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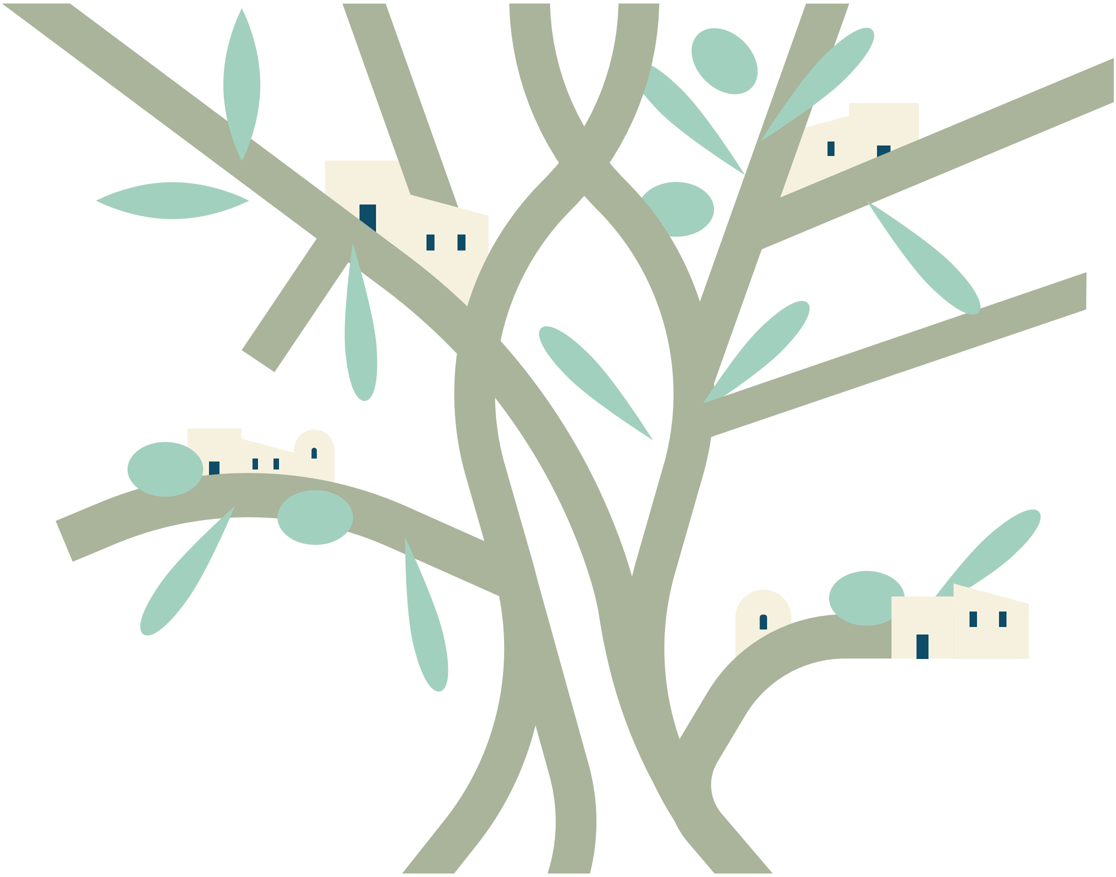

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Contents

Foreword

The relationship between SDG 2 (Zero Hunger) outcomes and agricultural input efficiency in OECD countries using an input-oriented DEA model has been analysed by *Guldal*. Results show that countries with high SDG 2 scores may still exhibit inefficiencies, while others achieve efficient practices with lower SDG 2 scores. The findings highlight the limitations of current SDG 2 indicators in reflecting sustainable resource management.

Missaoui et al. assess citizens' preferences for lagoon restoration in Tunisia and their willingness to support the EcoPact endeavour to enhance the prevailing circumstances and halter environmental degradation. The results showed that the aggregated benefits is very close to the required project cost for the high-impact scenario, suggesting that the project is almost viable only if the improvement is highly significant.

S.Ü. Kestane et al. analyse the suitability and tendencies of small-scale agricultural producers toward ecommerce and determine their readiness for this marketing method. The paper showed that small family farmers do not have infrastructure issues regarding e-commerce. However, their lack of knowledge about ecommerce, adherence to the existing system, and lack of trust in e-commerce are identified as the main obstacles to e-commerce implementation.

Gharbi et al. aim to create a business model for Farmers' Organizations in Tunisia. This business model will define, on the one hand, the necessary resources to realize its future projects and demonstrate their viability, and, on the other hand, the strategies to overcome existing constraints while leveraging local resources and creating sustainable activities. The business model provides a clear strategy for income-generating activities to be implemented and investments to be made in the short and medium term.

Tüzüntürk et al. analyse the effect of wheat producer support on wheat production using panel data methods. The findings indicate that countries should give importance to producer support policies in agriculture and develop new support policies. The study has significant consequences for the Mediterranean countries, which have a considerable share in world wheat imports during and after the analysis period.

Miran examines the EU fisheries sector's environmental efficiency based on CO_2 emissions from marine gas consumption. Results show that it is feasible to reduce CO_2 emissions from fishing activities. Some countries, such as Latvia, Lithuania, Netherlands, Poland, and Estonia, demonstrate exemplary environmental efficiencies with perfect scores.

Dagher et al. compares the economic benefits of producing Deglet Noor dates and common date varieties at farm level, when faced with different production stresses in Tunisia. The authors show that in absence of stress, Deglet Noor is the most profitable variety, but its profitability is particularly vulnerable to different stresses. Stress-free environments become increasingly rare in Tunisian oases. Hence, re-directing interest towards common date varieties could help building less vulnerable oasis farming.

Ounalli et al. evaluate the sustainability of small dairy cattle farms in northeastern Tunisia and explores pathways for improvement. The authors show that at regional level, sustainability was highest in agroecology, moderate in economics, and lowest in socioterritorial aspects.

Bridging the gap between SDG 2 indicators and agricultural efficiency: Insights from OECD countries

HUSEYIN TAYYAR GULDAL*

DOI: 10.30682/nm2504a
JEL codes: Q01, Q56, R15

Abstract

This study examines the relationship between SDG 2 (Zero Hunger) outcomes and agricultural input efficiency in OECD countries using an input-oriented DEA model. Analyzing key agricultural inputs—such as area harvested, employment, pesticide, fertilizer, energy, and water use—reveals discrepancies between SDG 2 scores, which emphasize social indicators, and efficiency scores based on resource utilization. Results show that countries with high SDG 2 scores may still exhibit inefficiencies, while others achieve efficient practices with lower SDG 2 scores. The findings highlight the limitations of current SDG 2 indicators in reflecting sustainable resource management. Incorporating efficiency metrics into SDG 2 could enhance its alignment with sustainability objectives, promoting resource conservation and food security. This study also underscores SDG 2's connections with other goals, advocating for a holistic approach to measuring progress.

