des pluies est définie comme étant la capacité de la pluie à produire l'érosion. Le calcul de l'érosivité des pluies R, est initialement basé sur les données pluviographiques de la station de Sidi hmed pour la période 1969-2005. Chaque intervalle d'averse est caractérisé par une intensité des pluies qui est déduite de la hauteur de l'orage en question. Pour toute averse, l'énergie totale E a été calculé selon la méthode décrite dans (Jebari et al, 2010). Après avoir calculé l'érosivité pour cette période, des simulations ont été réalisés pour estimer la valeur correspondante à l'année 2023.

Le facteur érodabilité du sol K caractérise la sensibilité du sol à l'érosion. Il mesure la plus ou moins grande résistance du sol à la dégradation. Les valeurs du facteur K sont définies en se basant sur la carte des sols en Tunisie (CRDS, 1979; échelle 1/200 000) (Tableau 2).

La topographie est représentée par la longueur de la pente et son degré, respectivement S et L. Pour mettre en évidence l'interaction des deux facteurs dans le processus de l'érosion hydrique des sols, on considère généralement un facteur unique (LS) calculé avec le System d'Information Géographique arcGIS (Renard, 1997).

Le facteur C exprime l'influence des méthodes culturales, des sols et des cultures sur les pertes en sol par érosion. Ce facteur incorpore les effets du couvert végétal de la séquence des cultures, du niveau de la productivité, de la longueur de la saison de croissance, des méthodes culturales et de la quantité des résidus laissés sur le sol (Tableau 3). Ajout d'une référence liée à la définition du paramètre P est le facteur des pratiques antiérosives. Il reflète les effets des pratiques qui réduisent la quantité d'eau de ruissellement ainsi que sa vitesse. Ce facteur limite l'importance de l'érosion. Il représente le ratio des pertes des terres associées à une pratique de conservation des sols associée à la culture en lignes dans le sens de la pente, toutes les autres conditions étant égales par ailleurs. Ce facteur est compris entre 0 et 1 (Cormary et Masson, 1964). Plusieurs travaux antérieurs réalisés en Tunisie dans des contextes hydrologiques et climatiques similaires ont déjà évalué la sensibilité du modèle RUSLE à ses paramètres d'entrée (Zante et Collinet, 2001). Les

résultats de ces études ont été pris en compte pour orienter le choix des paramètres et renforcer la robustesse des simulations produites.

Toute la procédure a été intégrée sous un Système d'Information Géographique (SIG) afin de quantifier et de cartographier l'aléa de l'érosion hydrique au niveau du bassin versant Douimis. Le modèle a été calibré pour l'année 2014, puis une simulation a été réalisée pour l'année 2023. La validation des résultats des pertes en sol considérés par le modèle pour le bassin versant Douimis est faite en se référant aux mesures bathymétriques du barrage Ghezala conduites par la DG/BGTH. La similarité entre les deux bassins versants ci-dessus mentionnés vient par la faible distance qui les sépare (10 km), l'appartenance au même étage bioclimatique et le partage des caractéristiques de l'occupation du sol. Le choix du bassin versant Ghezala comme référence, vient en absence de toute mesure d'érosion et d'envasement à l'échelle de l'unité hydrologique Douimis. Nous nous sommes référés aux données secondaires de l'Observatoire National de l'Agriculture (ONAGRI, 2021), qui rapporte les taux de sédimentation de plusieurs barrages en Tunisie. Plus précisément, nous avons utilisé le taux de sédimentation du barrage de Ghezala (17,3 t/ha/an) comme valeur de référence pour calibrer le modèle.

2.3. *Impact du changement climatique sur l'érosion des sols*

Les simulations de l'érosion sous contrainte climatique ont été réalisées à travers la modification de deux facteurs du modèle, à savoir : l'érosivité des pluies (R) et l'occupation du sol (C). Le facteur de l'érosivité (R) s'est basé sur les données pluviographiques (intensités de pluie max à pas de temps 15 minutes) de la station de Sidi Hmed située au gouvernorat de Bizerte. La durée d'observation considérée pour cette analyse est de 41 ans (1964 à 2005). Pour les années 2014 et 2023, l'érosivité des précipitations a été calculée en utilisant une série pluviométrique annuelle (1969-2023). Ceci, en raison de l'indisponibilité des intensités de pluie I15. Finalement, la considération de l'effet du changement climatique en terme du facteur R a été assurée à travers une analyse de la tendance.

Pour le paramètre du couvert végétal (C), l'intégration de l'effet du changement climatique a été faite à travers l'élaboration d'une carte d'occupation du sol à l'horizon 2050 déduite des résultats de l'étude d'adaptation des écosystèmes tunisiens (MARH, 2007).

2.4. *Évaluation de la réduction des pertes en terre selon le schéma d'aménagement préconisé*

Les actions suggérées pour une réduction de la vulnérabilité des ressources naturelles aux effets du changement climatique présentent les principes d'une gestion durable et résiliente au changement climatique des ressources naturelles. La combinaison de ces actions doit aboutir à une gestion cohérente et intégrée du paysage et des terres agricoles (GWP-Med, 2017). Dans la présente section, nous faisons référence plus spécifiquement aux actions de développement au niveau des terres privées soumises au régime forestier, le respect de la vocation des terres des cultures, le développement de l'agriculture de conservation, la protection et l'aménagement des terres de cultures par des ouvrages hydroagricoles. La combinaison et la planification spatiale de ces actions constitue le plan résilient au changement climatique de gestion des terres (GWP-Med, 2017). Ce plan de gestion des terres a été élaboré lors des réunions de planification en utilisant une matrice synthétique. Les actions d'aménagement de courts et longs termes sont traduits en cartes thématiques par l'outil SIG. Ce dernier, a permis de simuler les pertes en terres avec l'occupation de sol projetée, occupation qui intègre les mesures d'adaptation proposées. En effet, les discussions entreprises lors des ateliers ont couvert les types d'intervention ainsi que leur faisabilité. Ainsi, le plan d'aménagement a été conçu selon l'approche participative adoptée par le projet. Les aménagements proposés ont couvert une superficie de 48,83 km², soit 55% de la superficie totale du bassin et ont servi à assurer les simulations de quantification des pertes en terres. Le Tableau 1 suivant présentent l'emplacement et les superficies par type d'aménagements proposés. Les me-

Tableau 1 - Superficie des aménagements proposés.

Type d'aménagement	*Superficie (ha)*
Ados consolidés en espèces pastorales	60
Agriculture de conservation	1250
Bandes enherbées consolidées par l'acacia	198
Bandes alternées	323
Banquettes consolidées par des oliviers	425
Banquettes mécaniques	1060
Réservoir	133
Cordons en pierres sèches	1446
Cuvettes individuelles	803
Non Aménagé	2941
PPI	334

sures proposées ont été définies suite à un processus participatif impliquant les parties prenantes locales. Un dispositif de suivi-évaluation à long terme, incluant des indicateurs d'acceptabilité sociale, est recommandé pour assurer la durabilité des interventions.

2.5. *Comparaison des coûts et des avantages de deux situations : sans et avec aménagement*

L'évaluation économique du plan d'aménagement se base sur la comparaison des coûts et des avantages de deux situations, à savoir, sans et avec plan d'aménagement. La méthode d'analyse coût/bénéfice a été appliquée par plusieurs auteurs en Tunisie pour l'analyse économique de conservation des eaux et sols (Daly-Hassen *et al*., 2010; Daly-Hassen *et al*., 2019, Souissi *et al*., 2023). Cette méthode permet la prise de décision en matière d'investissement.

Ainsi, la méthode consiste à mesurer le contrefactuel et l'attribution afin de saisir le changement qui peut être spécifiquement à l'apport du projet. Cette comparaison doit prendre en compte la dimension temporelle. En effet, pour tout projet d'investissement les flux des dépenses et des avantages sont répartis dans le temps d'une manière inégale. La durée de vie du projet concernée par l'évaluation est fixée à 30 années au vu de l'importance de l'arboriculture et de l'impact à moyen et long terme des investissements en infrastructure et en aménagements hydro-agricoles.

L'analyse coûts-avantages (ACA) repose sur l'hypothèse que les avantages et les coûts occasionnés après le démarrage du projet doivent être actualisés afin de refléter leur valeur actualisée nette (VAN). A chaque fois qu'on a une VAN supérieure à zéro le projet est jugé rentable.

Mathématiquement la formule de calcul de la VAN en tenant de deux situations s'exprime comme suit (Gittinger, 1982 ; Bojo, 1992 ; De Graaff and Kessler, 2009):

$$VANs = \sum_{t=1}^{T} \frac{AA_{ts} - CA_{ts}}{(1+i)^t}$$

Avec :

VAN_s : Valeur actualisée nette (exprimée en Dinars) dans le scenario S

AA_{ts} : Avantage additionnel de l'année t et scénario S

CA_{ts} : Coût additionnel de l'année t et scénario S

T : Durée du projet exprimé en nombre d'année

i : Taux d'actualisation sociale exprimé en pourcentage

Trois autres critères d'évaluation de la rentabilité du projet ont été considérés. Le Ratio Avantages-Coûts (RAC) est obtenu en divisant la valeur actuelle du total des avantages par la valeur actuelle du total des coûts. Le RAC renseigne sur le nombre de dinars tunisien (DT) qu'a généré le projet pour chaque (DT) investi sur la période correspondante à la durée de vie du projet. Le taux de rentabilité interne TRI, n'est autre chose que le taux d'actualisation qui annule la somme des flux financiers actualisés et qui donne un RAC égale à l'unité. Le troisième critère est celui du délai de récupération du capital investi.

Les coûts additionnels sont déterminés par le coût d'investissement. Le coût total du plan d'aménagement territorial concerté du bassin versant de Douimis est de l'ordre de 19 272,5 mille DT. La répartition de ce coût par volet d'investissement est comme suit : infrastructures et ressources naturelles 15 155 mille DT, production agricole 3 689, 5 mille DT et accompagnement 435 mille DT. Les investissements pour la

concrétisation des composantes des trois volets seront réalisés durant les cinq premières années d'exécution du projet (GWP-Med, 2017).

L'estimation des avantages additionnels du projet s'est appuyée sur une série d'hypothèses qui reflètent la nature des interventions projetées dans le cadre du projet. Outre le changement dans l'occupation du sol et le redimensionnement des activités agricoles, la productivité de la terre augmentera sensiblement bénéficiant des investissements matériels et immatériels prévus. Toutes les analyses menées suite à l'enquête et aux multiples discussions de groupe sur le terrain avec la forte participation des habitants du BV et des responsables du développement à l'échelle régionale. La comparaison de deux situations permet de mettre en exergue le changement d'un système de production essentiellement céréalier à un système plus diversifié avec des produits à hautes valeurs ajoutées.

Pour le calcul de ces avantages additionnels, nous avons considérés la différence entre marge brute globale MBG avec projet (MBG-AP) et sans projet (MBG-SP). Les marges brutes moyennes des activités agricoles sont égales au produit brut moins les charges variables pour chaque spéculation. Les charges variables sont estimées en se basant sur des fiches technico-économiques représentatives de la moyenne de la zone (GWP-Med, 2017). Les MBG sans et avec projet sont estimés annuellement à 6 058 mille DT et 8 934 mille DT, respectivement. La MBG-AP, estimée pour une année de croisière, a été pondéré durant les sept premières années du projet pour tenir compte de l'évolution de la production arboricole et maraîchère (nouvelles plantations, nouveau périmètres irrigués) et du rythme d'adaptation des agriculteurs aux nouveaux systèmes de productions plus intensifs et aux nouvelles pratiques d'adaptation au CC.

Pour prendre en considération l'impact de la perte en terre sur la MBG-SP, trois taux d'abaissement de la MBG ont été testés. Le premier est une réduction annuelle de 1% de la MBG-SP (hypothèse réaliste et retenu pour le calcul du TRI) et le deuxième est une réduction du même résultat au rythme de 2% annuellement (hypothèse pessimiste). La troisième hypothèse, très optimiste, avec non-abaissement des résultats sous l'effet de la perte de sol.

3. Résultats et discussions

3.1. *Evaluation de l'érosion des sols à l'état actuel*

L'érosivité des précipitations est variable d'une année à une autre (Figure 4). L'agressivité moyenne annuelle des pluies sur la zone d'étude est évaluée à 681,6 MJ. mm/ha.h.an.

La quantification des pertes en sol à l'échelle du bassin versant Douimis en situation actuelle (année 2023) a permis de spécifier une valeur moyenne de l'ordre de 17.81 t/ha/an (Tableau

Figure 4 - Variation annuelle de l'érosivité des pluies/ titre graphique une barre de la moyenne devrait être représentée.

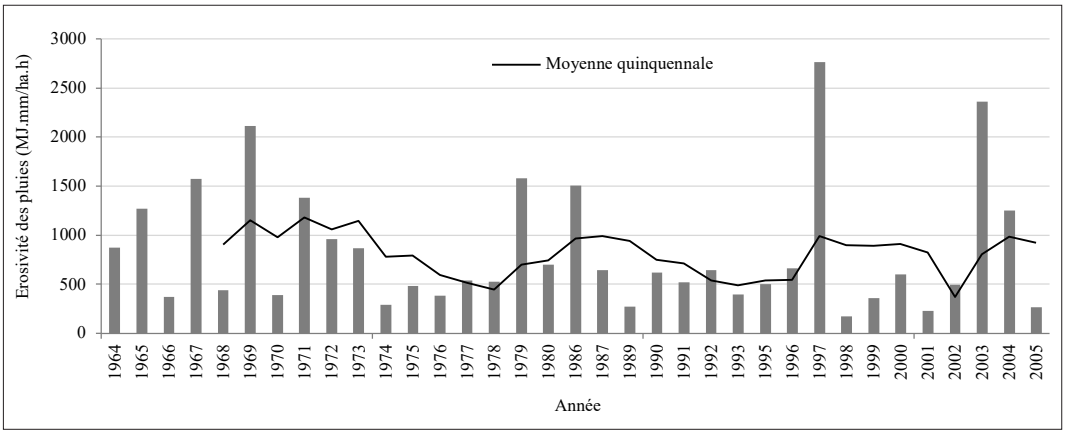
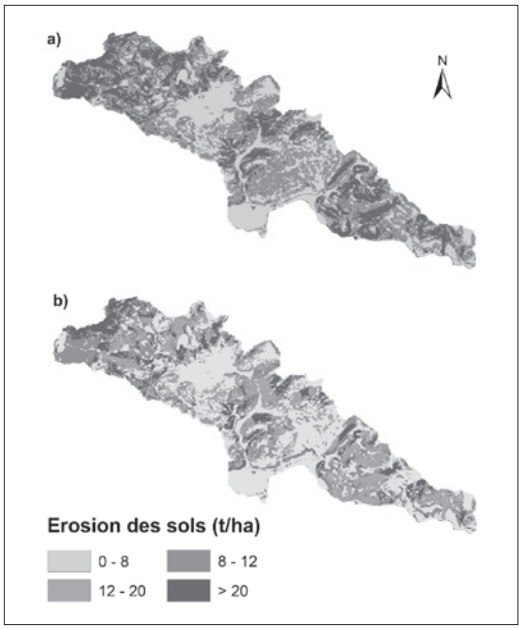


Figure 5 - Répartition spatiale des classes d'érosion des sols a) sous impact du changement climatique et b) en combinant impact changement climatique et plan d'aménagement proposé pour l'horizon 2050.



2). La description du taux de dégradation en considérant ls différentes classes d'érosion hydrique montre des proportions bien différentes. En effet, 32% de la superficie totale est soumise à un taux de perte en sol inférieur à 8 t/ha. Une seconde unité s'étend sur 18% de la superficie et se trouve soumise à des pertes en terre qui oscillent entre 8 et 12 t/ha/an. Une troisième unité de grandeur équivalente (22%) montre une érosion hydrique variant de 12 à 20 t/ha/an.

Une quatrième unité qui couvre 28% montre des taux d'érosion hydrique dépassant 20 t/ha/an (Tableau 3). Il s'avère que les valeurs faibles du risque érosif sont concentrées essentiellement dans la partie avale du bassin versant. Alors que les aires à risque élevé sont caractérisées par une végétation clairsemée et des altitudes élevées.

3.2. *Evaluation de l'érosion sous impact du changement climatique*

L'approche adoptée dans cette étude repose sur l'analyse des tendances historiques observées, conformément au cadre méthodologique exploratoire retenu. L'érosivité future des précipitations a été estimée à 558,912 MJ·mm/ha·h·an, correspondant à une diminution de 18 % par rapport à la situation actuelle. Cette valeur a servi de base pour évaluer l'impact potentiel du changement climatique sur les pertes en sol. Toutefois une combinaison de cette information à la dégradation du couvert végétal montre un taux moyen de pertes en sol de 23.25 t/ha/an montrant une augmentation globale de l'érosion hydrique de 30% à l'horizon 2050. Le Tableau 2 et la Figure 5a présentent les changements au niveau des superficies des classes d'érosion.

Les changements au niveau de la surface des classes d'érosion sont présentés dans le Tableau 2 et la Figure 5a. Le Tableau 2 illustre la détérioration de la situation sous l'effet du changement climatique. Les surfaces soumises à une érosion sévère augmentent de manière significative, représentant 49 %, soit près de la moitié du bas-

Tableau 2 - Répartition des classes des pertes en sol en situation actuelle, sous impact changement climatique et plan d'aménagement.