Keywords: *Sustainability, Food security, Resource use, Input-output analysis, Global hunger index*

1. Introduction

Global hunger remains one of the most pressing challenges of the 21st century, despite advancements in food production and distribution. Millions of people worldwide continue to experience undernourishment and food insecurity, underscoring the need for sustainable and equitable solutions (Wu *et al.*, 2014; Alaimo *et al.*, 2020; Cooper *et al.*, 2021). In response, the United Nations established the Sustainable Development Goals (SDGs) in 2015, with SDG 2 (Zero Hunger) aiming to end hunger, enhance food security, improve nutrition, and promote sustainable agriculture by 2030 (Table 1). However, achieving these goals requires not only addressing food access and malnutrition but also improving the efficiency of agricultural production systems.

SDG 2 primarily focuses on social outcomes such as the prevalence of undernourishment and malnutrition (Sabbahi *et al.*, 2018; Mensi and Udenigwe, 2021), yet the efficiency with which countries utilize agricultural inputs such as water, energy, and fertilizers plays a critical role in ensuring long-term food security and sustainability (Penuelas *et al.*, 2023). Agricultural systems that rely heavily on resource-intensive

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Table 1 - The Goals of the 2030 Agenda for Sustainable Development.

1. No poverty	4. Quality education	7. Affordable and clean energy	10. Reduced inequalities	13. Climate action	16. Peace, justice and strong institution
2. Zero Hunger	5. Gender equality	8. Decent work and economic growth	11. Sustainable cities and communities	14. Life below water	17. Partnership for the goals
3. Good health and well-being	6. Clean water and sanitation	9. Industry, innovation, and infrastructure	12. Responsible consumption and production	15. Life on land	

Source: UN, 2015.

practices may meet short-term food needs but risk degrading the ecosystems supporting future production. Moreover, inefficient resource use can increase production costs, reduce food availability, and worsen food affordability – ultimately exacerbating food insecurity and malnutrition (Ibrahim *et al.*, 2024; Karandish *et al.*, 2025). Thus, resource use efficiency must be a core consideration in evaluating progress towards SDG 2, ensuring that food security improvements do not come at the expense of long-term agricultural sustainability.

Figure 1 shows the current SDG 2 scores across OECD countries.

Although resource efficiency plays a crucial role in food security, current SDG 2 indicators fail to reflect the significance of optimizing agricultural inputs. As a result, discrepancies arise in the assessment of country performances. Various methodologies have been used to measure sustainable development (Böhringer and Jochem, 2007; Singh *et al.*, 2012), yet data inconsistencies persist. For instance, widely used indicators – such as the Food and Agriculture Organization's (FAO) undernourishment metric, household food consumption surveys, and anthropometric measurements – have exhibited inconsistencies across countries (De Haen *et al.*, 2011; Masset, 2011), raising concerns about the reliability of SDG assessments (Otekunrin *et al.*, 2019).

As a result, countries with strong social and nutritional outcomes may achieve high SDG 2 scores despite inefficient agricultural systems, while resource-efficient nations may receive lower SDG 2 rankings, despite their contributions to sustainability. These inconsistencies call for a re-

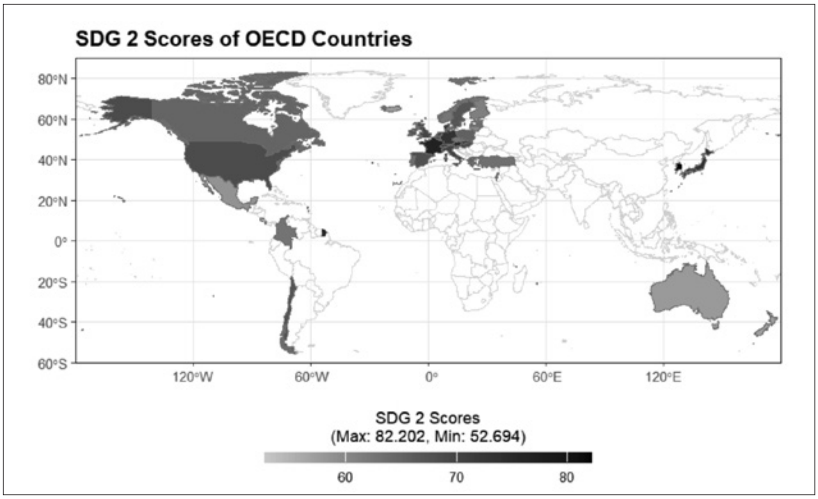


Figure 1 - SDG 2 scores of OECD Countries.
Source: SDR, 2024.

assessment of SDG 2 measurement, particularly regarding the role of resource management and agricultural efficiency (Burford *et al.*, 2016; Allen *et al.*, 2017; Guijarro and Poyatos, 2018). A refined evaluation framework should integrate both food security and sustainable resource use to provide a more accurate reflection of progress.

This study examines the relationship between SDG 2 outcomes and agricultural input efficiency in OECD countries using an input-oriented Data Envelopment Analysis (DEA). By analyzing key agricultural inputs – area harvested, agricultural employment, pesticide use, fertilizer use, energy use, and water use (Table 2) – this research investigates whether countries can achieve similar SDG 2 outcomes with fewer resources.

Despite SDG 2's pivotal role in addressing global hunger, it remains less studied than other SDGs (Salvia *et al.*, 2019). This study addresses two key questions: (1) Does agricultural input efficiency significantly impact SDG 2 outcomes? (2) Do existing SDG 2 indicators adequately capture both food security and agricultural sustainability? By challenging current measurement approaches and emphasizing the interconnections between SDG 2 and other sustainability goals, such as SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action), this research contributes to a more comprehensive understanding of sustainability and informs future policy directions toward achieving Zero Hunger.

2. Methodology

2.1. *Data sources and selection of variable*

This study relies on internationally recognized databases, including FAO and OECD, which provide standardized and comprehensive agricultural and economic indicators for OECD countries. The variables used in the model were sourced from these databases, ensuring consistency and reliability. The data reflects the most recent available year (2021) to maintain accuracy and relevance. To enhance validity, a cross-verification process was conducted by comparing overlapping variables from both sources. In cases of discrepancies, data from sources with direct national reporting were prioritized, ensuring consistency across multiple reporting years. The use of these internationally accepted datasets strengthens the robustness of this study's findings and allows for meaningful comparisons across countries.

This study used an input-oriented DEA method to evaluate the SDG 2 scores of OECD countries. The SDG 2 score was set as the output variable in the model, while the input variables included area harvested, agricultural employment, pesticide use, fertilizer use, energy use, and water use (Table 2).

SDG 2 aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture by 2030. It addresses multiple dimensions of food systems, including equitable access to nutritious food, eliminating all forms of malnutrition, and the sustainable production practices necessary to maintain long-term agricultural productivity. While SDG 2 indicators primarily focus on these social and health outcomes, achieving this goal also hinges on the efficient use of agricultural resources and minimizing environmental impact. Efficiency-focused agricultural studies, such as Ozden and Ozer (2019), highlight the need for sustainability-driven agricultural policies. Similarly, Ibrahim (2024) underscores the regional disparities in food security determinants, reinforcing the argument for a more holistic SDG 2 evaluation framework.