Scenario	*Etat actuel*	*Sous impact CC*	*Avec aménagement*
Erosion des sols moyenne (t/ha/an)	17.81	23.25	14.4

Tableau 3 - Répartition des classes des pertes en sol en situation actuelle, sous impact changement climatique et plan d'aménagement.

Classe d'érosion (t/ha/an)	*0 - 8*	*8 - 12*	*12 - 20*	*> 20*
Superficie en situation actuelle (%)	32	18	22	28
Superficie sous impact du changement climatique (%)	15.25	13.51	22.20	49.04
Superficie sous impact du changement climatique et aménagement (%)	33.5	21	17.5	28

sin versant. Simultanément, le pourcentage de terres faiblement érodées est de 15,25 %, ce qui indique une intensification généralisée des processus d'érosion. Les classes intermédiaires présentent également un déclin, ce qui indique un déplacement des caractéristiques de surface vers les classes les plus érodées. Ces résultats mettent en évidence l'augmentation du risque d'érosion due aux effets du climat futur.

3.3. *Évaluation de l'impact des pertes en terre selon le schéma d'aménagement préconisé*

En considérant la carte d'occupation des terres résiliente au changement climatique, la simulation entreprise par l'approche RUSLE/SIG a montré une réduction de la vulnérabilité de l'ordre de 30%. En effet, nous avons observé un passage du taux moyen d'érosion hydrique à l'échelle du bassin versant Douimis de 18 t/ha/an à 14.4 t/ha/an. Une carte des pertes en sol correspondante a été produite (Figure 5b). Ainsi, le plan d'aménagement proposé tiendra compte des actions de conservation des eaux et du sol pour le changement d'occupation du sol. Les pertes en terre estimées pour ce plan d'aménagement sont de 8.3 t/ha/an, alors qu'elles seront de 23.35 t/ha/an sous contrainte climatique et sans action spécifiques à entreprendre. L'introduction de mesures d'aménagement dans un contexte de changement climatique a permis une amélioration notable de la situation. Les superficies faiblement érodées (0–8 t/ha/an) passent de 15,25 % à 33,5 %, dépassant même la situation actuelle. De même, la proportion de terres soumises à une érosion très forte (>20 t/ha/an) revient à 28 %, soit un niveau équivalent à celui d'aujourd'hui. Les classes intermédiaires (8–12 et 12–20 t/ha/an) augmentent également, ce qui suggère une redistribution des superficies vers des niveaux d'érosion plus modérés. Ces résultats démontrent l'efficacité des actions d'aménagement en tant que levier d'adaptation, capables de compenser partiellement les effets négatifs du changement climatique sur l'érosion des sols.

Les simulations indiquent que l'extension des aménagements antiérosifs contribue à la diminution des taux des pertes en terres. Ce constat, vient confirmer l'importance des aménagements dans l'interception des eaux de ruissellement, l'amélioration de l'infiltration, la réduction de l'érosion des terres, la diminution de l'envasement des retenues, et le développement d'une agriculture familiale et vivrière essentielle pour la population locale. La Figure 5b présente le résultat de la simulation des pertes en sol en considérant l'occupation actuelle avec les aménagements CES projetés.

3.4. *Rentabilité économique du plan d'aménagement territorial du bassin versant de Douimis*

Les résultats de l'analyse économique sont présentés dans le Tableau 4. Ils montrent que les valeurs de la VAN sont dépendantes des taux d'actualisation. En général, ce projet est rentable pour un taux d'actualisation qui ne dépasse pas les 12% (TRI) et qui est supérieur aux taux considérés dans le calcul de la rentabilité de ce type du projet environnemental (taux social d'actualisation). En effet, le taux social utilisé est faible surtout pour les pays en voie de développement (Daly-Hassen *et al.*, 2019).

Les indicateurs économiques, autres que le TRI, militent aussi en faveur de la poursuite de la mobilisation régionale pour la recherche de financement. Le ratio Bénéfice/Coût du projet dépasse 1.3. Le délai de récupération du capital investi est de 11 années ce qui est relativement court pour ce genre de projet.

Sur la base de ces résultats, le plan d'aménagement du bassin versant Douimis constitue une opportunité d'investissement intéressante qui mérite l'attention des autorités locales et nationale pour la recherche de financement. Le projet, en plus de sa rentabilité monétaire apporte beaucoup d'avantages environnementaux et sociaux qui sont très importants pour la réduction de la pauvreté, l'adaptation au changement climatique la protection des ressources naturelles et l'amélioration des conditions de vie qui ne sont pas comptabilisés dans les calculs du TRI. Toutefois, notre analyse pourrait être améliorée dans le futur tout en considérant des bénéfices non marchands tels que les bénéfices environnementaux, l'améliorations des connaissances scientifiques et la création d'emploi.

Tableau 4 - Indicateurs de l'analyse économique.

Indicateurs	*Valeur*
TRI (sans dégradation de la MBG-SP)	9%
TRI (dégradation SP de 1% de la MBG-SP annuellement)	12%
TRI (dégradation SP de 2% de la MBG-SP annuellement)	14%
Ratio Bénéfice/Coût actualisation à 5% (dégradation SP de 1% de la MBG-SP annuellement)	1.2
Valeur actualisée nette au taux de 5% (dégradation SP de 1% de la MBG-SP annuellement)	22 121 671 DT
Durée de récupération du capital investi (cash- flow actualisé)	14 années

Finalement, il faut signaler que l'analyse a été menée en utilisant les prix du marché vu que les facteurs de conversion sont en majorité proches de l'unité et le coût d'opportunité de la main d'œuvre est proche du salaire pratiqué. Ainsi, les résultats de l'analyse économique et financière sont très proches.

3.5. *Discussion*

L'approche RUSLE/SIG permet de nos jours l'identification des zones où les taux de perte en sol sont les plus élevés et par conséquent, éclaire les décideurs et les aménagistes sur le choix adéquat des techniques et des mesures à entreprendre. Appliqué au bassin versant Douimis, l'approche a spécifié la valeur de l'érosion des sols à l'état actuel. Cette dernière dépasse largement le seuil universel des pertes en sol tolérées selon Wishmeir (1964) ainsi que celui décrit par Masson (1971) pour le cas de la Tunisie. Le seuil universel est de 12 t/ha/an et le local ne dépassant pas en moyenne les 8 t/ha/an. Ces seuils sont arrêtés en fonction du climat, du type de roches et de l'épaisseur des sols (Cormary et Masson, 1964). Sachant que la suppression totale de ce phénomène s'avère impossible, les pertes en sol tolérées par l'érosion hydrique visent de ce fait à ce que les pertes soient inférieures à la vitesse d'altération de la roche mère en question (Roose, 1994). Les deux principaux facteurs qui influent sur le phénomène de l'érosion des sols sont les facteurs naturels et les facteurs humains. Les facteurs naturels comprennent les précipitations, la végétation, la topographie et le sol. D'un point de vue macro, les facteurs liés au terrain et au sol sont relativement stables. Ils ne changeront pas beaucoup pendant des années, des décennies, voire des siècles (Bou Kheir *et al*., 2008).

La simulation des impacts du changement climatique montre qu'il est très probable que le Bassin Douimis soit confronté à des risques accrus d'érosion hydrique à l'avenir. En outre, cela pourrait être dû aux changements du régime pluvieux et de l'occupation des sols. Ce dernier élément, contribue de manière essentielle aux processus de l'érosion des sols, alors que le changement climatique est susceptible d'intensifier ce phénomène (Belay et Mengistu, 2021 ; Dash & Rajib Maity, 2023). Ces résultats sont également corroborés par des études antérieures selon lesquelles l'érosion des sols est considérablement influencée par les différents types de couverture et d'utilisation des terres (Bouguerra *et al*., 2021). Le changement climatique, caractérisé par le réchauffement climatique, affecte le processus régional des pertes en sol en modifiant les précipitations, leurs intensités et leurs répartitions spatiales. En effet, à mesure que la température augmente, l'énergie contenue dans l'atmosphère augmente, le flux d'air devient plus actif et l'évaporation devient plus vigoureuse. Cet enchainement de processus affecte la circulation atmosphérique et la configuration spatiale des précipitations en faveur d'évènements pluvieux plus intenses. Ce constat agit directement sur le facteur de l'érosivité qui conditionne la dégradation des sols.

A côté des processus climatiques, nous retrouvons les activités humaines. Ces dernières peuvent aussi bien aggraver l'érosion des sols ou bien l'atténuer (Lang et al, 2023). En ef-

fet, ces activités jouent un rôle substantiel dans le contrôle efficace de la dégradation des sols, principalement par le biais de projets de conservation de l'eau et des sols. Le facteur des pratiques de conservation (facteur P) utilisé dans cette étude sert à refléter la manière dont le changement d'utilisation des terres et les actions d'adaptation affectent la perte en sol. L'occupation des sols est considérée comme un reflet concentré des activités humaines, affectant la dynamique et les mécanismes de résistance à l'érosion des sols. Elle modifie à son tour les types de végétation et la couverture de la surface en introduisant des techniques d'aménagement. Cette méthodologie permet de planifier un système et des pratiques de gestion agricole appropriés contribuent également à atteindre les objectifs de développement durable en réduisant l'érosion des sols (Pal *et al.*, 2023).

En Tunisie, l'occupation des sols et les activités humaines sont des facteurs cruciaux de l'érosion des sols (Khemiri *et al*., 2021). En effet, malgré des efforts cités dans les stratégies antérieures, les taux d'érosion restent supérieurs au taux de formation des sols nécessaires à une agriculture durable (Zhao *et al*., 2019). Pour résoudre ce problème, il est important d'intensifier les efforts pour lutter contre les effets continus et intensifiés sous les effets du changement climatique. L'amélioration de l'expertise technique est également essentielle pour une atténuation efficace de l'érosion des sols.

Bien que cette étude ait produit des résultats significatifs, il est admis que l'utilisations des scenarios et des projections récentes des changements climatiques à partir de modèles climatiques globaux (GCM) pourraient enrichir davantage les conclusions. Cette limitation pourrait être surmontée dans de futures recherches en intégrant des comparaisons entre les scenarios de concentration de gaz à effet de serre (GES) de type Trajectoires Représentatives de Concentration (SSP) pour une évaluation plus précise. L'absence de données de terrain spécifiques au site d'étude n'a pas permis de valider directement les résultats du modèle, ce qui limite la portée des estimations et souligne la nécessité d'intégrer des mesures locales dans les études futures.

4. Conclusion

Cette étude a permis d'évaluer l'érosion des sols dans le bassin versant de Douimis en utilisant l'approche RUSLE/SIG. Plus encore, elle a analysé l'impact potentiel des changements climatiques futurs sur la dégradation des sols. Les résultats ont montré que les conditions climatiques actuelles favorisent une érosion modérée à sévère dans certaines zones sensibles, mais que l'intensité de cette érosion pourrait s'aggraver significativement sous l'effet des scénarios du changement climatique prévus.

Face aux effets néfastes mentionnés ci-dessus, un plan d'aménagement intégré et concerté avec les parties prenantes a été développé. Ce plan a inclus des mesures de conservation des eaux et des sols, telles que l'implantation de terrasses, la reforestation ainsi que des pratiques agricoles durables. L'analyse de ce plan, montre que les interventions suggérées peuvent réduire considérablement l'érosion hydrique et protéger les ressources en sols du bassin versant. La participation active des acteurs locaux a non seulement renforcé la pertinence des solutions proposées, mais aussi favorisé leur acceptation et mise en œuvre à moyen et long terme.

L'analyse de la rentabilité du plan d'aménagement montre que le projet constitue une opportunité d'investissement rentable. Le taux de rentabilité interne est de l'ordre de 12 %, le ratio avantage/coût du projet est de 1.3, et la durée de récupération du capital investi est de 11 années ce qui est relativement court pour ce genre de projet. Sur la base de ces résultats, le plan d'aménagement du bassin versant Douimis constitue une opportunité d'investissement intéressante qui mérite de bénéficier de l'attention des autorités locales et nationale pour la recherche de financement. Il est à rappeler que cette analyse pourrait être améliorée dans le futur en utilisant la méthode d'analyse économique élargie par la quantification des bénéfices et des coûts non marchands.

Par conséquent, cette étude souligne l'importance de l'adaptation proactive aux impacts du changement climatique et de la gestion participative des ressources pour préserver l'intégrité environnementale du bassin versant de Douimis et renforcer la résilience des écosystèmes et de

la population qui en dépend. Ces résultats pourraient servir de modèle pour d'autres régions confrontées à des défis similaires en matière d›érosion hydrique, de perte en terres et de changement climatique.

Remerciements

Ce travail est élaboré dans le cadre du programme panafricain «Eau, Climat et Développement pour l'Afrique (WACDEP)». Le programme WACDEP est un programme du Conseil des Ministres Africains de l'Eau (AMCOW) mis en œuvre pour l'Afrique du Nord par le Global Water Partnership Méditerranée (GWP-Med). Pour la Tunisie, le projet a été réalisé en collaboration avec la Direction Générale de l'Aménagement et de la Conservation des Terres Agricoles (DGACTA),

Les auteurs remercient l'Institut National de Recherches en Génie Rural, Eaux et Forêts (INRGREF), l'Institut National de la Météorologie (INM) et le Commissariat Régional au Développement Agricole (CRDA) de Bizerte pour leurs appuis.

Sihem Jebari acknowledges the support of the TRANS-SAHARA project, funded under Grant Agreement No. 101182176.

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Decoding farm size-performance relationship in Algerian agriculture: Toward a unified analytical framework

SAMI ASSASSI*, ZEBBAR NADJET*, FERIEL DIB*

DOI: 10.30682/nm2505h
JEL codes: L25, O13, Q12

Abstract

The relationship between farm size and performance remains a central but contested issue in agricultural economics. While existing studies tend to classify this relationship (positive, inverse, or neutral), they rarely explore the underlying mechanisms, leading to context-dependent findings. This study addresses this gap by analyzing three agricultural value chains in Algeria – artichoke, honey, and tomato – using a comparative, mixed-methods approach. It identifies "structural differentiation levers", internal or external factors rooted in specific spatiotemporal contexts, that indirectly affect performance via techno-organizational practices and economic mediators. In the artichoke chain, these levers relate to access to water and market structures favoring large farms. In the honey chain, they reflect sanitary, organizational, and commercial conditions benefiting small-scale producers. In the tomato chain, their absence explains the performance parity across farm sizes. The analysis shows that size-related advantages arise only when three conditions are met: favorable levers, a size suited to them, and the farmer's capacity to activate them.

Keywords*: Farm size, Performance, Structural differentiation levers, Agricultural value chains, Algeria.*

1. Introduction

The relationship between farm size and performance lies at the heart of debates on the efficiency, sustainability, and equity of global agricultural systems, including those in the Maghreb and broader Mediterranean regions, where land scarcity, informality, and fragmented farm structures are critical issues. These systems face increasing pressure to produce more with limited resources while addressing goals related to food security, employment creation, wealth generation, and ecosystem preservation (Eastwood *et al*., 2010). More broadly, these debates revolve around identifying the most effective productive configurations – whether based on land, livestock, or other structuring factors. Farm performance is closely linked to the techno-organizational model adopted, which is itself influenced by the size of the production unit. In this context, determining whether small or large farms are more efficient is crucial to inform agricultural policy. Research on the relationship between farm size and performance (whether measured in physical or value terms), which has seen renewed interest in recent years, is anchored in this fundamental question. These studies employ diverse methodologies and yield mixed results,

* École Nationale Supérieure Agronomique, Algiers, Algeria.
Corresponding author: assassisami@hotmail.com

leading to the identification of a typology of relationships (Deininger and Byerlee, 2012).

On one hand, some studies highlight a positive relationship between size and performance, emphasizing the advantages of larger farms. These include economies of scale, better access to modern technologies, and greater integration into global value chains. For instance, Adamopoulos and Restuccia (2014) demonstrated that in developed countries, large farms benefit from access to advanced technologies that boost productivity, a challenge also faced by Mediterranean regions seeking to modernize smallholder agriculture. Similarly, Yao and Hamori (2019), using aggregate data from 29 Chinese provinces, observed a long-term positive relationship and recommended expanding large farms to support agricultural development, a policy trend that echoes land consolidation debates in North Africa, particularly in the last decade. Similar observations have been made in developing countries, as in Muyanga and Jayne's (2019) study in Kenya, which is particularly relevant for countries with dualistic farm structures like Algeria. Assassi (2023) identified a positive relationship in Algeria's canning tomato sector, where larger producers leverage economies of scale through personal means of transport use and mechanized planting and harvesting operations.

On the other hand, a significant body of research supports an inverse relationship, where smaller farms outperform larger ones. These studies argue that small farms primarily rely on family labor, optimizing resource allocation. Fan and Chan-Kang (2005) found that in China, small farms outperformed large ones due to intensive land management and efficient labor allocation, a situation that mirrors many smallholder farming contexts in the Maghreb. Studies such as those by Deininger and Jin (2003) in Vietnam, Ansoms and Van Ranst (2008) in Rwanda, and Barrett et al. (2010) in Madagascar corroborate this conclusion by highlighting superior resource management in small farms. Blackmore et al. (2018) indicates their ability to diversify their production system and the positive impact of this approach on their income, which is particularly relevant in diversified agrosystems of Mediterranean oases and peri-urban zones. Temporal data also reinforce this finding but point to the weakening of the inverse relationship due to capital replacing labor, as shown by Deininger *et al*. (2018) in India, a trend that resonates with the increasing mechanization observed in North African horticulture.