The selection of variables in this study is strategically designed to provide a clearer and more practical understanding of the SDG 2 target by focusing on key agricultural inputs that directly affect productivity and sustainability. By analyzing variables such as water use, energy consumption, and pesticide application, we aim to demonstrate that the same SDG 2 scores can potentially be achieved with reduced resource usage, thus minimizing environmental impact and promoting sustainable agricultural practices. This approach advocates for a balanced strategy to achieve SDG 2 with optimized resource expenditure, aligning with the broader goals of sustainability and conservation (Table 3). Other potential indicators, such as mechanization or biodiversity loss, were not included due to data limitations or lack of direct relevance to input

Table 2 - Descriptive Statistics of Variables Used in the Analysis.

Variables	*Unit*	*Mean*	*Std. Dev.*	*Min.*	*Max.*
Output					
SDG2	Index score	66.333	6.138	52.694	82.202
Inputs					
Area harvested	ha (x1000)	7357.418	17345.250	2.914	201584.800
Agricultural employment	persons (x1000)	759.519	1417.490	3.325	6751.959
Pesticide use	kg/ha	4.491	4.095	0.01	17.410
Fertilizer use[1]	kg/ha	146.471	64.430	75.44	388.610
Energy use[2]	Toe (x1000)	1904.066	3344.991	27.255	19233.110
Water use[3]	%	33.363	30.795	0	90.887

Source: FAOSTAT, 2024; OECD, 2024; SDR, 2024.

[1] Fertilizer use amounts are calculated based on nutrients, with totals indicated for nitrogen (N), phosphate (P_2O_5), and potassium (K_2O).

[2] The amount of energy used considers the energy consumption directly used in agriculture. Toe refers to tonnes of oil equivalent, and this unit is used to compare and express the energy from different sources.

[3] The water use variable represents the percentage of freshwater use allocated to agriculture. This approach was taken due to the unavailability of precise freshwater usage data (in cubic meters) for agriculture across OECD countries.

efficiency in the context of SDG 2.

By focusing on these critical agricultural inputs, this study aims to assess SDG 2 progress and explores the potential for achieving the same outcomes through more efficient resource usage. This leads to the following hypotheses, which are designed to evaluate whether resource optimization can maintain or enhance SDG 2 scores while minimizing environmental impact and supporting broader sustainability objectives.

H_0: Agricultural input efficiency does not significantly impact SDG 2 outcomes, and the current SDG 2 indicators sufficiently reflect both social outcomes and agricultural sustainability.

H_1: Agricultural input efficiency significantly improves SDG 2 outcomes, and the current SDG 2 indicators fail to adequately account for agricultural resource management and sustainability.

Moreover, through the incorporation of these variables, the model not only assesses efficiency in the context of SDG 2 but also demonstrates alignment with a broader array of sustainable development goals. This multidimensional approach highlights how optimized agricultural practices can contribute to a more resilient and sustainable global food system.

2.2. *Analytical Framework*

The input-oriented BCC (Banker, Charnes, and Cooper) model was chosen in this study. This model is a widely used Data Envelopment Analysis (DEA) method for measuring agricultural input efficiency, particularly favored for optimizing agricultural production processes with limited resources. It is suited to situations where returns to scale are variable, meaning that each agricultural entity or country may operate at different efficiency levels depending on its scale (Banker *et al.*, 1984). In evaluating the efficiency of agricultural inputs such as water, fertilizer, and energy, the input-oriented BCC model reveals the potential for maintaining output levels while minimizing input usage (Coelli *et al.*, 2005).

One primary reason for the model's frequent use in agricultural studies is that agricultural production is inherently input-dependent, and efficient resource use is essential for sustainability (Zhu and Lansink, 2010). For instance, the efficient use of inputs like water and fertilizer not only enhances agricultural productivity but also mitigates environmental impacts. Numerous studies have shown that input-oriented DEA

Table 3 - Analytical Framework and Variable Justification.

SDG2 indicators	*Variables used in the model*	*Relationship explanation*
Prevalence of undernourishment (%)	Agricultural Employment, Area Harvested	Reducing undernourishment is directly linked to increasing agricultural production. Efficient use of labor and sustainable management of harvested areas affect food production (Hemathilake and Gunathilake, 2022).
Prevalence of stunting in children under 5 years of age (%)	Agricultural Employment, Pesticide Use	Pesticide use can affect stunting in children (Purwestri *et al.*, 2017; Kartin *et al.*, 2019; Jaacks *et al.,* 2019). Limiting the use of harmful pesticides is important for producing healthy food.
Prevalence of wasting in children under 5 years of age (%)	Area Harvested, Fertilizer Use	Efficient use of harvested areas and fertilizers can increase agricultural productivity and crop diversity, thereby improving food security and supporting better nutrition, which in turn may reduce wasting in children (Kumar *et al.*, 2015; Sekiyama *et al.*, 2020).
Prevalence of obesity (% of adult population)	Energy Use, Pesticide Use	Energy and pesticide use can lead to higher agricultural production; however, energy-intensive agricultural processes may facilitate the production of processed foods (Balogh and Hall, 2016), whose increased consumption can contribute to unhealthy dietary habits and raise obesity risks (Popkin and Reardon, 2018), with pesticides potentially exerting indirect effects on human metabolism (Kim *et al.*, 2017).
Cereal yield (tonnes per hectare)	Fertilizer Use, Water Use	Cereal yield can be directly improved through the use of fertilizers and irrigation. However, sustainable practices are critical for mitigating environmental impacts (Ladha *et al.*, 2005; Zhou *et al.*, 2011).
Proportion of agricultural area under productive and sustainable agriculture (%)	Water Use, Energy Use, Pesticide Use	Sustainable agriculture requires efficient and environmentally conscious water, energy, and pesticide management. Overuse of these resources may harm the environment (Fabiani *et al.*, 2020; Bwambale *et al.*, 2022).

models effectively assess the efficiency of water usage (Cao *et al.*, 2020), fertilizer and labor use (Manogna and Mishra, 2022), and energy consumption (Mousavi-Avval *et al.*, 2011) in agriculture. Additionally, there are studies in which the efficiency of capital in agricultural enterprises is measured (Gunes and Guldal, 2019), further underscoring the model's versatility and applicability in evaluating resource use in diverse agricultural contexts.

DEA was chosen over alternative efficiency analysis methods, such as Stochastic Frontier Analysis (SFA), due to its flexibility in handling multiple inputs and outputs without imposing a predefined functional form on the production process. Unlike SFA, which requires parametric assumptions, DEA provides a data-driven frontier, making it particularly useful for benchmarking efficiency across diverse countries. Additionally, DEA allows for the identification of best-practice decision-making units (DMUs) within a sample, making it well-suited for evaluating resource use efficiency in the context of SDG 2.