In parallel, other studies reveal complex, non-linear or null relationships. Savastano and Scandizzo (2017), for example, described a "direct-inverse-direct" dynamic in sub-Saharan Africa, influenced by factors such as public policies and infrastructure, elements that strongly shape farm performance in Algeria as well. Across multiple case studies from different continents, Rada and Fuglie (2019) demonstrated that agricultural mechanization tends to attenuate the inverse relationship between size and productivity, highlighting the impact of modernization and rising wages, both relevant to ongoing transformations in Maghrebian labor markets. Sheng *et al*. (2019) identified a U-shaped relationship in China, explained by inefficient input use. Finally, Benmehaia (2022) observed an almost absent relationship in greenhouse vegetable farms in Biskra, southeast Algeria.

A fourth category includes general studies that find no universal patterns. For instance, Eastwood *et al*. (2010) concluded that results vary based on factors such as infrastructure and agricultural policies, underlining the importance of context-sensitive analysis in regions like the Maghreb. Colin and Bouquet (2022) argued that the relative performance of farms depends on numerous, often localized factors. Other studies, such as Carletto et al. (2013), highlighted methodological biases influencing perceptions of this relationship.

Despite the wealth of existing research on the size-performance relationship, the literature primarily focuses on characterizing the type of relationship (positive, inverse, complex) and identifying the technical and organizational factors that shape it. These studies underscore the diversity of results, suggesting that this relationship varies according to local contexts and agricultural specificities. However, a fundamental question remains unexplored: are the underlying mechanisms – i.e., the operational processes – of this relationship themselves diversified, or do

they follow a systematic logic? Addressing this question could reveal whether it is possible to develop a unified framework for understanding the size-performance dynamic or whether each situation indeed requires a distinct contextual approach. This article addresses this novel issue, seeking to clarify whether contextual specificities can be transcended to construct a universal analytical methodology.

To answer this question, we selected three distinct agricultural value chains in Algeria: artichokes in Oued Rhiou (wilaya – province – of Relizane), honey in eastern Algiers, and greenhouse tomatoes in El Ghrous (wilaya of Biskra). These case studies allow for a comparison of varying relationships (positive, inverse, and null) between farm size and performance. An in-depth analysis of the underlying mechanisms is conducted for each value chain, considering structural factors, agricultural practices, and market contexts.

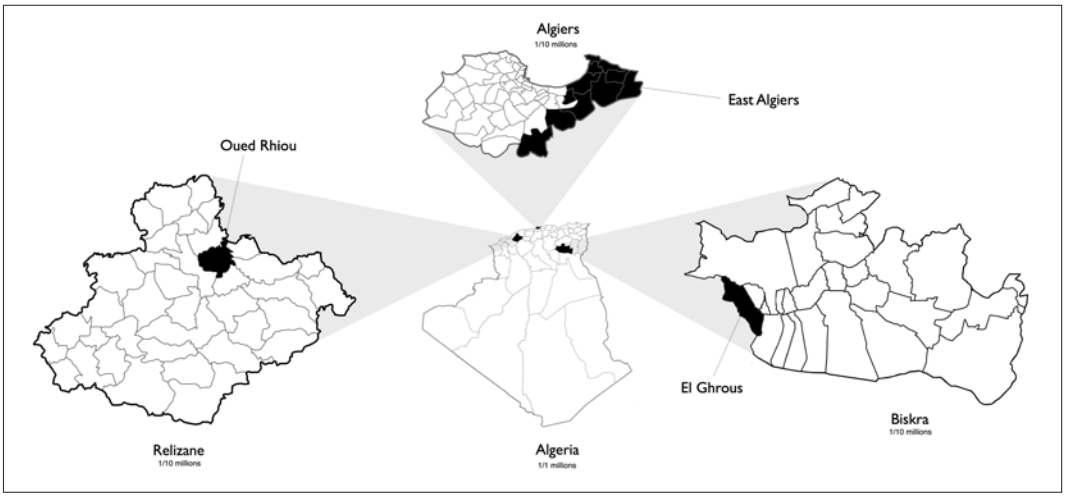
The article is structured into five main sections. The context section details the rationale for the selected case studies. The methodology section outlines the approach adopted. The results section presents the mechanisms observed in each sector. The discussion explores whether a systematic logic emerges or whether contextual specificities prevail. Finally, the conclusion summarizes the key findings and their implications for research and policy.

2. Context

This study examines three agricultural value chains located in distinct regions: artichoke in Oued Rhiou (Relizane province, 300 km west of Algiers), honey in East Algiers (across eight highly productive municipalities), and greenhouse tomato in El Ghrous (Biskra province, 400 km southeast of Algiers) (Figure 1).

In 2022, Oued Rhiou, a region known for cereals, citrus, and vegetables, dedicated 520 hectares to artichokes, cultivated by 87 producers (average farm size 5.9 ha), with a total output of 95,680 quintals (10% of national artichoke area – Relizane Agricultural Services Directorate, 2022). These lands, primarily state-owned, are operated under long-term usage rights granted to private concessionaires. Artichoke cultivation is centered in two irrigated perimeters, Bas-Chéliff and Mina, which face water shortages in July, crucial for crop maturation. Farmers with boreholes mix perimeter water with groundwater, though borehole use is restricted to large plots to protect the aquifer. Some producers use their own lands (including state-allocated), while others rely on informal seasonal rentals, accessing perimeter and borehole water when available. Tenants pay rental and water costs; plots are rented whole without subdivision. Boreholes are managed individually, with no water market. Harvesting, done approximately in three rounds, requires an important seasonal la-

Figure 1 - Map showing the location of the three study areas.



bor. Marketing is constrained by the absence of a local wholesale market: most sell at informal "stock exchanges" in Oued Rhiou and Djdiioua, in cafeterias where brokers set daily prices (from 120 DZD/kg in November to 10 DZD/kg in April 2022) based on quantity and quality, especially bract closure. Producers delegate negotiations to brokers, who receive per-kilogram commissions. Sales occur at farms, handled by producers with available labor or by wholesalers, who may charge for harvesting and transport.

East Algiers covers 10,277 hectares (9,212 hectares of usable agricultural area), dominated by arboriculture and vegetables. In 2023, it hosted 80 beekeepers managing 3,469 hives, producing 15,088 kg of honey. Production depends on self-financed beekeepers lacking credit access. Hives are placed in local orchards, forests, and melliferous zones of nearby provinces (Ouakli *et al*., 2019). Operations vary from sedentary to transhumant, seeking diverse melliferous resources. Productivity is enhanced by techniques like artificial swarming. Beekeepers fall into two groups: professionals combining beekeeping with farming, and amateurs with other jobs who value its flexibility and low labor demand (Neggache, 2018). Few belong to professional organizations, limiting collective structuring. Marketing involves a dominant short circuit of direct sales at local markets and a secondary circuit via wholesalers and retailers.

El Ghrous (Biskra province), also known for dates, is a key center for early-season greenhouse tomatoes. Production is driven by non-local farmers attracted by the land market, groundwater availability, and sunny climate. Land is leased per greenhouse unit, usually including water from private boreholes (with shared-use agreements), typically for three years with cash-paid, upfront seasonal rent (Daoudi *et al*., 2017). In 2023, 115 greenhouse farmers operated in the area; 90 grew tomatoes along with zucchini and peppers (Assassi et al., forthcoming). Highly perishable, tomatoes are marketed without storage through El Ghrous's wholesale market, where farmers sell directly alongside wholesalers from across Algeria. These wholesalers distribute rapidly to urban semi-wholesale markets, then to retailers, ensuring same-day delivery of fresh produce to consumers (Assassi *et al*., 2017).

3. Data and methodology

3.1. *Methodology*

This study examines whether the relationship between farm size and performance follows a systematic logic or depends on specific contextual factors. We adopt a bottom-up approach to detect causal effects, analyze underlying mechanisms, and identify structural levers influencing this dynamic across various spatio-temporal contexts. Three agricultural sectors were analyzed: artichoke farming in Oued Rhiou (Relizane), honey production in the East Algiers, and greenhouse-grown early-season tomatoes in El Ghrous (Biskra). These cases, selected based on their respective size-performance relationships (positive, inverted, and null) enable us to explore whether a systematic logic underpins these dynamics or if each sector follows a logic inherent to its specific characteristics.

Initially, Student's t-tests were employed to compare the performance of small and large farms across the three value chains. No control variables other than size were included to capture all potential differences. Performance was measured by net profit per unit of the principal factor for a complete campaign. Net profit refers to the difference between total revenues (calculated as selling price multiplied by quantity sold) and total production costs over a complete campaign, representing the farm's actual financial gain. Net profit was chosen as the analytical indicator for its ability to reflect all productive and financial differences. The main factor unit was used as a control element since it best represents farm size, and consequently the technical model adopted: land area for artichokes, number of hives for honey, and number of greenhouses for tomatoes. Consequently, performance indicators were net profit per hectare, per hive, and per greenhouse, respectively. The choice of a complete campaign lies in its ability to capture the full scope of production over an entire cycle, reflecting the seasonal variations in costs, yields, and revenues that can influence profitability.

We identified the determinants of net profit by analyzing performance mediators (cost, yield, sale price) to explain the observed differences

between small and large farms. This analysis was conducted using Student's t-tests to compare these mediators across the two farm types. To calculate the cost per main factor unit (C_{imfu}), we calculated the total cost (C_{iT}) of each farm and divided it by its size (S_{iT}) – total costs include all expenses actually incurred over a complete production cycle of the activity, including input costs, access to natural resources, energy, services, equipment depreciation, marketing, and labor costs; the latter corresponds to wages effectively paid to hired workers or to family labor, valued at zero when unpaid :

$$C_{imfu} = \frac{C_{iT}}{S_{iT}} \quad (1)$$

Once key mediators were identified, we explored the techno-organizational determinants (inputs, production and commercial practices) responsible for these differences, again using Student's t-tests.

To detect techno-organizational differences attributable to farm size, we conducted linear regressions (Equation 2). Each techno-organizational factor (dependent variable) was related to farm size (independent variable). These analyses were restricted to value chains where significant net profit differences were observed, namely artichoke farming and honey production.

$$Y_{it} = B_0 + B_1 \, x \, Size_{it} + \varepsilon_{it} \quad (2)$$

Where:

Y_{it}: Dependent variable representing the techno-organizational factor for farm *i* in value chain *t*.

$Size_{it}$: Independent variable representing the size of farm *i* in value chain *t*.

B_0 : Constant, representing the regression intercept.

B_1 : Coefficient associated with farm size, indicating its effect on the dependent variable.

ε_{it} : Error term.

To address endogeneity biases in the analysis between size and techno-organizational factors, an adjusted size variable was created for each value chain. This variable was derived from a linear regression using instrumental variables strongly correlated with size but independent of net profit and performance mediators. Instrumental variables were selected after qualitative analysis and correlation tests. In the artichoke sector, the chosen instrumental variables were total land area owned and the number of tractors, reflecting the capacity to cultivate irrigated areas. For honey production, variables such as the age and experience of the farmer and engagement in complementary activities were chosen, as these factors influence hive management. The resulting linear regressions corrected biases by assigning the adjusted size variable an independent role, enabling a more precise and reliable analysis of farm size effects on performance.

Causal relationships between farm size and organizational determinants, highlighted by linear regressions, were corroborated through qualitative analyses. These analyses relied on targeted interviews with farmers, elucidating the underlying mechanisms driving the observed differences and providing contextual validation for the quantitative results.

3.2. *Sampling and data collection*

The adopted methodology relies on primary and secondary data collected for the three value chains studied. The value chains were selected following an exploratory survey conducted in consultation with the National Chamber of Agriculture, which guided the initial choice. After validation through exploratory investigations, certain options were excluded; the canning tomato value chain in Guelma and the citrus value chain in Blida were deemed unsuitable and were replaced respectively by early-season tomatoes from El Ghrous and honey from East Algiers, which were better aligned with the study's objectives.

Secondary data, provided by the Ministry of Agriculture and the agricultural directorates of the concerned wilayas, allowed for contextualization of the territories and value chains through information on farms, cultivated areas, and geographic distribution.

Primary data targeted agricultural farms, covering their structure (area, number of hives or greenhouses, equipment), the farmers (age, training, labor force), their operations (financing, land access, farming practices, marketing), and their performance (costs, yields, selling prices).

This information was collected through surveys of 90 farmers (30 per value chain), with each sample including 15 small and 15 large farmers selected randomly. Excluding medium-sized farms simplifies the analysis and allows for capturing clear contrasts in production models and performance, as these farms often mix practices from both extremes. This represents 50% of small-scale and 88% of large-scale artichoke producers in Oued Rhiou, 63% of small and 94% of large honey producers in East Algiers, and 50% of small and 83% of large tomato producers in El Ghrous.

Given that farm size is used as a control variable in this study (as in all similar studies) to reflect the technical model adopted, we have established thresholds based on technical criteria identified during exploratory surveys to classify the surveyed farms. Accordingly, we define a small farm as one that can be managed by a single individual without requiring sophisticated equipment, while a large farm is characterized by the need for hired labor or reliance on advanced equipment:

- Artichoke: Large farmers (≥8 ha), small farmers (≤3 ha).
- Honey: Large farmers (≥100 hives), small farmers (≤20 hives).
- Tomatoes: Large farmers (≥20 greenhouses), small farmers (≤5 greenhouses).

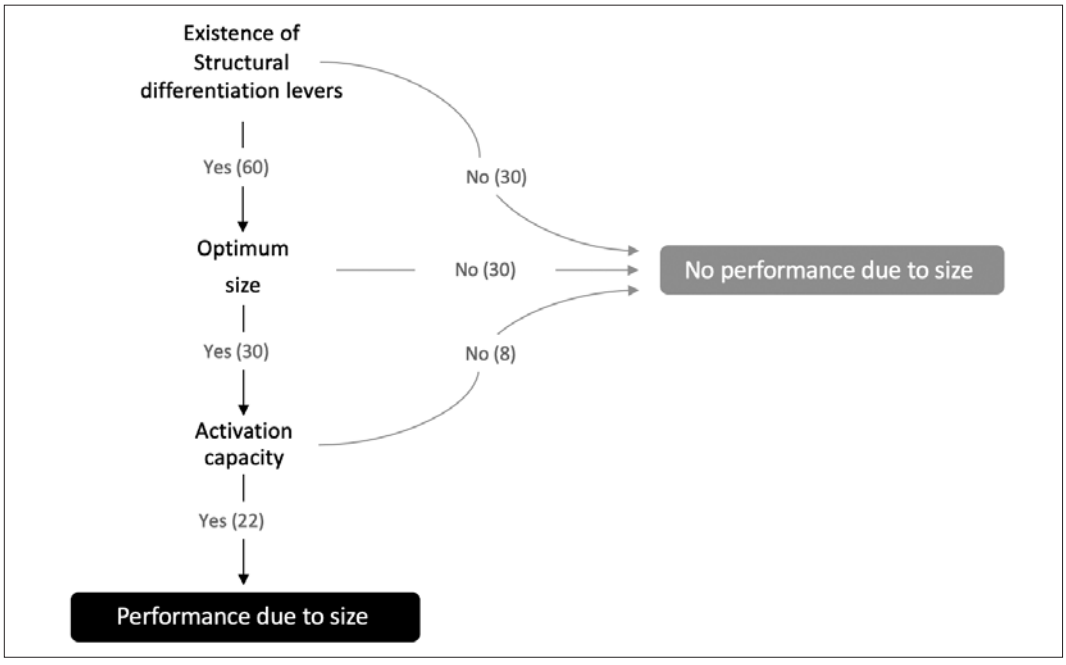
Considering that beekeeping is practiced recreationally by a large number of citizens in the study area, we chose to survey only professional beekeepers, those integrated into the market (who sell their products).

The data for artichokes and tomatoes pertain to the 2022 farming season, while the data for honey pertains to the 2023 season.

4. Results

The relationship between farm size and performance follows a systematic logic, regardless of its nature. It depends on the presence and the nature of factors that we refer to as "*structural differentiation levers*". These levers, whether internal or external to the farm, are specific to a spatio-temporal context and influence performance without being directly controllable by the farmers. They can be either permanent or temporary. When present, these levers favors a certain

Figure 2 - Conditional process of achieving size-related performance.



farm size by influencing techno-organizational practices (technical pathways or commercial strategies). These practices, in turn, affect performance mediators such as costs, yields, and prices, thereby impacting profits. In their absence, the relationship between size and performance tends to neutralize.

As shown in Figure 2, for a farm to gain economic advantages from its size, three conditions must be met: (1) the presence of favorable differentiation levers in its context, (2) the possession of an optimal size suited to these levers, in other words, a farm size that allows producers to benefit from structural advantages in the context, regardless of their strategy or intention, and (3) the ability of the concerned farms to activate these levers, which depends on certain "baseline conditions" such as the availability of resources and access to complementary infrastructures. These must accompany the condition of optimal size. Thus, even with an optimal size in a favorable context, potential gains remain contingent upon the farm's capacity to mobilize the necessary resources. In the absence of these conditions, the expected advantages linked to optimal size may fail to materialize, thereby limiting performance in an otherwise favorable environment. These aspects will be elaborated in the following sections.

4.1. *Characterization of small and large producers in the three value chains*

Table 1 highlights several similarities between small and large artichoke producers, particularly regarding the age of household heads, indicating generational consistency in this activity. Ownership of transport means is also comparable, reflecting similar mobility conditions. Larger farms, however, exhibit more frequent access to rented land and a stronger tendency towards polyculture. Differences in pluriactivity, tractor ownership, and the number of family members involved in farming are not statistically significant.

In the honey value chain, there are no significant differences between groups in the average number of years of education, practice of other agricultural activities, or the adoption of modern beehives. Larger farms, however, have significantly greater experience in honey production, an almost universal practice of transhumance, and greater use of specialized equipment, signaling higher levels of professionalization and agricultural intensification. The significantly older household heads in larger farms may suggest a correlation between accumulated experience and the capacity to develop larger-scale operations. While pluriactivity is marginally more frequent in smaller farms, the difference is not statistically significant.

In the tomato value chain, both groups share similarities in the age of household heads and levels of education. Neither engages in pluriactivity or owns tractors, indicating similar limitations regarding heavy agricultural equipment. However, larger farms exhibit higher ownership of transport means and a stronger tendency towards polyculture. They also involve more family members in farming, potentially reflecting intensified familial efforts to sustain larger operations. Access to leased land, though slightly more common among larger farms, is a widespread practice in both groups, emphasizing its relevance in this value chain.

4.2. *Comparison of the performance of small and large producers in the three value chains*

The performance comparisons between small and large producers in the three value chains validate the rationale for selecting them as case studies. As shown in Figure 3, the relationship between size and performance is positive in the artichoke value chain, reversed in the honey value chain, and neutral in the tomato value chain.

As illustrated Table 2 of Student's t-test, large artichoke producers achieve 114% higher net profit per hectare compared to small producers, owing to yields and selling prices that are 20% and 16% higher, respectively. Conversely, in the honey value chain, small producers obtain the highest profit per hive, with gains 27% higher than those of large producers. This is explained by selling prices that are 21% higher and production costs that are 34% lower. No difference was observed between small and large tomato producers, as performance mediators (costs, yields, and prices) were similar in both groups.

Table 1 - Comparison of characteristics of small and large producers in the three value chains.

	Variables	*Large farmers*	*Small farmers*	*Difference*	*p-value*
Artichoke	*Household characteristics*				
	Age of head of household (years)	45.8	46	-0.13	0.97
	Number of family workers	1	0.27	0.73	0.41
	Multiactivity (dummy)	0.13	0	0.13	0.46
	Multicrop (dummy)	0.47	0.93	-0.47	0***
	Number of years studied	7.93	7.60	0.33	0.86
	Agricultural training (dummy)	0.01	0	0	-
	Farm characteristics				
	Area under artichoke (hectare)	14	2.35	11.65	0***
	Access to land by renting (dummy)	0.53	0.27	0.26	0.26
	Possession of means of transport (dummy)	0.27	0.27	0	1.00
	Ownership of a tractor (dummy)	0.80	0.60	0.20	0.42
Honey	*Household characteristics*				
	Age of head of household (years)	52.1	43.34	8.73	0.07*
	Number of family workers involved in agriculture	0	0	0	-
	Multiactivity (dummy)	0.60	0.87	0.27	0.21
	Other agricultural activities (dummy)	0.53	0.47	0.07	0.72
	Number of years studied	11.33	11.67	-0.33	0.81
	Experience in honey production (years)	17.20	4.67	12.53	0***
	Farm characteristics				
	Number of hives	138.20	11.27	126.93	0***
	Practice of transhumance (dummy)	0.67	0	0.67	0***
	Use of modern hives (dummy)	0.80	0.73	0.7	1
	Use of specialized equipment (dummy)	1	0.33	0.67	0.00**
Tomato	*Household characteristics*				
	Age of head of household (years)	32.6	34.1	-1.5	0.43
	Number of family members involved in agriculture	2.9	1.7	1.2	0.02**
	Multiactivity (dummy)	0	0	0	-
	Multicrop (dummy)	0.53	0	0.53	0.0013***
	Number of years studied	9.87	9.13	0.73	0.46
	Allochthonous (dummy)	0.86	0.73	0.13	-
	Farm characteristics				
	Number of tomato greenhouses	32.00	6.40	25.60	0***
	Access to land by renting (dummy)	1	0.93	0.07	0.33
	Possession of means of transport (dummy)	1	0.60	0.40	0.01***
	Ownership of a tractor (dummy)	0	0	0	-

*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

Figure 3 - Visualization of the evolution of net profit as a function of farm size.

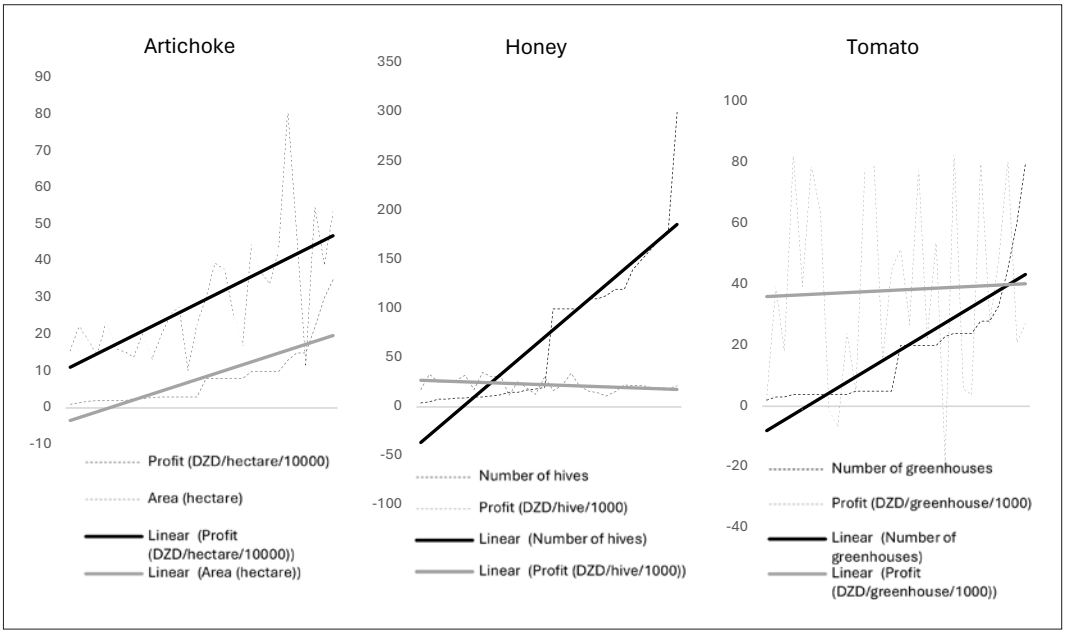


Table 2 - Comparison of performance of small and large producers in the three value chains.

	Variables	*Large farmers*	*Small farmers*	*Difference*	*p-value*
Artichoke	Cost (DZD/hectare)	390,791	379,508	11,284	0.68
	Yield (quintals/hectare)	143	119	24	0.00***
	Price (DZD/kg)	55	47	8	0.00***
	Profit (DZD/hectare)	395,574	185,158	210,416	0.00***
Honey	Cost (DZD/hive)	9,041	6,003	3,037	0.00***
	Yield (kg/hive)	10,6	9,47	1	0.10
	Price (DZD/kg)	2,720	3,286	-566	0.00***
	Profit (DZD/hive)	19,738	25,156	-5,417	0.03**
Tomato	Cost (DZD/greenhouse)	246,542	240,966	5,576	0.71
	Yield (quintals/greenhouse)	30.1	30.2	-1	0.93
	Price (DZD/kg)	93.9	94.2	0	1
	Profit (DZD/greenhouse)	36,805	34,194	2,611	0.67

*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

The differences in performance mediators between small and large producers of artichokes and honey can be attributed to certain techno-organizational differences, such as inputs and production and commercial practices. Some of these differences are related to farm size, while others are not. Those attributable to size stem from internal or external configurations or characteristics that favors a specific farm size. These configurations and characteristics act as structural differentiation levers, which we will detail below.

4.3. *Analysis of the size-performance relationship: structural differentiation levers at play*

4.3.1 *Artichoke value chain: levers for a classical positive size-performance relationship*

The structural differentiation levers enabling large artichoke farmers to mobilize more production factors and achieve higher prices include both permanent and temporary factors. These encompass the conditions for granting drilling permits, the structure of the rental land market (primarily consisting of indivisible plots) the artichoke harvest schedule, and the size of buyers in the local market.

As shown in Figure 4, the superior yields of large farmers are attributed to their more effective technical practices, notably supplementary irrigation, a higher number of plants per hectare, and the use of manure. These statistically significant differences are confirmed through linear regression, highlighting the impact of techno-organizational practices on yield.

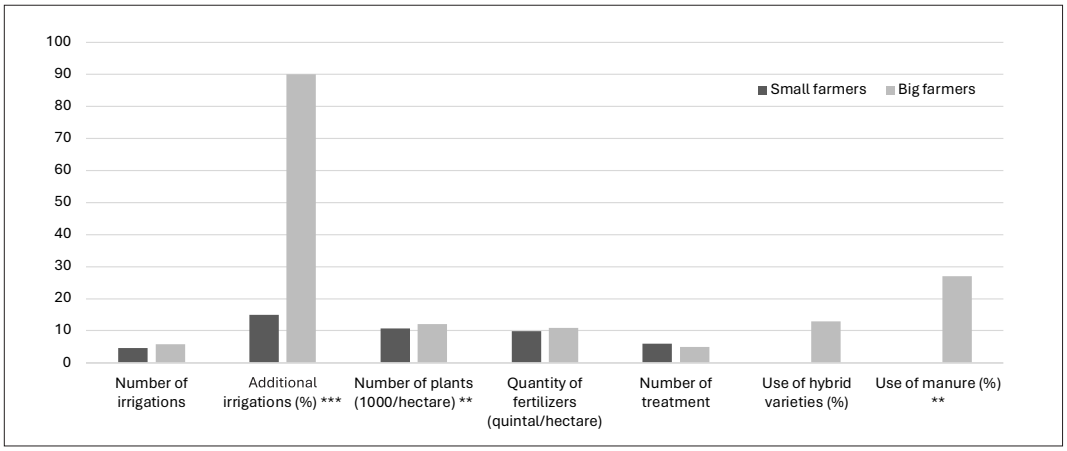
Regression results of various techno-organizational determinants based on adjusted farm size (obtained through linear regression with instrumental variables: total area and number of owned tractors – Equation 3), presented in the Table 3, indicate that only the application of supplementary irrigation is significantly influenced by farm size.

$$\text{Adjusted artichok surface area} = 2{,}8 + (0{,}2 \times \text{total surface area}) + (0{,}5 \times \text{number of tractors}) \quad (3)$$

Large farmers' irrigation practices surpass those of small farmers, particularly in quality. While large farmers conduct an average of two additional irrigations, they primarily perform more supplementary irrigations during dry periods. All plots are within the large irrigated perimeter, which is often inefficient during periods of high-water demand. Access to supplementary irrigation options, such as groundwater, is thus a decisive advantage. Only large farmers, whether landowners or tenants, benefit from boreholes on their plots, as drilling permits are more frequently granted to large farms. Plots with boreholes are often indivisible on the rental market, limiting small farmers' access to groundwater. In the rare cases where plots are divisible, groundwater access remains exclusive to the tenant of the plot containing the borehole. Conversely, small farmers primarily rely on the large irrigated perimeter, facing difficulties during dry periods when it fails to supply water. This lever is temporary and depends on public policies, the rental land market, and the efficiency of the large irrigated perimeter.

Although only two farmers use high-yield hybrid varieties, and the difference between small and large farmers is not significant, these varieties have been recently introduced in the region.

Figure 4 - Comparison of input quantities used by small and large artichoke farmers.



*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

Table 3 - Regression results of variations in artichoke production factors based on farm size.

	R Square		*Coefficients*	*Standard Error*	*P-value*	*Lower 95.0%*	*Upper 95.0%*
Additional irrigation	0.27	Intercept	0.03	0.16	0.86	-0.30	0.35
		Adjusted size	0.06	0.02	0.00	0.02	0.09
Number of plants/hectare	0.04	Intercept	11,395	762	0.00	9,834	12,957
		Adjusted size	16.81	80.84	0.84	-148	182
Use of manure	0.03	Intercept	0.68	0.79	0.40	-0.95	2.30
		Adjusted size	0.02	0.08	0.86	-0.16	0.19

They could become a future differentiation lever for large farmers, who generally have greater capacity to test and scale up such innovations.

Although large producers obtain a higher average selling price than small producers (Table 2), the regression between farm size and artichoke selling prices (Table 4) is not statistically significant. This can be attributed to the nature of the director price in this value chain: it is a market-determined selling price, set daily, making most producers – large and small alike – essentially price takers. Consequently, not all large producers consistently secure higher prices, as detailed further in section 5.4.

Nevertheless, the higher prices obtained by certain large producers, which raise the average for the entire large farm category, stem from three main strategic levers. According to respondents, irrigating a few days before harvest results in artichokes with tightly closed bracts, synonymous with higher gustatory and nutritional quality. However, harvesting occurs during the dry season (July), when water resources in the irrigated perimeter are limited. Large farmers, with alternative irrigation options, can irrigate at critical times, delivering superior quality and thus securing higher prices. In contrast, small farmers typically face greater difficulty meeting these quality standards.

Moreover, certain large artichoke producers gain additional bargaining power due to their size and higher production volumes. This advantage primarily arises from two structural elements. First, the local artichoke market lacks a formal wholesale structure and relies heavily on brokers acting as intermediaries. These brokers, remunerated per kilogram traded, prioritize quantity over unit price and actively compete to retain large producers to maximize their commissions, particularly in Oued Rhiou, the main production basin. Being fewer than traders, brokers wield substantial influence, thus enabling advantageous price negotiations for select large producers. Second, the combination of substantial production volumes and a harvesting process typically completed in three operations allows these large farmers to sell significant quantities per transaction. Consequently, these large producers hold a stronger bargaining position with buyers, unlike small farmers, who, constrained by lower volumes, must frequently accept prevailing market terms. In contrast to the tomato value chain, where buyers significantly exceed producers in size and negotiating power, large artichoke farmers enjoy a more balanced relationship with their buyers.

Finally, respondents highlighted that certain large farmers also benefit from stronger networks and closer relationships with market actors, particularly brokers motivated to retain their business. This grants them privileged access to strategic market information regarding prices, demand fluctuations, and optimal sales timing, enabling them to better manage their marketing strategies.

Table 4 - Regression results of variations in artichoke prices based on farm size.

	R Square		*Coefficients*	*Standard Error*	*P-value*	*Lower 95.0%*	*Upper 95.0%*
Selling price (DZD/kg)	0.01	Intercept	49.93	3.00	0.00	43	56
		Adjusted size	0.13	0.37	0.73	-0.63	0.88

Small producers, lacking such relationships, are less able to leverage information effectively, limiting their ability to optimize sales.

4.3.2 *Honey value chain: levers supporting an inverse size-performance relationship*

The structural levers enabling small honey producers to better control their costs and sell at higher prices are primarily permanent factors. These include the structure of beekeeping diseases, bee physiology, hive sensitivity to individual care, the compensation of family labor, and the structure of the honey market in Algeria, particularly the perception of artisanal products.

As illustrated in Figure 5, the divergence in production costs favoring small beekeepers stems from significant differences in costs associated with health treatment, feeding, harvesting, transhumance, and packaging.

The regressions of various costs as a function of adjusted size (obtained through linear regression with instrumental variables: the beekeeper's age, beekeeping experience, and engagement in another income-generating activity – Equation 4), presented in Table 5, show that only the costs of health treatment, harvesting, and packaging are significantly influenced by the number of hives.

$$\text{Adjusted number of hives} = 98{,}9 + (-1{,}8 \times \text{age}) + (7{,}4 \times \text{experience}) + (-27{,}9 \times \text{other source of income}) \quad (4)$$

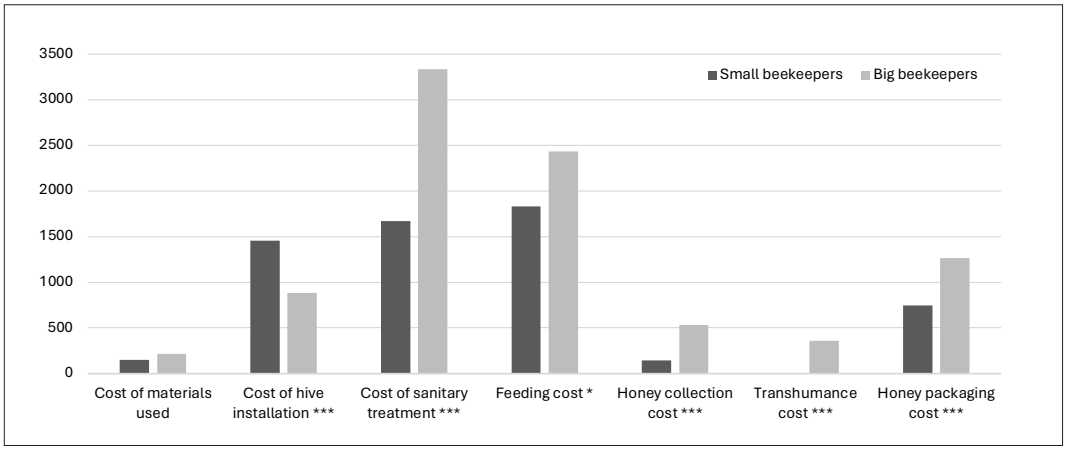
Small beekeepers spend less on health treatment for their hives for three main reasons. First, having fewer hives reduces the concentration of bees in a given area, thereby limiting disease transmission. Additionally, they can monitor each hive more closely and intervene promptly without resorting to mass treatments. Finally, unlike large beekeepers, who are constrained to use low-handling techniques such as chemical treatments with strips, small producers prefer less expensive solutions, such as organic acids or homemade biological remedies, which require frequent applications feasible for small farms.