The input-oriented BCC model further provides a fair assessment tool for cross-country comparisons by enabling each country or agricultural entity to reach optimal efficiency with its available resources (Aldanondo-Ochoa *et al.*, 2014). This approach supports sustainable agricultural production by promoting efficient use of limited natural resources, making it a valuable tool for addressing sustainability goals within the sector.

The input-oriented BCC model is calculated through the following linear programming problem:

Minimize *Θ*

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \Theta x_{io}, \quad \forall_i = 1,2, \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \le y_{ro}, \quad \forall_r = 1,2, \ldots, s \qquad (1)$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda \ge 0, \forall_j = 1,2, \ldots, n$$

Θ: The input-oriented efficiency score represents the technical efficiency of the evaluated Decision-Making Unit (DMU), in this case, the country. The score ranges between 0 and 1. If $\Theta = 1$, the DMU is considered efficient; if $\Theta < 1$, the DMU is inefficient and has the potential to reduce its input usage.

x_{ij}: Input i of DMU j

y_{rj}: Output r of DMU j

x_{io}: Input i of the evaluated DMU

y_{ro}: Output r of the evaluated DMU

λ_j: Weight variables representing the contribution of each DMU's performance to the evaluation

n: Number of decision-making units (DMUs)

m: Number of input variables

s: Number of output variables

The model's objective is to minimize the value of Θ, which allows us to determine how each country can use its resources more efficiently while maintaining its current SDG 2 score. Doing so reveals how countries can improve agricultural productivity and sustainability through more efficient resource use.

Although SDG 2 scores do not directly account for these inputs (as shown in Table 2), these inputs indirectly impact the efficiency and sustainability of agricultural production processes. Therefore, the input-oriented model used in this study aims to demonstrate how agricultural inputs can be minimized and used more efficiently to achieve the SDGs, particularly SDG 2.

3. Results and Discussion

3.1. *DEA Results and Benchmark Analysis*

The results of the DEA provide valuable insights into the agricultural efficiency of OECD countries concerning SDG 2 targets. The analysis highlights both efficient and inefficient use of resources across different nations by examining key input variables such as water use, energy consumption, pesticide and fertilizer application, agricultural employment, and harvested area. This section discusses the efficiency scores of the countries, identifies key patterns in the data, and explores the implications of these findings for sustainable agricultural practices. Additionally, the results are interpreted in the context of the broader SDG 2 objectives, emphasizing the potential to achieve similar food security outcomes with optimized resource use, thus minimizing environmental impact.

The DEA results, presented in Table 4, reveal how efficiently OECD countries utilize agricultural inputs to achieve their SDG 2 (Zero Hunger) scores. Countries such as Estonia, Iceland, Luxembourg, Mexico, and Australia demonstrate full efficiency (VRS score = 1.000), indicating that they are optimally utilizing their key inputs like water, energy, and pesticides (Table 4). These nations also efficiently manage agricultural labor and harvested area, maintaining high SDG 2 performance. Their ability to balance agricultural productivity with sustainable resource use underscores their effectiveness in achieving food security goals without excessive input consumption.

Conversely, countries such as Chile, Colombia, and Costa Rica show lower VRS efficiency scores, ranging from 0.393 to 0.585, indicating suboptimal resource utilization (Table 4). Chile and Colombia, in particular, exhibit inefficiencies in both resource use and operational management, suggesting that these countries could improve their SDG 2 performance by optimizing agricultural inputs, reducing excessive resource use, and enhancing their food security outcomes.

The benchmark analysis (Table 5) further

Table 4 - Efficiency Scores of OECD Countries (Input-Oriented BBC).

Countries	*Technical Efficiency Score (CRS)*	*Pure Technical Efficiency Score (VRS)*	*Scale Efficiency Score (SE)*
Australia	**1.000**	**1.000**	1.000
Austria	0.821	**1.000**	0.821
Belgium	0.530	**1.000**	0.530
Canada	0.743	0.777	0.955
Chile	0.358	0.585	0.612
Colombia	0.216	0.393	0.550
Costa Rica	0.499	0.548	0.912
Czechia	0.663	0.664	0.999
Denmark	0.805	**1.000**	0.805
Estonia	**1.000**	**1.000**	1.000
Finland	0.993	**1.000**	0.993
France	0.666	**1.000**	0.666
Germany	0.675	**1.000**	0.675
Greece	0.734	0.792	0.927
Hungary	0.638	0.731	0.872
Iceland	**1.000**	**1.000**	1.000
Ireland	0.218	**1.000**	0.218
Israel	0.521	0.643	0.810
Italy	0.817	0.939	0.870
Japan	0.514	0.614	0.837
Latvia	0.846	0.860	0.983
Lithuania	0.694	0.716	0.969
Luxembourg	**1.000**	**1.000**	1.000
Mexico	**1.000**	**1.000**	1.000
Netherlands	0.486	**1.000**	0.486
New Zealand	0.074	0.075	0.984
Norway	0.595	0.830	0.717
Poland	0.720	0.787	0.914
Portugal	0.529	0.536	0.987
South Korea	0.833	**1.000**	0.833
Slovakia	0.676	**1.000**	0.676
Slovenia	0.429	**1.000**	0.429
Spain	0.638	0.711	0.897
Sweden	0.971	**1.000**	0.971
Switzerland	0.805	**1.000**	0.805
Türkiye	0.629	0.647	0.972
United Kingdom	0.554	**1.000**	0.554
United States of America	0.777	0.914	0.851

Notes: CRS (Constant Returns to Scale), VRS (Variable Returns to Scale), and SE (Scale Efficiency) are efficiency measures used in Data Envelopment Analysis (DEA). CRS measures efficiency assuming constant returns to scale, meaning that input and output are proportionally scalable. VRS allows for variable returns to scale, meaning that the relationship between input and output may change as the scale of operations changes. SE (Scale Efficiency) is the ratio of CRS efficiency to VRS efficiency, indicating how close a decision-making unit (DMU) is to optimal scale.

Table 5 - Benchmark Analysis Results for Enhancing Agricultural Efficiency.

Country	*Efficiency Score (VRS)*	*Benchmark Countries*	*Benchmark Weight*	*Interpretation*
Chile	0.585	Denmark, Iceland, Ireland, Slovakia, Switzerland	0.2335, 0.3115, 0.0425, 0.2264, 0.1859	Chile can improve its efficiency by modeling 23.35% of Denmark's performance, 31.15% of Iceland's, etc.
Colombia	0.393	Denmark, Iceland, Ireland, Slovakia	0.2500, 0.6564, 0.0716, 0.0022	Colombia should focus on adopting Iceland's strategies (65.64%) and Denmark's (25%).
Canada	0.777	Austria, Estonia	0.1699, 0.8300	Canada can enhance efficiency by following 83% of Estonia's and 16.99% of Austria's practices.
Türkiye	0.647	Estonia, Slovakia, Sweden	0.9337, 0.0047, 0.0019	Türkiye should primarily model Estonia's high efficiency (93.37%) for improvement.