Similarly, small beekeepers often harvest honey manually, with the help of unpaid family labor, thus reducing costs. In contrast, large producers must hire employees and use specialized equipment.

Finally, small beekeepers often use improvised, low-cost, or free packaging, such as recycled jars, which are accepted by their customers who perceive their products as artisanal. In contrast, large producers are required to purchase specific packaging.

Although small beekeepers achieve higher average selling prices, the regression between hive number (farm size) and honey selling price is not statistically significant (Table 6). Similar to the artichoke value chain, this lack of significance stems from the nature of the director price in the honey value chain: a market-determined selling

Figure 5 - Comparison of costs incurred by small and large honey producers.



*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

Table 5 - Regression results on the variation of different honey production factors and practices based on farm size.

	R Square		*Coefficients*	*Standard Error*	*P-value*	*Lower 95,0%*	*Upper 95,0%*
Feeding	0,11	Intercept	1,762	247	0.00	1,254	2,269
		Adjusted size	4.96	2.60	0.07	-0.37	10.30
Health treatment	0,22	Intercept	1,613	405	0.00	781	2,444
		Adjusted size	11.88	4.27	0.01	3.14	20.62
Transhumance	0,03	Intercept	15,041	10,316	0.16	-6,091	36,174
		Adjusted size	99	108	0.37	-122	321
Harvesting	0,60	Intercept	-4,003	7,948	0.62	-20,285	12,278
		Adjusted size	554	83	0.00	383	726
Packaging	0,24	Intercept	745	111	0.00	518	973
		Adjusted size	3.49	1.17	0.01	1.10	5.88

Table 6 - Regression results of variations in honey prices and direct retail sales practices based on the number of hives.

	R Square		*Coefficients*	*Standard Error*	*P-value*	*Lower 95,0%*	*Upper 95,0%*
Selling price (DZD/kg)	0,22	Intercept	2,890	128	0.00	2,628	3,152
		Adjusted size	1.51	1.23	0.23	-1.00	4.02
Direct retail sales	0,54	Intercept	0.99	0.11	0.00	0.77	1.21
		Adjusted size	-0.01	0.00	0.00	-0.01	-0.01

price, at which both small and large producers generally remain price takers. Thus, not all small beekeepers consistently secure higher prices, as explained further in section 5.4.

Nevertheless, the price advantage of other small producers, which also raises the average selling price for their category, is largely attributable to their direct retail sales practices. This practice constitutes the most notable and statistically significant difference in commercial practices between small and large beekeepers. According to regression analysis (Table 6), engaging in direct retail sales significantly increases the honey price by approximately 635 DZD/kg, and is strongly influenced by the adjusted operational size of the beekeeper.

The significant impact of retail sales on honey prices in Algeria relates directly to specific market characteristics. Given the absence of formal mechanisms for verifying agricultural product quality, consumers highly value personal verification, particularly for expensive products such as honey, which in 2023 was priced on average 60 and 33 times higher than artichokes and tomatoes, respectively. In this context, purchasing honey directly from producers serves as an informal guarantee of quality.

Consequently, small producers, due to their lower production volumes, predominantly sell honey directly to consumers, emphasizing its artisanal quality. This short supply chain allows them to capture intermediary margins while effectively branding their honey as handcrafted and authentic. Conversely, larger producers, constrained by higher production volumes, rely on longer distribution channels involving wholesalers and retailers, resulting in lower wholesale prices and reduced opportunities to ensure the perceived artisanal quality of their honey.

4.3.3. *Tomato value chain: lack of levers and neutralization of the size-performance relationship*

The profits of small and large tomato farmers are similar due to comparable yields, costs, and selling prices. This homogeneity stems from the

identical production and marketing practices shared by both groups.

Small and large farmers employ closely aligned technical pathways, with statistically insignificant differences. Nearly all farmers access land through rental agreements and use boreholes for irrigation, performing a similar number of irrigations (28 for large farmers, 24 for small farmers). All use tunnel greenhouses, hybrid varieties, and similar inputs: approximately 8 quintals of fertilizer, 12 and 13 quintals of manure per greenhouse, and 11 phytosanitary treatments per season.

Two factors explain this uniformity. First, all producers have equitable access to divisible resources such as water and land, rented by greenhouse unit, or inputs available in small quantities (e.g., manure sold by trailer). This divisibility, a structural feature for decades, ensures accessibility for all. Second, neither group benefits from major innovations unavailable to the other. The absence of innovation as a differentiation factor is not structural. The last significant innovation, the hybrid variety Tofane, introduced in the late 2000s, temporarily advantaged large farmers, increasing their yields by 18% and profits by 59%. However, this innovation has since become widely adopted.

On the commercial front, small and large farmers exhibit similar behaviors towards buyers. The high perishability of tomatoes plays a central role in shaping these practices. Unlike artichokes, whose harvests can be delayed by a few days to avoid unfavorable market conditions, and honey, which can be stored for extended periods without loss of quality, tomatoes must be harvested progressively as they ripen. This perishability leads farmers to carry out numerous small harvest operations (14 on average), resulting in modest transaction volumes at each sale. It also puts them under constant pressure to sell quickly, limiting their ability to negotiate and pushing them to accept similar trading conditions regardless of farm size. In terms of daily trade volumes, farmers are 4 to 12 times smaller than the average wholesalers at the El Ghrous market. This power imbalance, which is not entirely structural, has intensified over the past decade, with a 30% increase in traders' purchasing capacities between 2013 and 2023. This disparity is reflected in the average profits achieved in 2023: 27.4 DZD/kg of tomato for wholesalers compared to 14 DZD/kg of tomato for farmers.

4.4. *Assessment of farms' activation capacities*

The effectiveness of structural differentiation levers relies on farms' ability to activate them to enhance their performance. Not all producers, even in favorable contexts, fully utilize these assets optimally. Some farms, despite their advantageous size, have failed to meet the necessary conditions to leverage these levers, resulting in profits lower than the average benefit achieved by disadvantaged producers (Table 7).

This failure notably concerns the inability to activate levers related to selling prices, which explains the lack of statistical significance in the direct regressions between farm size and selling prices observed in both the artichoke and honey value chains.

Indeed, three large artichoke farmers, who achieved low profits, sold their produce at a price 27% lower than other large farmers. This stems from their inability to harvest independently due to a lack of suitable labor in their locality. Consequently, they are compelled to sell standing crops to a small group of traders with access to specialized seasonal workers. In addition to conceding an extra margin for harvesting, this reduces their pool of clients, thereby weakening their bargaining power – an essential structural differentiation lever within this value chain.

Similarly, five small honey producers, who also reported low profits, sold their products at an average price 14% lower than their peers. Favoring other time-consuming activities, they rely on local shops to market their products, which limits the artisanal value addition and access to retail prices. Furthermore, their yields – 47% lower than their peers – reflect inadequate sanitary management caused by their low presence on the farm. This situation prevents them from activating the levers of retail sales and sanitary risk management.

Moreover, no theoretically disadvantaged farmers (small artichoke producers and large

Table 7 - Comparison of performance between advantaged producers who achieved high profits and those who did not.

	Artichoke			*Honey*		
	Large farmers with better profits than the average profit of small farmers	*Large farmers with profits lower than the average profit of small farmers*	*p-value*	*Small farmers with better profits than the average profit of large farmers*	*Small farmers with profits lower than the average profit of large farmers*	*p-value*
Profit (DZD/ hectare or hive)	449,985	177,933	0.45***	29,839	15,790	7.52***
Price (DZD/kg)	57	45	0.63**	3,430	3,000	2.03**
Yield (kg/ hectare or hive)	14,792	12,500	0.23	10.6	7.2	4.29***
Cost (DZD/ hectare or hive)	394,348	376,566	0.88	6,100	5,809	0.27

*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

honey producers) activated these levers, consistently recording profits below those of their advantaged counterparts. This confirms that while a favorable size alone is insufficient, it remains indispensable for leveraging these structural differentiation levers and maximizing profits.

5. Discussion

This study brings new insights into the size–performance relationship in agriculture, a domain marked by fragmented and often contradictory findings (Eastwood *et al*., 2010). While the literature has identified several influencing factors, it lacks a unified analytical framework. To address this gap, we introduce the concept of "*structural differentiation levers*," a common label for heterogeneous factors that initiate size-performance effects. These levers demonstrate that the relationship is contextual, non-linear, and activated under specific conditions. Unlike earlier works focusing on isolated variables (Ali and Deininger, 2015), this study proposes a comprehensive framework that integrates these factors and accommodates local contexts, contributing to a more coherent understanding of the mechanisms behind size-related advantages.

Large artichoke farms benefit from productive and qualitative advantages not only due to classical economies of scale (mechanization, input efficiency – Deininger *et al*., 2018), but also because of structural elements like land configuration and favorable market access. Their access to borehole-equipped plots, essential for irrigation in semi-arid regions, is a critical advantage, especially for sensitive crops like artichokes. This aligns with findings by Assunção and Braido (2007) on differentiated water access for large farms, though few studies focus on vegetables. Our findings also echo Assassi (2023), who notes large farmers' access to healthier land, while contrasting with Barrett *et al*. (2010), who argue small farmers often benefit from better-located plots. Other levers include resource management and harvest timing, which allow larger farms to optimize quality and align production with high-price periods – a mechanism mentioned in World Bank (2016), though underexplored in local vegetable markets.

Similarly, small beekeepers in eastern Algiers show distinct advantages over large operations, particularly in cost control, consistent with Barrett *et al*. (2010). They use internal resources like family labor to maintain profitability, unlike larger farms that rely on outsourcing, which raises costs. A key, under-studied lever is direct sales: small producers use short supply chains to sell high-priced artisanal products. Addition-

ally, although small producers are often seen as having weaker sanitary controls (Morris *et al*., 2023), our results show a more nuanced situation. With fewer hives, they apply targeted treatments more effectively and at lower cost.

The observed parity between small and large tomato producers illustrates a neutral size-performance relationship – meaning size has no direct impact on productivity or profit. This rare finding is in line with Benmehaia (2022), who notes that without structural triggers, no differentiation emerges. Our study advances this by showing how these triggers evolve over time and across space, as suggested by Rada and Fuglie (2019), who highlight the transformative role of technology and policy. In our case, uniform access to inputs (water, seeds, credit) and standardized practices explain the uniformity in performance, resembling Gourlay *et al*. (2017), where similar inputs ensure similar yields across farm sizes. This contrasts with Huang and Wang (2024), who show significant disparities in China due to unequal access to capital and technology. The absence of technological change in the studied tomato chain limits scale-based advantages, unlike other chains where tech adoption quickly favors large farms (Rada and Fuglie, 2019).

Finally, consistent with Colin and Bouquet (2022), this study confirms that the size–performance relationship is neither universal nor linear – it depends on chain-specific and contextual triggers. Where levers are present, they create size-based differentiation; where absent, they suspend it. These findings stress the importance of examining underlying mechanisms to fully grasp the dynamics of this relationship.

6. Conclusion

This article aimed to determine whether the relationship between farm size and performance reflects a systematic pattern or is shaped by specific contexts. Relying on comparative evidence from three Algerian value chains (artichoke, honey, and tomato) and combining quantitative and qualitative analysis, the study identified a consistent explanatory mechanism despite differing relationship types across chains.

Rather than focusing solely on performance gaps between farm sizes, the analysis highlights the contextual conditions – referred to as structural differentiation levers – that shape these gaps. These levers, which vary by chain, include resource access, institutional arrangements, and commercialization channels. Their presence, alignment with farm size, and activation by farmers determine whether size translates into performance advantages.

These findings hold practical implications for public policy. While farmers operate within constraints, in addition to guiding policymakers in promoting one production model over another, they can also influence the underlying levers, such as access to water, land, and markets, to create more balanced or strategically differentiated support systems across farm sizes, in a more equitable or efficient direction.

The study's scope is limited to three chains and a single production year, which restricts its temporal and spatial generalizability. Future work should expand to other contexts and adopt a longitudinal lens to assess how these structural levers evolve and condition the size–performance relationship over time.

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Beyond access: Evaluating the impact and counterfactual outcomes of input subsidy programmes on smallholder maize farmers' yield and income in Zambia

GOSPEL IYIOKU*, EBENEZER DONKOR*, WILLIAM NKOMOKI*, JANA MAZANCOVA*, JIRI HEJKRLIK*

DOI: 10.30682/nm2505i
JEL codes: N57, O38, Q13, Q18

Abstract

This study examines the problems of low productivity, inefficiency and food insecurity among smallholder farmers in Zambia despite the efforts of input subsidy programs such as the Farmer Input Support Programme (FISP) to enhance access to improved seeds and fertilisers. Using a counterfactual non-experimental design approach, this study uses a sample of 404 maize farmers (234 FISP beneficiaries and 170 non-beneficiaries) across the Southern province of Zambia. An initial probit regression model was used to identify the determinants of FISP access, and an endogenous switching regression model was used to measure the effect of FISP access on maize yield and income. The results show that age, household size, marital status, cooperative membership, and off-farm income are all positively related to FISP access, while gender, farm size, and farming experience are all negatively related to FISP access. The endogenous switching regression results suggest that FISP access is a real boon for beneficiaries in terms of increasing maize yield and farm income. For instance, beneficiaries of FISP would have harvested 144.97kg/ha less maize and earned 744.69 ZMW less in the absence of input subsidy. On the other hand, the non-beneficiaries would have harvested 730.815kg/ha more maize and earned 2233.09 ZMW more if they had accessed the input subsidy. These results show that FISP positively impacts agricultural production and economic returns and calls for targeted policies that address gender barriers, support smallholder farmers, and improve cooperative structures.

Keywords*: Farmer input subsidy programme, Maize yield, Farm income, Gender disparities, Endogenous switching regression.*

1. Introduction

Agriculture plays a significant role in the economies of nations in Sub-Saharan African countries like Zambia. It provides livelihood means for individuals by offering employment opportunities to most rural residents (ILOSTAT, 2024). Zambia boasts land resources that can enhance agricultural production and make substantial contributions to increased crop yields,

* Faculty of Tropical AgriSciences, Czech University of Life Sciences, Prague, Czech Republic.
Corresponding author: hejkrlik@ftz.czu.cz

farm revenues, and food stability (Kuntashula & Mwelwa-Zgambo, 2022) worldwide. Notwithstanding this, farmer input subsidy programmes aimed at promoting both agricultural production diversity and dietary diversity as the gateways for improving household nutritional status, have been a major agricultural policy thrust in most countries in sub-Saharan Africa, including Zambia. However, information on the effects of Zambia's Farmer Input Support Policy (FISP). Small-scale farmers who are major contributors to the country's staple crop struggle with challenges such as productivity and inefficient production methods, leading to increased poverty levels and food insecurity issues. In 2023, Zambia's share of agriculture in the country's Gross Domestic Product (GDP) was at 3.09%, a huge drop from 8.23% over the last 10 years (Aaron, 2024). According to Gatti *et al*. (2023) agricultural productivity remains low. While potential maize yields in Zambia are 9 t per hectare (t/ha, the average national maize production level in Zambia has remained stagnant at 2.2 tons per hectare, lagging behind neighbouring countries in the Saharan African (SSA) zone even though the nation boasts Africa's highest maize output potential of 9.8 tons per hectare. This significant decline underlines the gap between existing crop yields and the attainable standards that can be reached by small-scale farmers. According to recent studies such as Hall *et al*. (2023), the estimated achievable standards for small-scale farmers in Zambia are 5 tons per hectare for open-pollinated varieties and 10 tons per hectare for hybrids. The increase in yield is essential since the majority of rural households rely heavily on farm outputs for livelihood (Silva *et al*., 2023). Muzari (2016) opined that shortages in maize production can cause food scarcity while also undermining the economic sustainability of farming, resulting in a vicious cycle of poverty, malnutrition and economic downturn. This highlights the necessity of implementing specific agricultural measures to increase crop production and ensure both food availability and economic prosperity in rural regions.

Burke *et al*. (2012) argue that growth in the agricultural sector in Africa is hindered by the availability of resources such as quality seeds and fertilizers, attributing this to the inadequate support for their adoption. Additionally, Dlamini *et al*. (2019) highlighted that small-scale farmers continue to face obstacles in accessing inputs like maize seeds due to the high cost of agricultural inputs and low market prices for maize. The use of inputs such as fertilizer in Africa could be higher and also attributed to a need for a more focused approach to increasing fertilizer utilization as a result of market failure (Burke *et al*., 2012). Similarly, in Southern African countries such as Zambia, farmers' access to inputs such as fertilizers and seeds poses a significant challenge for smallholders in their efforts to increase their production. Hence, this drawback encourages farmers to seek out these farm inputs at subsidized prices (Blekking *et al*., 2021).

In order to enhance maize yield and increase farm earnings while ensuring food stability and reducing poverty rates among small-scale farmers, the government of Zambia provide subsidized inputs to impoverished farmers. This initiative is guided by policy frameworks, such as the National Agricultural Policy and the Seventh National Development Plan (SNDP). While the main goal of the National Agricultural Policy is to boost productivity and ensure food security, the 7NDP focuses on diversification and reduction of poverty by stressing the importance of agriculture as a crucial sector for inclusive growth and development (Ministry of Agriculture Zambia, 2023). One significant step towards this agricultural growth and development was the introduction of the Farmer Input Support Programme (commonly known as FISP), which was introduced in 2009 following the initiative called the Fertilizer Support Program (referred to as the FSP), which was launched back in 2002 and is currently being carried out under Zambias National Agricultural Policy (Mason *et al*., 2013). The revised FISP program was designed to support small-scale farmers by offering discounted supplies, like high-quality maize seeds and fertilisers. This initiative aimed to help increase crop yields and boost household incomes (Kuntashula & Mwelwa-Zgambo, 2022; Ministry of Agriculture Zambia, 2023) worldwide. Notwithstanding this, farmer input subsidy programmes aimed at promoting both agricultural production diversity and dietary diversity as the

gateways for improving household nutritional status, have been a major agricultural policy thrust in most countries in sub-Saharan Africa, including Zambia. However, information on the effects of Zambia's Farmer Input Support Policy (FISP).

In Zambia, the FISP is overseen by the Ministry of Agriculture, with inputs channelled through agricultural cooperatives, prioritising farmer membership (Blekking *et al*., 2021). This, however, stimulates the membership of farmers in cooperatives, a crucial pillar of agricultural development, to access various programmes that boost input use and improve productivity levels while augmenting their household incomes (Blekking *et al*., 2021). Improving the availability of farm inputs through cooperatives and initiatives plays a huge role in several countries, like Zambia, which prioritizes agricultural growth and development (Blekking *et al*., 2021). Likewise, engaging in subsidised input support programs provides a means to secure farming inputs and enhance productivity while facilitating market access, increasing income levels, ensuring food security and reducing poverty (Fischer and Qaim, 2012; Mason *et al*., 2013).

Several research studies have looked into the impact of cooperatives and input access on farmers' productivity and resource utilisation levels. For instance, studies by Blekking *et al*. (2021), which examined the impact of agricultural input cooperatives in Zambia on farmers' yields, found that farmers who participated in cooperatives achieved higher yields and used more improved seeds and fertilizers. Other studies by Burke *et al*. (2012) and Mason & Tembo (2015) confirmed that input support programs have a reasonably positive effect on yield measures for maize. Moreover, further crop yields lead to boosted farm earnings income (Blekking *et al*., 2021; Setsoafia *et al*., 2022; Akinola *et al*., 2023) fertilizer, and soil and water conservation, providing families with improved security and lessening their susceptibility to poverty. Using published data by the Ministry of Agriculture in Zambia, Funsani *et al*. (2017) reported that the input support programme increased the household annual maize income of participants by 30.8% and total household income by 13.9% for 2013/15 and 2014/15 crop seasons. The authors are of the opinion that the increment in farmers' income is not large enough to lift farmers' households above the poverty line (Funsani *et al*., 2017). In another study carried out by Kuntashula & Mwelwa-Zgambo (2022) worldwide. Notwithstanding this, farmer input subsidy programmes aimed at promoting both agricultural production diversity and dietary diversity as the gateways for improving household nutritional status, have been a major agricultural policy thrust in most countries in sub-Saharan Africa, including Zambia. However, information on the effects of Zambia's Farmer Input Support Policy (FISP), the authors confirmed that FISP has a direct and positive impact on crop diversity, agricultural production and diversification of household diets. These impacts were attributed to fertilizer usage among farmers in Zambia.

While several studies have tried to examine the impact of input support programs on the income and productivity of farmers (Burke *et al*., 2012; Mason *et al*., 2013; Mason & Tembo, 2015; Blekking *et al*., 2021; Setsoafia *et al*., 2022; Akinola *et al*., 2023) fertilizer, and soil and water conservation, there still exists gaps in terms of understanding the selection mechanisms and heterogeneity in its effects among smallholder maize farmers. Several studies have adopted the use of Propensity Score Matching (PSM) technique to understand the impact of subsidies on farmers' yield and income (Fischer & Qaim, 2012; Funsani *et al*., 2017; Mojo *et al*., 2017; Blekking *et al*., 2021), this approach does not fully account for selection bias and unobserved heterogeneity. This study is novel in terms of using an endogenous switching regression (ESR) model, which is a more robust econometric approach that controls selection bias and allows for counterfactual analysis. This study also offers a more comprehensive assessment of the effectiveness of FISP by not only estimating the impact on beneficiaries but also the potential gains for non-beneficiaries had they received the subsidy. Additionally, this study further contributes to the literature by extending the analysis to include not only individual and farm characteristics as in previous studies but also institutional and social factors to understand barriers and enablers of FISP access further. Furthermore, the study

integrates gender-disaggregated analysis to examine disparities in subsidy distribution and impact, thus contributing to the ongoing discussion on inclusive agricultural policy. The objective is to provide policymakers with insights into how access to subsidized inputs can enhance livelihoods and help alleviate poverty.

This study is set up in the following way. Chapter 2 focuses on the study area, the data collection and analytical techniques adopted in this study; section 3 reveals the findings of the study; and finally, sections 4 and 5 delve into the discussion, conclusions and recommendations from this study.

2. Materials and Methods

2.1. *Study Context*

In Zambia, maize is the staple food, predominantly cultivated by smallholder farmers, who manage over 80% of the country's arable land yet often operate on plots smaller than 2 hectares (Mulenga & Chapoto, 2021). Farm typologies are stratified by landholding size, with subsistence-oriented households (≤2 ha) constituting approximately 70% of maize producers, while emergent (2–5 ha) and commercial (>5 ha) farms account for the remainder (Mulenga & Chapoto, 2021; Silva *et al*., 2023). This fragmentation exacerbates yield gaps, as smallholders face unequal access to fertile land, credit, and inputs like fertilizers and hybrid seeds—despite state interventions such as the FISP (Blekking *et al*., 2021) but because not all rural households can afford to join cooperatives, this raises questions about membership inclusivity and whether cooperatives advantage some smallholders over others. Agricultural cooperatives can serve as an institutional vehicle for policymakers to deliver direct benefits to smallholder farmers in the form of subsidized agricultural inputs, usually improved seed varieties and fertilizers. They can also serve as platforms for collective action through which smallholders can reduce transportation and transaction costs or disperse the costs of marketing. In Zambia farmers are required to join a cooperative to qualify for seed and fertilizer support through the national Farmer Input Support Program (FISP). Critically, gendered land tenure norms further constrain women's participation in input subsidy schemes (Fisher & Kandiwa, 2014). These structural barriers raise questions about whether input subsidies alone can overcome systemic productivity constraints, motivating this study's evaluation of FISP's effectiveness in Southern Zambia, a region typifying these challenges.

2.2. *Sampling and Data Collection*

Maize plays an important role in Zambia's national diet and food security. It is also the FISP's primary focus, making it integral to the program's objectives. Hence, this study aims to determine the direct effect of FISP on maize, the most widely cultivated crop among smallholder farmers in Zambia. The study employed counterfactual non-experimental analytical methods to determine the effect of FISP on the yield and income among smallholder maize farmers in Zambia. The methodology adopted for this study was a comparison between two different groups of farmers: those who had received the subsidy and those who had not.

This sampling technique was used to provide a representative sample of both subsidy beneficiaries and non-beneficiaries across four districts of the Southern province: Pemba, Monze, Choma, Kalomo, Mongu and Limulunga. These districts were selected on the basis of their agricultural activities to ensure a good representation of smallholder farmers. For beneficiaries of the FISP, a random sampling method was used, using a list of subsidy recipients from local agricultural offices which keep records of subsidy distribution within these districts. This guarantees that the selection of participants was random and, therefore, not biased in any way and representative of the various means by which farmers can receive subsidies. On the other hand, purposive sampling was adopted for farmers who did not receive the subsidy but were from the same areas as the recipients to ensure that the non-recipients were also included in the same local samples. This decision was made since there was no complete list of the non-recipients, and it was necessary to target

Table 1 - Questionnaire Structure.

Sections	*No of questions per section*	*Variables per section*
Farmer Characteristics	5	Age, gender, marital status, education (years), household size
Farm Characteristics	7	Farming experience (years), no. of cattle, maize area cultivated (ha), maize yield (kg/ha)
Institutional Characteristics	6	Membership in cooperatives, land ownership, participation in other social groups, frequency of extension contacts in a year
Access to FISP	9	Status of access to FISP, frequency of access, satisfaction with FISP, challenges in accessing FISP, farm income

farmers who had not received FISP for a balanced comparative study.

A sample size of 404 maize farmers (273 men and 131 women), where 234 were FISP beneficiaries (158 men and 76 women) and 170 were non-beneficiaries of the subsidy (115 men and 55 women). Data collection was carried out between July to September 2022. Questionnaires in the form of closed-ended questions were used to collect data on farmer, farm and institutional characteristics (see Table 1). The questionnaire also included specific questions relating to FISP to ensure that the subsidy receipt was well captured for each participant.

Additional data was collected through interviews with key informants: five regional government units (Departments of Cooperatives) and eight members of the boards of farmers' cooperatives involved in the distribution of FISP. This was done to gather more elaborate information on the system of operation and the relations between the government representatives, the Camp Agriculture Committee (CAC) and the cooperatives. Also, five Focus Group Discussions (FGDs) were held with the farmers. The target groups for these discussions included three groups of FISP beneficiaries and two groups of non-beneficiaries.

The interviews and FGDs focused mainly on topic areas such as the criteria used for selecting the FISP beneficiaries, local power dynamics, the efficiency of the existing distribution process, as well as the challenges faced by both subsidy beneficiaries and non-beneficiaries. The participants involved were from units of the regional government and cooperatives involved in the distribution of FISP in the six provinces.

2.3. *Analytical Framework on Access to Input Subsidy*

Farmers' access to FISP was conceptualized within the context of the random utility theory framework. This theory is based on the assumption that a farmer's decision to apply for an input subsidy is based on the utility they expect to derive from the subsidy. Even though the final decision is made by the CAC, we applied random utility theory to explain the factors that influence farmers to apply for the subsidy.

The utility associated with the perceived benefits of accessing input subsidy is captured by a latent variable, D_J^*, which is a function of observable characteristics and attributes denoted as Z in the latent variable model:

$$D_J^* = Z_J\gamma + \varepsilon_J;\ D_J = 1 \text{ if } D_J^* > 0;\quad D_J = 0 \text{ if } D_J^* \leq 0 \tag{1}$$

Here, D_J^* is a dummy variable, which takes the value of 1 for access to input subsidy and 0 for non-access. γ represents the estimated parameters in the model, while ε is the error term with a mean value of zero. The farm, farmer, and institutional factors that influence access to input subsidy is denoted by Z. The binary choice model was estimated using a probit regression in Stata 15 to analyse the factors influencing farmers' access to input subsidies.

Fischer & Qaim (2012) and Mojo *et al*. (2017) recommended the use of personal and demographic characteristics as independent variables for the binary model. These include age, gender, marital status, household size, farmer's education level, farm size, farming experience, number of cattle (a proxy for farmer's wealth),

Table 2 - Variables included in the study.

Variables	*Description*	*Measurements*
Access to input subsidy	Farmer's access to input subsidies	Non-access – 0; Access – 1
Age	Age of farmers	Years (continuous)
Household size	Number of people living in the farmer's household	Number of individuals (continuous)
Education	Educational attainment of farmers	Years (continuous)
Farming experience	Years of farming experience	Years (continuous)
Gender	Gender of farmers	Female – 0; Male – 1
Marital status	Marital status of farmers	Non-married – 0; Married – 1
Membership in cooperatives	Membership in any farmers cooperative	No – 0; Yes – 1
Land ownership	Ownership of land	No – 0; Yes – 1
Participation in other social group	Membership in any social group aside from agricultural cooperatives - a proxy for farmers' social capital	No – 0; Yes – 1
No. of cattle	Number of cattle owned by the farmer	Number of cattle (continuous)
Farm size	Area of maize cultivation in the last farming season	Hectares (continuous)
Farm income	Income generated from maize farming activities in last farming season	ZMW (continuous)
Off-farm income	Income generated from non-farming activities in the last farming season	ZMW (continuous)
Extension contacts	Number of contacts with agricultural extension services in a year	Number of contacts (continuous)
Distance to extension service	Distance from farm to extension office	km (continuous)
Maize yield	Yield of maize produced in last farming season	kg

ZMW is Zambian Kwacha. 1 US Dollar is 17.88 ZMW in December 2022.

access to extension, off-farm income, land ownership, and participation in social groups. Table 2 contains a detailed description and measurement of all variables used in the study.

Our outcome variables in the model are maize yield and farm income. While the maize yield is used as a direct indicator of the program's effectiveness, it reflects the productivity and efficiency of farming outputs that are affected by access to subsidy. Farm income is also used as an outcome variable to capture the farmer's economic well-being and the financial stability of smallholder farmers, which is important in determining the impact of subsidies on improving their living standards.

2.3.1. *Endogenous Switching Regression Model*

The endogenous switching regression (ESR) model was preferred over instrumental variable (IV) or Heckman selection methods due to its ability to account for both observable and unobservable sources of selection bias, estimate heterogeneous treatment effects by specifying separate outcome equations for FISP beneficiaries and non-beneficiaries, and also generate robust counterfactuals without relying on exclusion restrictions (Lokshin & Sajaia, 2004). Given the non-random allocation of FISP subsidies by CACs—where unobserved factors (for instance, farmer motivation, local political ties) likely influence both access and outcomes—ESR provides consistent estimates under such endogeneity. While some studies analyze subsidy reforms using demand systems (for instance, Hosni & Ramadan, 2018), our approach focuses on causal identification of program impacts using quasi-experimental methods suited to household-level observational data.

This ESR model was therefore employed to address potential selection bias in estimating the effect of input subsidy access on farmers' yield and farm income. The model was estimated using Stata version 15. The utility (yield and farm income) that farmers get from input subsidy is denoted by Y_{JM} while the utility from non-access is represented by Y_{JNM}. The two regimes for the endogenous switching regression is estimated mathematically as follows:

Regime 1 (access):

$$Y_{JM} = X_J \beta_M + u_{JM} \; if \; D_J = 1 \tag{2}$$

Regime 0 (non-access):

$$Y_{JNM} = X_J \beta_{NM} + u_{JNM} \; if \; D_J = 0 \tag{3}$$

Here, Y_{JM} and Y_{JNM} are the outcome variables (for yield and farm income) for access (M) and non-access (NM), respectively. Also, X_J is a vector of the farm, farmer characteristics, and institutional characteristics, while β is the parameter to be estimated for access (M) and non-access (NM), respectively. Lastly, u represents the error term in the model.

Based on the inspiration from Kanburi Bidzakin *et al*. (2019) and Mojo *et al*. (2017), it is assumed that the three error terms (u) in equation (1), (6) and (7) follow the trivariate normal distribution with the mean vector zero and the covariance matrix below:

$$Cov\,(u_M, \varepsilon, and\; u_{NM}) = \Sigma = \begin{bmatrix} \sigma_M^2 & \sigma_{MNM} & \sigma_{M\varepsilon} \\ \sigma_{MNM} & \sigma_{NM}^2 & \sigma_{NM\varepsilon} \\ \sigma_{M\varepsilon} & \sigma_{NM\varepsilon} & \sigma_{\varepsilon}^2 \end{bmatrix} \tag{4}$$

Here, *M* and *MN* denote the farmers who have access to input subsidy and non-access, respectively $Var\,(u_M) = \sigma_M^2$; $Var\,(u_{NM}) = \sigma_{NM}^2$; $Var(\varepsilon) = \sigma_\varepsilon^2$ and $Cov\,(u_M, u_{NM}) = \sigma_{MNM}$; $Cov\,(u_M, \varepsilon) = \sigma_{M\varepsilon}$; *and* $Cov\,(\varepsilon, u_{NM}) = \sigma_{NM\varepsilon}$

In equation (8), the error terms, which are conditional on the sample selection criterion, have non-zero expected values. The OLS estimates of coefficients β_M and β_{NM} will also be affected by sample selection bias, according to Kanburi Bidzakin *et al*. (2019) and Lee (1982). The values of the truncated error term $u_M \,|D = 1)$ and $u_{NM} \,|D = 0)$ is given as:

$$u_M \,|\, D = 1) = E(u_M | \varepsilon > -z'\gamma) = \sigma_{M\varepsilon} \frac{\partial \left(\frac{z'\gamma}{\sigma}\right)}{1 - \emptyset \left(\frac{z'\gamma}{\sigma}\right)} \equiv \sigma_{M\varepsilon} \lambda_M \tag{5}$$

and

$$u_{NM} | \, D = 0) = E(u_{NM} | \, \varepsilon \leq -z'\gamma) = \sigma_{NM\varepsilon} \frac{\partial \left(\frac{z'\gamma}{\sigma}\right)}{1 - \emptyset \left(\frac{z'\gamma}{\sigma}\right)} \equiv \sigma_{NM\varepsilon} \lambda_{NM} \tag{6}$$

Where ∂ and $\emptyset$ denotes the probability density and cumulative distribution function of the standard normal distribution, respectively. λ_M and λ_{NM} represent the inverse Mills ratio of M and NM, respectively. The inverse Mills ratio λ_M and λ_{NM} is included in the equation (5) and (6) to account for selection bias. If the estimated covariance of σ_M and σ_{NM} are statistically significant, it implies that access to input subsidy and outcome variables (maize yield and farm income) are correlated. This means that there is endogenous switching, and consequently, the null hypothesis of no selection bias has to be rejected.