Notes: Benchmark Unit: This represents the efficient units that inefficient units should reference to become efficient. They provide insights into how inefficient units can improve their performance to achieve efficiency. Benchmark Weight: This represents the contribution of efficient units to the performance improvement of inefficient units. A higher benchmark weight indicates that the inefficient unit should rely more heavily on the referenced efficient unit to improve its performance and achieve efficiency.

highlights reference countries that can serve as models for improvement. For example:

Chile (efficiency score = 0.585) should consider the performance of Denmark (0.2335), Iceland (0.3115), Ireland (0.0425), Slovakia (0.2264), and Switzerland (0.1859) as benchmarks (Table 5). The assigned weights indicate that Chile could increase efficiency by modeling 23.35% of Denmark's strategies and 31.15% of Iceland's practices, along with the other reference countries.

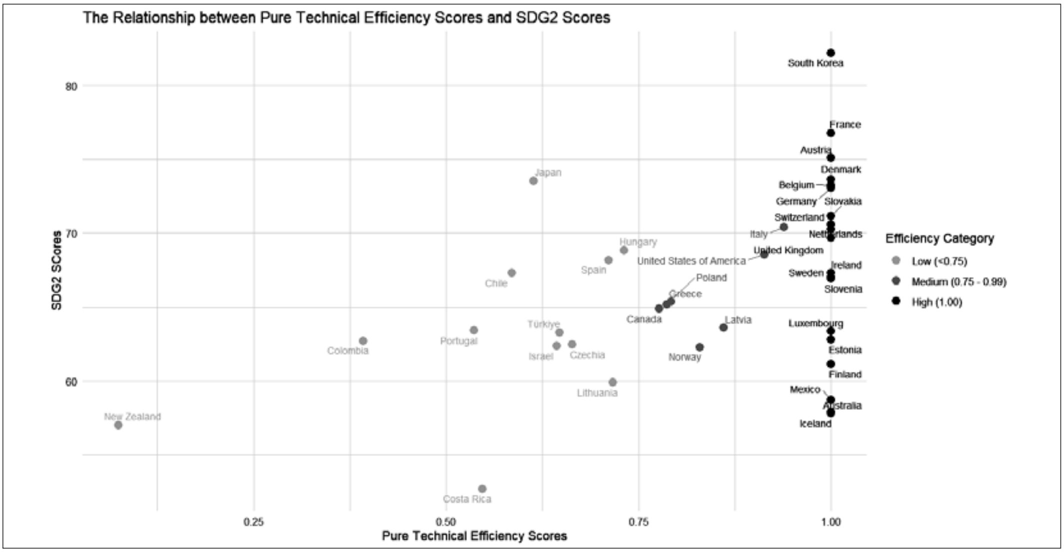
Colombia (efficiency score = 0.393) has benchmark countries Denmark (0.2500), Iceland (0.6564), Ireland (0.0716), and Slovakia (0.0022) (Table 5). Iceland's high weight (65.64%) suggests that Colombia could significantly enhance efficiency by adopting Iceland's agricultural resource management strategies.

For Canada, with an efficiency score of 0.777, the benchmark countries are Austria (0.1699) and Estonia (0.8300). Canada can improve its efficiency by adopting 83% of Estonia's and 16.99% of Austria's practices. This mix shows that Estonia's strategies are particularly relevant to Canada's agricultural efficiency (Table 5).

Türkiye (efficiency score = 0.647) is primarily benchmarked against Estonia (0.9337), Slovakia (0.0047), and Sweden (0.0019). The dominant benchmark weight (93.37%) from Estonia suggests that Türkiye should prioritize adopting Estonia's agricultural efficiency strategies to enhance its performance (Table 5).

Benchmarking high-performing reference countries is a widely accepted approach in DEA studies, particularly within agricultural and environmental contexts (Cook and Zhu, 2007). Previous research has demonstrated that adopting strategies from efficient benchmark countries can enhance resource efficiency and sustainability. Studies by Reinhard *et al.* (2000) and Kyrgiakos *et al.* (2021) indicate that adapting best practices from high-performing countries helps less efficient nations identify areas for improvement, such as optimizing input management and applying advanced agricultural techniques. Further research, including Sachs (2012), Hickmann *et al.* (2023), and Thow (2024), highlights that implementing policies from successful countries can effec-

Figure 2 - The Relationship Between Pure Technical Efficiency Scores and SDG2 Scores.



Source: Own source.

tively enhance efficiency and promote sustainable development. This underscores the value of cross-national learning for policy development and resource optimization.

3.2. *Comparing DEA Scores with SDG 2 Scores*

As shown in Figure 2, the comparison between SDG 2 and efficiency scores based on agricultural inputs reveals notable discrepancies. While SDG 2 indicators focus primarily on social and health outcomes, the efficiency scores – calculated through resource utilization metrics – highlight the potential to achieve similar food security objectives with optimized input use. This gap underscores the need to reassess how SDG 2 success is measured, particularly for countries that perform well in social indicators but fall behind in resource efficiency.

a) South Korea: A Model of Balance

South Korea serves as a leading example of balanced progress. Ranking at the top of SDG 2 scores and achieving a high-efficiency score, South Korea exemplifies how efficient agricultural practices can support social well-being and food security objectives (Figure 2). Notably, South Korea is ranked 11th out of 38 OECD countries in cereal yield indicator[1] (SDR 2024), which underscores its ability to maintain high productivity while optimizing resource inputs. This alignment between high productivity and social impact supports the vision of Target 2.3[2], which aims to double agricultural productivity and incomes for small-scale producers by 2030. South Korea's success demonstrates that efficient management of agricultural inputs – such as land, water, and energy – enables countries to meet food security goals sustainably. This synergy should ideally be reflected across all nations.

[1] Cereal yield is one of the few indicators within the SDG 2 framework that attempts to capture agricultural productivity.