In order to estimate the endogenous switching regression, there have to be instrument variables in the utility model in equation (1). The access of farmers to extension services is endogenous with access to input subsidies. Hence, the distance to the extension service centre (in km) was used as the instrument that affects access to extension service, and the residual of the extension was added to the utility model. This instrument was tested for validity before being used in the endogenous switching regression, as other researchers have used.

The endogenous switching regression model will be employed to compare the maize yield and farm income of the farmers who accessed input subsidy in equation (7) and those who did not in equation (8). Furthermore, the model will be used to estimate the hypothetical yield and farm income in the counterfactual scenarios: what the yield and farm income would be if the farmers who accessed input subsidy had not accessed it (equation 9), and what the yield and farm income would be if the non-accessing farmers had accessed the

subsidy (equation 10). Below are defined the four scenarios' conditional expectations of yield and farm income:

D_i = 1 represents access to input subsidy; D_i = 0 represents non-access to input subsidy; Y_{JM} and Y_{JNM} are the yield and farm income if the farmer accessed input subsidy and non-access, respectively. ATT represents the average treatment effect on the treated (farmers who accessed input subsidy); ATU represents the average treatment effect on the untreated (farmers who did not receive input subsidy).

$$E(Y_{JM} \mid D = 1) = X\beta_{JM} + \sigma_{M\varepsilon}\,\lambda_M \quad (7)$$

$$(Y_{JNM} \mid D = 0) = X\beta_{JNM} + \sigma_{NM\varepsilon}\,\lambda_{NM} \quad (8)$$

$$E(Y_{JNM} \mid D = 1) = X\beta_{JM} + \sigma_{NM\varepsilon}\,\lambda_M \quad (9)$$

$$E(Y_{JM} \mid D = 0) = X\beta_{JNM} + \sigma_{M\varepsilon}\,\lambda_{NM} \quad (10)$$

Equations (7) and (8) are the actual expectations observed in the sample; equations (9) and (10) are the counterfactual expected outcomes. Further, following Kanburi Bidzakin *et al*. (2019) and Mojo *et al*. (2017), we calculate the average effect on the treated (access to input subsidy on yield and farm income) as the difference between equations (7) and (9). We also calculate the average treatment on the untreated as the difference between equations (10) and (8). ATU and ATT are estimated below in equations (11) and (12), respectively.

$$TT = E[Y_{JM} \mid D = 1] - E[Y_{JNM} \mid D = 1] = X(\beta_{JM} - \beta_{JNM}) + (\sigma_{M\varepsilon} - \sigma_{NM\varepsilon})\,\lambda_M \quad (11)$$

$$ATU = E[Y_{JM} \mid D = 0] - E[Y_{JNM} \mid D = 0] = X(\beta_{JM} - \beta_{JNM}) + (\sigma_{M\varepsilon} - \sigma_{NM\varepsilon})\,\lambda_{NM} \quad (12)$$

As suggested by Kanburi Bidzakin *et al.* (2019), the difference between equations (7) and (10) (for members) and the difference between equations (8) and (9) is the heterogeneous treatment effects. Hence, the heterogenous treatment effect can be defined as the differences in the yield and farm income to inherent differences but not that of the treatment.

$$BH_M = E[Y_{JM} \mid D = 1] - E[Y_{JM} \mid D = 0] = \beta_{JM}(X_{JM} - X_{JNM}) + (\lambda_M - \lambda_{NM})\,\sigma_{M\varepsilon} \quad (13)$$

$$BH_{NM} = E[Y_{JNM} \mid D = 1] - E[Y_{JNM} \mid D = 0] = \beta_{JNM}(X_{JM} - X_{JNM}) + (\lambda_M - \lambda_{NM})\,\sigma_{MM\varepsilon} \quad (14)$$

To determine whether the effect of access to input subsidy is greater or smaller for the subsidised or non-subsidised farmers in the counterfactual case, or in other words, to estimate transitional heterogeneity, we calculate the difference between equations (11) and (12).

3. Data Description

3.1. *Socio-economic Characteristics of Respondents*

Table 3 presents a comparison between maize farmers with and without access to FISP. The result reveals several differences in demographic characteristics, resource availability, and economic outcomes. On average, farmers with access to input subsidies are older (46 years), with approximately 68% of them being male. The result shows a statistically significant and positive difference between farmers with and without access to input subsidy in terms of household size, number of cattle, number of contacts with extension agents in a year, distance to extension service and yield. Additionally, farmers with access to subsidies are members of one or more agricultural cooperatives while they are also participants in other social groups.

3.2. *Determinants of Access to Input Subsidy*

The result of the probit regression model, as shown in Table 4, shows that farmers' likelihood to get input subsidy increases significantly and positively with age, household size, off-farm income, and being married. The result also suggests that the gender of the farmer, that is, being female, having more farming experience, and having larger farm sizes, decreases the chances of getting input subsidies. Additionally, membership in cooperatives and participation in other social groups significantly increase the likelihood of receiving an input subsidy.

Table 3 - Socio-economic Characteristics of Maize Farmers (N=404).

Variables	*Access (SD)*	*Non-access (SD)*	*Mean Difference*
Age (years)	45.80 (11.17)	43.91 (12.71)	1.90
Household Size	7.47 (2.83)	6.93 (2.82)	0.54 *
Education (years)	8.75 (2.24)	8.29 (2.39)	0.46 *
Farming experience (years)	19.43 (10.72)	20.14 (11.25)	-0.70
No. of cattle	7.43 (5.28)	6.34 (4.72)	1.09 **
Farm size (ha)	2.21 (0.96)	2.17 (1.11)	0.04
Farm income (ZMW)	12,454.14 (8,083.45)	11,407.35 (7,014.77)	1,046.79
Off-farm income (ZMW)	2,881.47 (2,904.08)	3052.94 (2605.28)	-171.46
No of Extension contacts in a year	7.20 (4.56)	5.54 (4.92)	1.66 ***
Distance to extension service (km)	4.11 (2.62)	4.94 (2.60)	00.83 ***
Yield (kg/ha)	2,289.27 (1,668.01)	1976.72 (996.60)	312.55 **
	Categories	*Access Freq. (%)*	*Non-access Freq. (%)*
Gender	Female	76 (32.48)	55 (32.35)
	Male	158 (67.52)	115 (67.65)
Marital status	Non-married	34 (14.53)	32 (18.82)
	Married	200 (85.47)	138 (81.18)
Membership in cooperatives	No	173 (73.93)	166 (97.65) ***
	Yes	61 (26.07)	4 (2.35)
Land ownership	No	208 (88.89)	146 (85.88)
	Yes	26 (11.11)	24 (14.12)
Participation in other social group	No	22 (9.40)	84 (49.41) ***
	Yes	212 (90.60)	86 (50.59)

*Note: ***, **, and * represent 1%, 5%, and 10% levels of significance, respectively.*
SD = Standard Deviation
Mean difference estimated with independent sample T-test at 5% level of probability.

3.3. *Effect of Access to Input Subsidy on Yield and Farm Income*

3.3.1. *Estimation Results of the Endogenous Switching Regression*

Table 5 shows the effects of input subsidy access on both the actual and hypothetical scenarios for both the beneficiary and non-beneficiary groups. In the case of yield, the results show that the farmers who took the subsidy would have produced 144.97 kg/ha less maize than they actually did had they not received subsidy (ATT). On the other hand, farmers without access to subsidy would have produced approximately 730.82 kg/ha more if they had access to the subsidy.

In terms of farm income, the results of the study show that the farmers who got the input subsidy would have earned 744.69 ZMW less without the subsidy. On the other hand, farmers who did not receive the subsidy would have earned 2,233.09 ZMW more had they received it.

Additionally, the analysis reveals the presence of transitional heterogeneity, with estimated values of 585.84 kg/ha for yield and 1,488.40 ZMW for income. These results suggest that the potential benefits of the subsidy programme would have been greater for non-participants than for those who actually received it. This highlights the need to improve targeting mechanisms to

Table 4 - Determinants of FISP Access.

Input subsidy	*Coef.*	*St. Err.*	*Marginal effect*	*St. Err.*
Age	0.016*	0.01	0.006*	0.004
Gender	-0.59***	0.211	-0.215***	0.072
Household size	0.065**	0.032	0.025**	0.012
Marital status	0.442*	0.236	0.173*	0.093
Education	-0.045	0.04	-0.017	0.015
Farming experience	-0.039***	0.011	-0.015***	0.004
No. of cattle	0.025	0.02	0.01	0.008
Farm size	-0.263***	0.097	-0.101***	0.037
Land ownership	-0.012	0.231	-0.005	0.089
Cooperative membership	1.644***	0.294	0.443***	0.042
Participation in other social groups	1.296***	0.237	0.483***	0.076
Extension access	0.092	0.064	0.035	0.025
Off-farm income	0.012**	0.004	0.013**	0.005
Extension residual	-0.065	0.066	-0.025	0.025
Constant	-0.975**	0.472		
Number of obs.	404			
Pseudo r-squared	0.279			
Chi-square	153.213			
Prob > chi2	0			
Correctly predicted observations	365			
Overall prediction accuracy (%)	90.4			

*Note: ***, **, and * represent 1%, 5%, and 10% levels of significance, respectively.*

Table 5 - Average expected maize yield and farm income; heterogeneity and participation effect in Southern province.

Yield (kg/ha)	*To have access*	*Not to have access*	*Effect of Access*
Farmers who have access	2288.655 (47.521)	2143.682 (30.025)	ATT= 144.973 (56.211)***
Farmers who do not have access	2707.622 (54.805)	1976.807 (34.963)	ATU= 730.815 (65.007)***
Diff.	HE1= -418.967 (72.735)***	HE2= 166.875 (46.141)***	HE3=-585.842 (6.053)***
Farm Income (ZMW)			
Farmers who have access	12453.63 (270.903)	11708.94 (275.666)	ATT= 744.69 (386. 497)**
Farmers who do not have access	13640.31 (272.165)	11407.22 (359.429)	ATU= 2233.09 (450.847)***
Diff.	HE1= -1186.68 (393.509)***	HE2= 301.72 (445.466)	HE3= -1488.4 (41.798)***

ATT is Average Treatment Effect on the Treated; ATU is Average Treatment Effect on the Untreated; HE1is the difference in outcome for those with access compared to those without access; HE2 is the difference in the potential outcome for those with access if they did not have access; HE3 is the difference in the potential outcome for those without access if they had access.
*Note: ***, **, and * represent 1%, 5%, and 10% levels of significance, respectively.*

Table 6 - Outcomes of the endogenous switching regression for maize yield and farm income.

Variables	*Yield*		*Farm income*	
	Access	*Non-access*	*Access*	*Non-access*
Age	-5.645 (13.986)	2.333 (9.585)	52.131 (65.561)	-23.16 (58.54)
Gender	405.244 (267.355)	-415.833 (189.409)**	1334.2 (1290.14)	-2309.13 (1166.212)**
Household size	-18.086 (43.414)	4.591 (35.208)	-134.745 (205.079)	90.889 (213.597)
Marital status	-8.653 (355.113)	458.101 (231.487)**	2197.139 (1668.549)	1878.648 (1405.804)
Education	-77.46 (47.036)*	68.504 (37.395)*	128.982 (217.188)	209.459 (221.902)
Farming experience	13.591 (15.363)	7.537 (12.687)	-36.129 (75.27)	143.046 (78.781)*
Number of cattle	76.269 (22.99)***	42.286 (22.136)*	316.229 (105.536)***	399.887 (130.405)***
Farm size	-624.785 (119.807)***	1.504 (89.186)	640.754 (640.754)	1428.171 (525.299)***
Land ownership	-517.66 (321.248)*	-781.231 (212.31)***	2561.993 (1485.254)*	-1339.193 (1263.495)
Cooperative membership	150.255 (291.213)	69.842 (567.68)	1923.371 (1595.117)	1052.749 (3663.594)
Participation in other farmer association	-220.498 (397.454)	-128.809 (275.021)	-999.152 (2117.633)	-1254.173 (192)1.929
Off-farm income	0.028 (0.039)	-0.019 (0.033)	0.771 (0.186)***	-0.075 (0.204)
Extension access	81.414 (22.756)***	-7.961 (18.009)	-12.779 (105.412)	293.404 (107.212)***
Constant	3407.59 (846.94)***	1088.697 (422.216)***	2758.677 (4405.412)	653.197 (2491.540)
rho	-0.997 (0.001)	0.924 (0.034)***	-0.988 (0.008)***	−0.089 (0.537)
LR test of indep. eqns.		($\chi^2(2) = 37.46$***		($\chi^2(2) = 11.04$***
Number of observation		404		404
Wald chi2(13)		44.6		124.65
P-value		0		0

ensure that farmers with the highest potential to benefit are prioritized in subsidy distribution.

The outcome of the endogenous switching regression model, as presented in Table 6. To validate the appropriateness of the Endogenous Switching Regression (ESR) model, we examined the significance of the rho parameters, which measure the correlation between the error terms of the selection and outcome equations. Statistically significant rho values indicate the presence of unobserved selection bias, thereby justifying the use of the ESR framework. For maize yield, the rho estimates were −0.997 (0.001) for the non-access group and 0.924 (0.034) for the access group, both statistically significant at the 1% level. For farm income, the rho estimate for the non-access group was −0.988 (0.008), also significant, while the estimate for the access group (−0.089 with a standard error of 0.537) was not statistically significant. In addition, the likelihood ratio (LR) tests of independence between the selection and outcome equations were statistically significant for both models, with chi-squared values of 37.46 for yield and 11.04 for income. These results confirm the presence of selection bias and support the application of the ESR model.

For maize yield, the gender coefficient shows that female farmers who did not receive input subsidies had a consistently negative effect compared to their male counterparts in the same situation. Also, the size of the maize farm has a consistently negative and significant impact on the yield of farmers with access to subsidies. Conversely, marital status has a positive and significant impact on the farmers who have not received input subsidies. This suggests that married farmers tend to achieve higher maize yields than their unmarried counterparts, even when they have not received subsidies. The result showed that land ownership has a significant and negative influence on both subsidised and non-subsidised farmers. Furthermore, farmers' wealth, measured as the number of cattle owned, has a consistently significant and positive effect on both subsidized and non-subsidized farmers. Access to extension services also showed a positive and significant effect on maize yield for the farmers who received input subsidies.

The findings from the endogenous switching regression model show that being a female farmer has a negative effect on the farm income of non-subsidised farmers. This result contrasts with the positive effects that are observed in the farming experience and the size of maize farms within the same group of farmers. The wealth of farmers has a consistent positive influence on farm income for both subsidised and non-subsidised farmers. Furthermore, land ownership and off-farm income demonstrate significant positive associations with farm income among subsidised farmers.

Moreover, based on interviews conducted with smallholder maize farmers in the study area, it was a unanimous opinion that receiving input subsidies through the FISP enhances maize yield and farm income. The farmers pointed out that without these subsidies, their maize yield would be considerably lower, affecting their financial position and their ability to continue farming.

4. Discussion

The probit regression estimates of determinants of access to the FISP indicate that the age of the farmers is a positive determinant of access to subsidy. It appears that older farmers are more likely to get or have the FISP. Older farmers are probably more aware of the programme, have more experience with the subsidy system, or are considered more credible or deserving recipients by the subsidy administrators. This result is in line with other similar studies in Zambia and Malawi, where Holden & Lunduka (2010) argued that older farmers have more experience and have more connections with the agricultural sector networks to access subsidies and other agricultural support services.

The analysis also shows that being a female farmer is a deterrent to FISP access, as shown by the analysis in this paper. This suggests that female farmers are less likely to get the input subsidy packages than their male counterparts. Authors like Fisher & Kandiwa (2014) argued that women farmers are discriminated against in their access to inputs and services, including subsidies. As pointed out by these authors, such biases are based on gender stereotypes and cultural norms that prevent women from participating in agricultural production and resource management decisions. Furthermore, extension services, which are a common channel through which subsidies are offered, are not fully available to women farmers, which reduces the take-up rate among female farmers (Diaz & Najjar, 2019). This restricted accessibility is, to some extent, because extension programs are usually developed without taking into consideration the particularities of female farmers—for instance, their restricted access to transport and time because of their domestic responsibilities.

Household size and marital status were also seen to be significant and positive in influencing access to the FISP among farmers. This could mean that married farmers who have larger households are more likely to get subsidies than those who are not married and have smaller households. This could be due to their stability, the need for them to be more responsible in the running of the farming business and the availability of labour and resources. Therefore, households with more labour resources and a stable farm operation can improve their position to take advantage of the input subsidies and other agricultural programs (Njuki *et al*., 2013; Fisher & Kandiwa, 2014).

In terms of farming experience, the result of the probit model shows a negative relationship with FISP access. This suggests that experienced farmers may use their own approaches and are not very interested in subsidy programs. Matuschke & Qaim (2009) and Baffoe-Asare *et al*. (2013) established that veteran farmers tend to prefer the conventional approach and, therefore, are less likely to embrace new programs or technologies. In the same manner, farm size emerged as another key factor that determines FISP access. According to the results, smaller farms are more likely to receive subsidies. This is in conformity with policy changes favouring equitable resource distribution to help small-scale farmers. For instance, Mason & Tembo (2015) argued that FISP targets smallholder farms in order to achieve the highest impact; Abbott *et al*. (2017) pointed out that subsidies are usually given to smaller farms in order to increase food security and improve the fight against poverty. These findings are also supported by Mason *et al*. (2013), who stated that farmers with land holdings of less than 2.5 hectares are targeted to ensure that resources are equally distributed.

Analysis of determinants of FISP access also indicates that cooperative membership and participation in other farmer associations positively influence farmers' access to FISP.

The analysis of the determinants of FISP access also shows that cooperative membership and participation in other social groups have positive effects on farmers' access to FISP. The influence of cooperative membership on access shows that cooperative networks play a very important role in facilitating access to subsidies through group support and information sharing. In relation to the FISP eligibility criteria, cooperatives are a channel through which farmers get the subsidy package (Mason *et al*., 2013). In the same manner, the participation of farmers in other farmer groups–a measure of farmers' social capital, degree of openness to work with other people, and willingness to accept new technologies and innovations (Matuschke & Qaim, 2009; Fischer & Qaim, 2012), stresses the significance of social networks and collaborative use of agricultural resources to influence FISP access among farmers. Collective action among smallholder farmers increases the chances of accessing resources and markets, validating our observation that membership in social groups and other farmer groups plays a significant role in subsidy access (Fischer & Qaim, 2012; Donkor & Hejkrlik, 2021).

Farmers with other sources of income are more likely to navigate the subsidy application process successfully than farmers without such sources. This is because farmers who have a better financial situation as a result of having other sources of income may have the necessary stability and resources to pay for or meet any other costs or conditions that are associated with the subsidy application process. Haggblade *et al.* (2010) argued that non-farm income diversification increases financial stability and enhances the availability of agricultural inputs, a hypothesis that is consistent with our finding that off-farm income improves farmers' ability to navigate the FISP application process.

Our results on the actual impact of subsidy access using an endogenous switching regression model reveal that beneficiaries of input subsidies would have harvested significantly less maize—approximately 144.97 kg/ha less—if they had not participated in the subsidy programme. At the same time, farmers would have gained 744.69 ZMW less in annual farm income if they had not received the subsidy. This indicates that subsidy access enhances agricultural productivity and income among its beneficiaries (Burke *et al.*, 2012; Mason *et al.*, 2013; Blekking *et al*., 2021). Such an increase in yield due to subsidy access can translate into higher farm income (Funsani *et al.*, 2017), emphasising the economic viability of smallholder farming operations. Similar findings in other regions have supported this direct relationship between input subsidies and increased yield. For example, Xu *et al.* (2009a) demonstrated in their study that input subsidies in China significantly boosted rice yields by enabling access to fertilisers and improved seed varieties.

Based on qualitative interviews with smallholder maize farmers in the study area, farmers consistently reported that without these subsidies, their maize yields would be significantly lower, thus affecting their overall farm income.

Farmers shared that the increased yields from subsidies enable them to generate higher income, which is crucial for sustaining their farming operations and improving their livelihoods. According to one of the male respondents, "As a smallholder farmer in Zambia, the FISP subsidies have improved my maize yields and farm income. Since receiving the subsidies, my harvest has increased by about 145 kilograms per hectare, improving my family's economic stability by 745 ZMW per hectare. The access to quality fertilisers and seeds has made all the difference, enhancing both productivity and profitability on my farm."

Our model also highlights a significant opportunity cost for farmers without access to the FISP. Our analysis suggests that non-subsidised farmers could have also increased their maize yield if they had participated in the FISP. This aligns with the findings of Xu *et al.* (2009b) and Mason *et al.* (2013) that access to subsidies, such as fertiliser, significantly increases maize yields. Their findings suggest that subsidies provide crucial inputs that enhance crop productivity for all farmers. Holden & Lunduka (2010) also argued that fertiliser subsidies significantly improve land productivity and crop yields, supporting our result that farmers without access to the FISP miss out on substantial yield increases. Furthermore, our findings could suggest that the lack of FISP access contributes to income disparities among farmers, as those without subsidies miss out on increased revenue from higher yields. While FISP access plays a significant role according to our results, it is important to recognise that other factors also influence income disparities, including market access (Camara & Savard, 2023), availability of extension services (Nnahiwe *et al.*, 2023), farming techniques (Phiri *et al.*, 2020), and socio-economic conditions (Zulu *et al.*, 2007). Hence, the productivity gap affects individual farm incomes and has broader implications for food security, gender inequality and economic stability in rural communities (Funsani *et al.*, 2017).

The endogenous switching regression model results reveal that gender significantly, and in the case of women farmers, negatively influences maize yield and farm income among farmers without access to the FISP. Specifically, the negative impact of gender on maize yield suggests that female farmers face greater challenges in achieving high yields without subsidies. According to Quisumbing & Pandolfelli (2010), female farmers often have less access to agricultural inputs, services and technology, such as land, credit and training, which are crucial not only for improving crop yields but also for enhancing overall farm productivity, income stability, and resilience to economic and environmental shocks. This limited access results from socio-cultural norms and institutional biases favouring men in agricultural extension services and input distribution. These disparities negatively impact the productivity of female farmers but also perpetuate gender inequalities in agriculture, aligning with the findings from our analysis. Consequently, this limited access to agricultural inputs, services, and technology can negatively impact the income generated from the farm, leading to income disparities. This aligns with our findings on the impact of gender on non-subsidised farmers, where female farmers, in particular, experience lower yields and reduced farm income due to these constraints (Njuki *et al*., 2013).

The positive effect of marital status on yield for non-subsidised farmers could suggest that married farmers have better access to labour and resources within their households. This includes the support of their spouses and children, who can contribute to farming activities, thereby enhancing productivity even without subsidies. Additionally, married farmers might benefit from pooled financial resources and shared responsibilities, which can further improve farm management and efficiency. This aligns with findings from Fisher & Kandiwa (2014) that being married provides a stable family structure that supports farm operations through shared responsibilities and collective decision-making. This stable environment can lead to more efficient farm management and higher productivity, even without subsidies. These findings also underscore the importance of social and family networks in enhancing agricultural productivity (Ramirez, 2013).

Farmers' education has a contrasting influence on maize yield, with a negative impact among the

FISP beneficiaries and a positive impact among non-beneficiaries. This suggests that while educated farmers can better utilise available resources without subsidies, the specific requirement to channel the subsidy to designated crops, primarily maize, may limit the flexibility of educated farmers who might have alternative methods that could potentially yield better results. While education generally empowers farmers with better knowledge and skills, which can lead to improved agricultural practices and higher yields, their benefits may be maximised when farmers have access and flexibility of use regarding necessary inputs and resources (Xu *et al.*, 2009b; Njuki *et al.*, 2013). However, when participating in subsidy programmes, they may be constrained by programme stipulations, reducing their ability to innovate or apply their advanced knowledge effectively (Xu *et al.*, 2009b). This implies that while education generally enhances farmers' ability to improve productivity, the terms of subsidy programmes like the FISP may not fully utilise the potential of educated farmers. For non-beneficiaries, education directly translates to better yields as they can independently apply their knowledge and innovations without the constraints of subsidy guidelines.

The number of cattle, a proxy for farmers' wealth, positively and significantly influences both maize yield and farm income among farmers with and without access to subsidies. This consistent positive influence indicates that wealthier farmers, as measured by livestock ownership, have better resources and resilience, enhancing their productivity. Holden & Lunduka (2010) pointed out that asset ownership, such as livestock, provides farmers with the financial stability and resources needed to invest in productive inputs and technologies. This investment capability allows wealthier farmers to achieve higher yields and, consequently, higher farm incomes, which aligns with our findings.

Farm size significantly influences yield and income, with a negative effect on yield among subsidised farmers and a positive effect on income among non-subsidised farmers. The negative effect on yield suggests that farmers with lesser farm size benefit more from subsidies, likely due to better management and utilisation of inputs. Mason & Tembo (2015) and Camara & Savard (2023) argued that smaller farms, when given subsidies, experience significant productivity gains, aligning with our findings. However, larger farms, with their inherent resource advantages, can achieve higher incomes without subsidies, indicating a differential impact based on farm size (Camara & Savard, 2023). The positive impact on income for larger farms without subsidies indicates a knowledge and resource advantage that can be leveraged to assist less experienced and smaller-scale farmers (Mason & Tembo, 2015; Camara & Savard, 2023).

Our analysis showed contrasting impacts of land ownership on maize yield and farm income. While land ownership positively influence farm income, we find a negative influence of this variable on maize yield. While land ownership could enhance access to credit and long-term investment and diversification (Jiang *et al.*, 2020), which could significantly boost farm income, Holden & Ghebru (2016) argued that during the initial adjustment period after obtaining land title, productivity might decline as farmers focus on securing and managing their newly formalised land holdings, despite the long-term benefits for farmers. Hence, when farmers acquire land, they might focus on long-term investments in their land, such as infrastructure improvements, soil conservation, and other practices that do not yield immediate increases in crop productivity. This shift can temporarily decrease crop yields as immediate inputs are sacrificed for future gains.

Off-farm income positively impacts farm income among farmers with access to the FISP, which indicates that farmers with additional income sources are better positioned to navigate subsidy applications and enhance overall farm profitability (Haggblade *et al.*, 2010).

Our analysis indicates that access to extension services has a positive impact on maize yield among farmers with access to the FISP and positively influences farm income for farmers without access to the FISP, highlighting the dual role of extension services in enhancing agricultural productivity and economic outcomes, depending on farmers' access to subsidies (Nnahiwe *et al.*, 2023). For farmers with access to subsidies, extension service

could impact yield due to the knowledge and support that help to utilise the inputs provided by subsidy programmes effectively. Extension services could equip farmers without subsidies with the necessary skills and knowledge to optimise their existing resources and diversify their income sources (Quisumbing & Pandolfelli, 2010). Hence, for both categories of farmers, extension services are crucial for maximising the effectiveness of subsidy programmes and improving the overall economic well-being of farmers.

5. Conclusion

This study aimed to identify factors that determine access to the Farm Input Subsidy Programme (FISP) and how this influences maize yield and farm income in the Southern province of Zambia. The probit regression model was employed to identify the determinants of FISP access among farmers. The study also adopted the use of an endogenous switching regression model to address unobservable bias in our estimate of the effect of input subsidy on yield and farm income. The model was used to compare the yield and farm income of the FISP beneficiaries and the non-beneficiaries, as well as estimate the values of the outcome variables in the counterfactual hypothetical cases. The probit regression analysis results showed that age, household size, marriage, cooperative membership, participation in other social groups, and off-farm income positively influence FISP access. Farm size and the farmer's gender (being female), as well as farming experience, were found to be negative predictors of FISP access. The endogenous switching regression model revealed that the farmers who were subsidy beneficiaries had higher maize yield and higher income compared to those who were not subsidy beneficiaries and could have had a significantly higher yield and income if they had been subsidized.

The study's findings reveal several key policy implications. First of all, gender inequality in FISP access indicates a need for targeted policies to support female farmers by providing gender quotas to pursue parity, enhanced access to extension services, and credit facilities to ensure gender equity. Additionally, the eligibility criteria for FISP might be challenging for female farmers to meet, necessitating a review and potential adjustment of these criteria to make them more inclusive and accessible to women. This could include considerations such as flexibility in land ownership requirements and tailored support to address the unique barriers faced by female farmers. Prioritising smallholder farmers, with particular emphasis on women farmers, in subsidy programmes is crucial for equitable resource distribution, which can promote productivity and income among the most vulnerable groups. Strengthening cooperative networks and farmer associations is essential to facilitate better access to subsidies and support collective action, which can improve agricultural productivity. Expanding extension services is vital to provide all farmers, especially women, with the necessary training and support, maximising the effectiveness of subsidies and improving economic outcomes. Encouraging income diversification through policies facilitating access to credit, training, and market opportunities can enhance farmers' financial stability, enabling better investment in agricultural inputs and overall farm profitability.

List of Abbreviations

ATT - Average Treatment Effect on the Treated
ATU - Average Treatment Effect on the Untreated
CAC - Camp Agricultural Committee
FGD - Focus Group Discussion
FISP - Farmer Input Support Programme
FSP - Fertilizer Support Programme
FSPP - Food Security Pack Programme
MAL - Ministry of Agriculture and Livestock
SD - Standard Deviation
ZMW - Zambian Kwacha

Funding

This work was supported by the Internal Grant Agency of the Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague [Grant No. 20253128].

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NOTES

Food security in the Mediterranean: An economic and political challenge

GIULIO MALORGIO
University of Bologna

The Mediterranean region is facing complex global and regional challenges such as the increasing severity of climate change, declining food security, growing dependence on international markets, increasing water scarcity, the ongoing degradation of soils and biodiversity, and, finally, geopolitical uncertainties.

Food dependence levels in South-East Mediterranean Countrie (SEMCs) are around 50%, with a rising volume of imports, particularly of cereals. In fact, with 6% of the world's population, the region accounts for 15% of global cereal imports and 30% of world wheat imports.

The population is growing at an average rate of 1.5% in the last 20 years, leading to an increase in food demand.

In parallel, the region has experienced a marked urbanization trend, with urban growth increasing by 270% over the past four decades. This process has been accompanied by a decline in the rural population, leading to a reduction in agricultural supply and the abandonment of less fertile lands. The region is also undergoing sustained economic growth, which has contributed to a rise in food availability — from 2,700 kcal per capita in 1990 to 3,300 kcal in 2023. However, the expansion of the middle class has fostered a significant dietary transition: from a traditional, seasonal diet rich in whole grains, fruits, and vegetables to a more standardized, 'Westernized' dietary pattern.

Consequently, malnutrition rates have increased, affecting approximately 8% of the population in SEMCs, while 35% of adults are classified as overweight.

Another consequence of full integration into international markets is price volatility, as observed over the past ten years. This has generated significant market instability, with major repercussions on farmers' incomes, consumers' purchasing capacity, and has exacerbated the difficulties of access to food for the most vulnerable population groups, as well as placing additional pressure on public budgets.

The heavy reliance on external markets, the fragility of production structures, the volatility and rising prices of food commodities, and the limited availability of resources that characterize the reality of the Southern Mediterranean contribute to increasing levels of vulnerability and the risk of food insecurity, with implications for social stability and the sustainability of production systems.

We can therefore state that the current modes of food consumption and production are not sustainable in the Mediterranean basin, and this issue extends beyond the region itself.

According to the FAO's definition of food security — whereby all individuals, at all times, have physical and economic access to sufficient, safe and nutritious food — several critical challenges can be identified within the current food system model in the SEMCs, in particular:

Availability
- Increasing dependence on international markets;
- Rising food demand driven by population growth combined with the scarcity of land and water resources;
- Pressure on natural resource consumption, resulting in the depletion of basic natural resources and biodiversity loss.

Accessibility
- Limited access for small-scale farmers to distribution channels and growing distances between producers and consumers;
- Distortion of mechanisms governing the "food environment";
- Decline and inequality in consumers' purchasing power.

Utilization
- Homogenization of diets;
- Increased production of calorie-dense but nutrient-poor foods;
- Rising levels of malnutrition and overweight.

Local economies: a support for food sovereignty

A shift in the organizational and developmental model of the food system must be considered. Such a shift, even if only partial and complementary to the mechanisms of globalized international markets, could be embodied in the concept of food sovereignty. This concept should not be understood as a simple protection of national production, but rather as a strategy aimed at strengthening stable national or regional trade relations capable of combining both quantity and quality in raw materials and finished products.

More concretely, this should lead to a rethinking of resource use — for example, by reclaiming unused land, scaling up the dissemination of agroecological practices, and increasing the use of renewable energy. Ideally, it would also help address issues related to value distribution along supply chains. This includes promoting disintermediation systems capable of interacting with distribution networks, thereby supporting an evolution of supply that is more responsive to new market demands in terms of sustainability and equity.

In the face of recent developments related to the ecological transition and the food and energy crises, the issue of territorial and local economies as a strategy for development and territorial regeneration — in response to the shortcomings of economic globalization — has returned to the center of public debate.

Current production paradigms must be transformed to move beyond the perception of nature as a mere economic resource. This requires introducing alternative models to traditional business models, embracing cooperative logics in which territorial embeddedness, the recovery of traditional production, and a focus on sustainable practices become key drivers of innovation and change within local farming communities.

The aim is to identify alternative models to the dominant approach, based on social innovation — models that enable a reterritorialization of development, transforming and regenerating territorial ecosystems. Within such models, all actors, including those on the demand side, can engage in meaningful and value-generating participation.

Local economies draw inspiration from these new models of development and territorial value creation, particularly by recognizing the territory as a contextual space of production and purchasing/consumption.

This leads to a more complex form of organization and development based on interactions between enterprises, the territory, and the broader socio-cultural and institutional context. It is a production system that is deeply embedded in the territory, enhancing both productive and cultural biodiversity rooted in tradition, productive specialization, and agricultural vocation.

This development model must be founded on innovative planning, aimed at achieving a new dynamic balance between economic growth and the valorisation of local resources. It requires the active involvement of public institutions and the implementation of integrated planning based on strengthening infrastructure and fostering technological innovation.

Such an approach implies considering the socio-political dimension, not merely relying on the logic of the global economy. This means:

- Prioritizing local and national economies and markets;
- Supporting family farming;
- Promoting food production, distribution, and consumption based on environmental, social, and economic sustainability;
- Embedding stronger ethical and social values into food systems;
- Encouraging resilient agricultural practices that enhance productivity and production through agricultural vocation and the creation of shared value among different stakeholders.

NEW MEDIT

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Printed in Italy
December 2025