[2] By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

b) Japan: A High Social Performer with Efficiency Gaps

In contrast, Japan presents a discrepancy within the SDG 2 framework. Despite ranking highly in SDG 2 due to strong social indicators such as food security and nutrition, Japan exhibits lower agricultural efficiency (Figure 2). This inefficiency is largely attributed to resource-intensive agricultural practices, which – while yielding positive social outcomes – suggest opportunities for improvement in input optimization. Japan ranks 12th in cereal yield, indicating high productivity; however, the current SDG 2 indicators fail to fully capture its potential for improving sustainability by enhancing efficiency in water and energy use. This example illustrates a key limitation of SDG 2 measurement, as the strong focus on social outcomes does not adequately reflect resource management efficiency, which is crucial for achieving long-term agricultural sustainability, particularly within Target 2.3.

c) Iceland and Australia: High Efficiency, Low SDG 2 Scores

On the other hand, Iceland and Australia represent a different type of discrepancy. These countries achieve high-efficiency scores, reflecting strong resource management practices, yet rank lower in SDG 2 (Figure 2). For instance, despite Iceland's relatively low cereal yield ranking, it has successfully implemented effective water and energy conservation strategies, resulting in high agricultural efficiency. Similarly, Australia, though ranking lower in cereal yield and SDG 2, excels in land and resource use efficiency but does not fully meet the social targets outlined in SDG 2. This further emphasizes the gap in SDG 2 criteria: while efficiency is essential for sustainable agriculture, the existing SDG 2 indicators fail to account for resource optimization.

d) Mexico: Efficient but Struggling with Social Performance

Mexico also illustrates this complexity. While scoring well in efficiency due to streamlined input use, its social outcomes are less pronounced, leading to lower SDG 2 rankings (Figure 2). This suggests that, despite effectively optimizing agricultural inputs, Mexico faces challenges in ensuring food security and equity. Similar to Iceland and Australia, Mexico's case indicates that efficiency alone does not guarantee strong social performance. Instead, a more comprehensive approach is needed—one that balances efficient input use with equitable access to resources.

e) Mediterranean Countries: Strong Social Outcomes, Uneven Resource Efficiency

The Mediterranean OECD countries – France, Italy, Spain, Greece, and Türkiye – exhibit diverse patterns in agricultural efficiency and SDG 2 performance, reflecting the complex interplay between food security outcomes and sustainable resource use.

Among these nations, France stands out as a strong performer, achieving both a high SDG 2 score and full efficiency, indicating a well-balanced agricultural system that effectively integrates resource management with food security goals. Similarly, Italy, with a relatively high SDG 2 score and efficiency level, demonstrates effective input use, yet still holds potential for further optimization in agricultural resource management.

Conversely, Spain and Greece exhibit moderate SDG 2 rankings while struggling with efficiency gaps, suggesting that despite favorable social outcomes, there is room for improving resource utilization. The case of Türkiye, which has the lowest SDG 2 score among Mediterranean OECD countries and a relatively low efficiency score, underscores challenges in both food security and agricultural sustainability. These disparities suggest that food security improvements in the region must be accompanied by stronger commitments to optimizing agricultural inputs, particularly given the Mediterranean's exposure to climate change, water scarcity, and land degradation (Gürsoy, 2020).

The clustering analysis by Coluccia *et al.* (2024) and Miglietta *et al.* (2023) further supports these findings, indicating that Mediterranean nations follow distinct patterns in agricultural sustainability and food security. The results align with previous research on SDG 2 food security assessments in the Mediterranean, which highlight regional disparities and policy gaps. These observations reinforce the argument that SDG 2 indicators should integrate efficiency metrics to better capture sustainability challenges across diverse agricultural systems.

3.3. *Interconnections with Other SDGs*

The country-specific findings illustrate the complex relationship between SDG 2 outcomes and agricultural efficiency. While the primary goal of SDG 2 is to ensure food security, the agricultural inputs analyzed in this study – water, energy, pesticides, fertilizers, employment, and harvested area – extend beyond food production, influencing multiple sustainability objectives. These interconnections emphasize the need for integrated policy approaches that optimize resource use while maintaining both environmental sustainability and social equity.

Water management plays a pivotal role in achieving both SDG 2 and SDG 6. Efficient water management in agriculture reduces water scarcity, minimizes waste, and helps preserve aquatic ecosystems, supporting long-term agricultural productivity and environmental health. Excessive or inefficient water use, by contrast, risks resource depletion and degraded water quality, ultimately threatening food security and ecological stability (Chartzoulakis and Bertaki, 2015; Li *et al.,* 2025).

Similarly, energy use in agriculture directly relates to SDG 7 (Affordable and Clean Energy) and SDG 13. Agricultural activities with high energy demands, especially from non-renewable sources, increase greenhouse gas emissions, impacting climate resilience (Khan *et al.,* 2014; Mohammadi *et al.*, 2014). Transitioning to renewable energy sources within agriculture could mitigate these effects, fostering climate stability while reducing operational costs for farmers (Chang *et al.*, 2015; Khan *et al.*, 2018).

The use of pesticides and fertilizers, while essential for agricultural productivity, also has significant environmental consequences, particularly affecting SDG 14 (Life Below Water) and SDG 15 (Life on Land). Excessive or improper application of these inputs leads to soil degradation, water pollution, and biodiversity loss (Campbell *et al.,* 2018). Implementing precision farming and controlled application techniques can help mitigate these risks, reducing agriculture's environmental footprint without compromising yields or food security.

Lastly, agricultural employment and harvested area directly influence SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) by providing jobs and sustaining rural economies (Nasr-Allah *et al.,* 2020). However, ensuring fair wages, safe working conditions, and responsible land use practices is essential for achieving sustainable agricultural growth without compromising worker welfare or ecosystem integrity.

3.4. *Policy Implications for Agricultural Efficiency and SDG 2 Integration*

Current agricultural policy frameworks, such as the Common Agricultural Policy (CAP) in the EU and USDA agricultural programs in the U.S., are primarily designed to enhance food production, support farm incomes, and promote environmental conservation. However, despite their extensive role in shaping agricultural systems, these policies lack mechanisms to systematically evaluate how efficiently resources such as water, energy, and fertilizers are utilized in achieving food security (Cuéllar *et al.*, 2014; Grethe *et al.*, 2018). As a result, agricultural policies remain largely output-driven, focusing on production growth rather than sustainability and efficiency metrics. This limitation mirrors a broader concern regarding SDG 2 indicators, which primarily assess food security through social and nutritional outcomes while neglecting the sustainability of agricultural production processes. The absence of efficiency-based assessments within both policy frameworks and SDG 2 measurements raises critical questions about how agricultural sustainability is evaluated and incentivized in global food security strategies.

In parallel, technological advancements are rapidly transforming agricultural practices (Guldal and Ozcelik, 2024), offering opportunities to improve resource efficiency while maintaining high productivity. Precision agriculture, remote sensing, and AI-driven irrigation systems allow farmers to optimize input use, reducing water and chemical applications without compromising yields (Guldal, 2022). However, despite the demonstrated benefits of these innovations, their adoption remains uneven across OECD countries, often influenced by economic, infrastructural, and policy constraints (Wreford *et al.*, 2017; Dibbern *et al.*, 2024). Nations with lower efficiency scores may face greater challenges in integrating such technologies due to limited access to financial support, digital infrastructure, or technical expertise. This discrepancy highlights the critical role of national policies in facilitating the transition toward more sustainable and resource-efficient agricultural systems. Without structured incentives or regulatory frameworks that encourage efficiency improvements, many countries risk continuing resource-intensive production models that may undermine long-term food security and environmental sustainability.

4. Limitations and Future Research

While this study provides valuable insights into the efficiency of agricultural inputs in achieving SDG 2, it has certain limitations. First, the analysis is constrained by data availability, as some OECD countries lack comprehensive records on resource use. Second, the DEA model does not account for external factors such as climate change or geopolitical disruptions, which may influence efficiency scores. Future research could explore alternative methodologies, such as SFA, to validate the robustness of these findings. Additionally, longitudinal studies could assess how efficiency trends evolve over time, providing deeper insights into the long-term sustainability of agricultural practices in OECD countries.

5. Conclusion and Recommendations

5.1. *Conclusion*

This study reveals notable discrepancies between SDG 2 scores and agricultural efficiency among OECD countries, highlighting the need for a more refined approach to measuring progress toward the Zero Hunger goal. While SDG 2 indicators emphasize social and health outcomes such as undernourishment, malnutrition, and food access efficiency scores provide a different perspective by assessing how effectively agricultural inputs like water, energy, and fertilizers are managed. This divergence exposes a fundamental gap in how agricultural performance is evaluated within the SDG framework.

The findings emphasize the importance of considering agricultural input efficiency alongside social outcomes in SDG 2 assessments. Some countries optimize their resource use yet do not achieve high SDG 2 scores, while others rank well in social indicators despite inefficient resource utilization. This inconsistency suggests that SDG 2 evaluations may not fully capture agricultural sustainability, potentially overlooking the vital role of resource efficiency in achieving long-term food security.

Beyond SDG 2, optimizing agricultural input use has broader sustainability implications, as efficient water, energy, and input management supports environmental resilience and resource conservation. Aligning agricultural efficiency with SDG 2 would strengthen its synergy with other SDGs, such as SDG 6, SDG 13, and SDG 12 (Responsible Consumption and Production).

5.2. *Policy Recommendations*

To enhance SDG 2's effectiveness in measuring food security and sustainability, efficiency-based indicators should be integrated into both policy frameworks and SDG 2 assessments. While CAP and USDA policies address agricultural sustainability, they do not systematically evaluate resource efficiency, highlighting the need for performance indicators that align food security goals with sustainable input use.

Additionally, accelerating the adoption of precision agriculture, smart irrigation, and remote sensing technologies through targeted investments and digital infrastructure development will help countries optimize agricultural efficiency. Finally, enhancing global collaboration and standardizing efficiency indicators within SDG 2 evaluations would ensure a more comprehensive approach to food security, balancing both productivity and sustainability.

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Heterogeneity in citizens' valuation of ecosystem services from a Mediterranean Sea-connected lagoon restoration: Evidence from Tunisia

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Abstract

The North African region's lagoon ecosystems face numerous challenges, including urbanization, wastewater pollution, and overexploitation. The negative impact of these challenges on the ecological health of lagoons is evident, leading to socioeconomic consequences that have proven to be detrimental. Therefore, we conducted a choice experiment to assess citizens' preferences for Mediterranean Sea-Connected lagoon restoration in Tunisia, as a case study and their willingness to support the EcoPact endeavor to enhance the prevailing circumstances and halter environmental degradation. This research devised two improvement scenarios and utilized a Latent Class Model to gauge citizens' utility in a lagoon restoration. The results revealed two citizen classes, "Pro-restoration" and "Reluctant to Restore". The majority are pro-restoration citizens willing to voluntarily pay (WTP) up to $165.58 for one-year contribution for a high-impact scenario. The other class, Reluctant to Restore, appear to recognize the value of the project's attributes, as evidenced by their significant WTP for high-level attributes. However, they still prefer to maintain the current situation for other reasons, resulting in an insignificant WTP for the overall high or medium scenario. The results showed that the aggregated benefits is very close to the required project cost for the high-impact scenario, suggesting that the project is almost viable only if the improvement is highly significant. Hence, further evaluation is required to validate these results.

Keywords: *Bizerte citizens' preferences, Latent heterogeneity, Choice experiment, Lagoon restoration, Developing countries.*

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1. Introduction

Lagoons are among the most productive and ecologically significant ecosystems, offering many goods and services vital to local communities' well-being (El Zrelli *et al.*, 2021). These dynamic environments serve as crucial food sources, supporting fisheries and contributing to local economies and food security. Beyond their direct provisioning of resources, lagoons also offer recreational opportunities, including water sports, bird watching, and scenic spaces that enhance community leisure and tourism activities (Conde *et al.*, 2015; Jorge *et al.*, 2023). Moreover, lagoons are essential in supporting various industrial processes, such as salt production and aquaculture, which provide employment and stimulate economic growth in coastal regions. They deliver critical ecosystem services, including water purification, climate regulation through carbon sequestration, and protection against storm surges, thereby mitigating the impacts of climate change. Additionally, lagoons possess rich cultural legacies, deeply embedded in the history and traditions of local communities, fostering a sense of identity and heritage (Lopes and Videira, 2013; Newton *et al.*, 2018). Their unique biodiversity (Tonin, 2018), also makes them prime sites for ecotourism, attracting visitors interested in experiencing the natural beauty and diverse wildlife of these Mediterranean coastal landscapes (Newton *et al.*, 2018). However, despite their immense value, lagoons face significant vulnerability and threats, primarily from pollution caused by human activities, including industrialization, agriculture, and climate change, which profoundly affect water bodies. This susceptibility manifests by introducing various organic, inorganic, and nutrient pollutants (Newton *et al.*, 2018). Excessive amounts of pollutants, particularly nitrate and phosphate, can lead to the eutrophication of marine ecosystems (Elizabeth and Joy, 2018; Owa, 2013).

Globally, the adverse impacts of marine pollution and freshwater contamination on human health and their contribution to the loss of local sense of place and cultural identity have been extensively documented (Mechler *et al.*, 2019). For example, recent research by McNamara *et al.* (2021)and will continue to experience, extensive non-economic loss and damage (NELD investigated stakeholder perceptions of non-economic loss and damage in Pacific island contexts, aligning with prior studies and elucidating anticipated risks and impacts such as escalating temperatures, fish protein shortages, and substantial biodiversity threats. Consequently, ecological restoration is essential for preserving marine ecosystem services, fostering conservation efforts, and enhancing human welfare (Stainback *et al.*, 2020; Paramana *et al.*, 2023).

The body of literature highlights the necessity of lagoon restoration (Tuan *et al.*, 2014; Clara, 2018; Beharry-Borg and Scarpa, 2010; Smyth *et al.*, 2009; Eggert and Olsson, 2009; Beharry-Borg and Scarpa, 2010; Wang *et al.*, 2013; Newton *et al.*, 2018; Pacifico *et al.*, 2025) prompting policymakers to enact directives to protect ecological well-being, animal welfare, and water standards by aiming for sustainability. However, restoration has financial costs to society. While pollution is a pressing issue in developing and developed countries, its significance is particularly pronounced in developing nations due to the wide use of unsustainable industrial waste management systems. Tunisia is a pertinent example of a developing country grappling with pollution challenges.

Croitoru and Sarraf (2010) documented the order of magnitude of marine pollution externalities in Tunisia. They conducted a study to measure the cost of water degradation in Tunisia due to inappropriate agricultural practices, transport, industry, and power generation. The estimated total cost was approximately $165.8 million[1] in 2004.

At a regional level, Bizerte Lagoon, located in northern Tunisia, represents one of the most productive marine ecosystems. It contributes to the country's GDP through fishery products,[2]

[1] 0.6% of the GDP in 2004 (INSTM, 2004).

[2] The total annual fishery production in 2020 was 62417 kg ≅ 62 tons (INSTM, 2020).

aquaculture, shellfish farming, and industrial activities. However, the region is suffering the consequences of misusing the lagoon. Untreated water sewage, lack of treatment plants, wastewater discharges, and gas emissions from factories installed around the lagoon represent the major causes of environmental degradation, making the lagoon unsuitable for reaction activities and commercial fishing. Moreover, the fish and seafood caught in the lagoon are unsafe for human consumption (El Zrelli *et al.*, 2021).

Because of these concerns, the EcoPact[3] project was implemented to enhance the socioeconomic and environmental situation in the Bizerte Lagoon. In particular, the project aimed at (1) reducing industrial pollution (i.e., atmospheric emission, liquid effluents, solid waste, and wastewater collection and treatment), (2) extending the artisanal port[4] of Manzel Abderrahmèn to reduce exposure to storms and increase its boat accommodation capacity, and (3) developing an esplanade to the east of Manzel Abderrahmèn port to improve the lagoon frontage of the region. Throughout an initial 5-year period, the project plans to significantly reduce indirect pollution impacting the Mediterranean Sea through an integrated and concerted approach.

The existing literature indicates that citizens in developed countries are generally willing to pay for ecosystem restoration (Anaya-Romero *et al.*, 2016; Birol *et al.*, 2006; Blasi *et al.*, 2023; Martínez-Paz *et al.*, 2013; Perni *et al.*, 2011; Xu *et al.*, 2020). This study contributes to the limited body of research on estimating the economic values of lagoons in developing countries (Ahmed *et al.*, 2005; Ali *et al.*, 2014; Diop *et al.*, 2016; Ghermandi & Nunes, 2013; Kairo *et al.*, 2008; Lal *et al.*, 2024; Rönnbäck *et al.*, 2007). It aims to enhance our understanding of how local communities perceive and prioritize various ecosystem attributes. Focusing on Tunisia, this study expands the geographic scope of discrete choice experiment (DCE) applications in environmental valuation, an area that remains underexplored in North Africa. It is the first lagoon valuation study conducted in Tunisia. It provides insights into the trade-offs people are willing to make for improved lagoon management, better water quality, and biodiversity conservation.

To our knowledge, no previous study has evaluated the benefits of restoring lagoons in Tunisia, particularly in Bizerte. This gap can be attributed to two main factors: first, there is a lack of economic information on lagoon restoration; second, few valuation studies have assessed the benefits or non-use values of lagoon restoration, especially in developing countries.

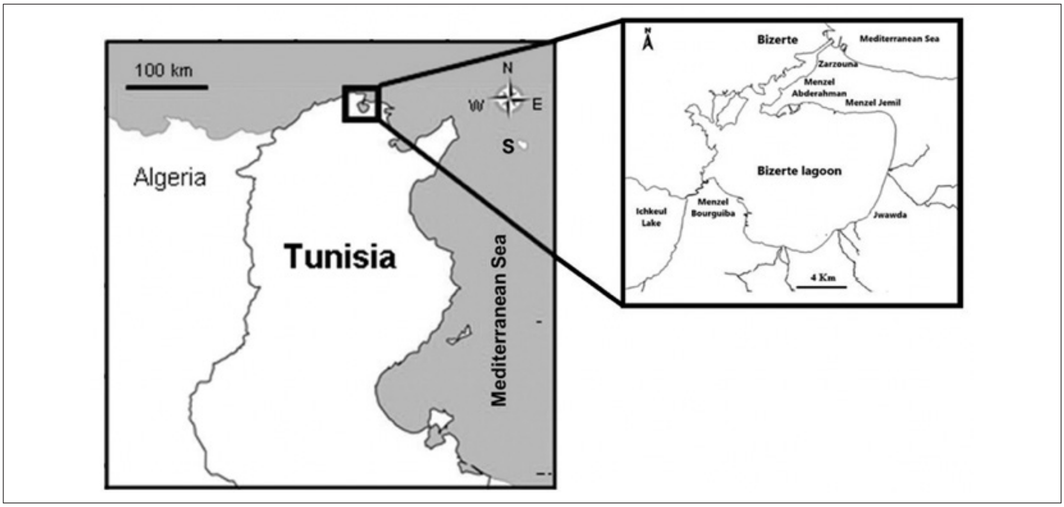
Additionally, using traffic light indicators as a communication tool enhances accessibility for non-expert respondents, ensuring that valuation outcomes reflect broader societal preferences. This study examines preference heterogeneity, offering deeper insights into variations in public attitudes toward lagoon conservation. These findings are particularly relevant for policymakers in developing countries, where financial and institutional constraints often limit effective environmental management. They highlight the support of Bizerte citizens for lagoon restoration, providing concrete evidence of the project's feasibility. The insights gained can help secure further backing and ensure a thorough evaluation of the project's potential viability. By offering valuable support to policymakers and illuminating social demand in Tunisia, this study may also guide future investments from international organizations, such as the Food and Agriculture Organization (FAO) and the World Bank (WB), fostering opportunities for development and investment in Tunisia.

The article is structured as follows. The next section overviews the Bizerte Lagoon, followed by a description of the design and the survey's conduction. Subsequently, the results are presented in Section 3, while the discussion and conclusions are offered in Section 4.

[3] Details of the project are available at http://ecopact.tn.

[4] The port is situated inside the Bizerte lagoon, approximately 5 km from Manzel Jemil and 4 km from Bizerte.

Figure 1 - Bizerte Lagoon, Main Industrial Agglomeration.



Source: Nasri et al. (2022).

2. Methods

2.1. *Study Area*

The Bizerte Lagoon is located on the northern coast of Tunisia. It has an area of 150 km² and an average depth of 7 m (Figure 1). The lagoon is connected to the Mediterranean Sea by a 7-km-long channel and Lake Ichkeul by the Tinja River, which supplies it with irregular fresh water. According to the National Institute of Statistics (INS,[5] 2023) census, approximately 300,000[6] people live around it (90% are in the city of Bizerte).

Bizerte is recognized for its industrial heritage, tourism, agriculture, fishing, and a significant commercial port, supported by free trade zones that encourage investment with tax exemptions (Ministry of Environment[7], 2016). The city is home to around 274 industrial companies, including 172 exporters, with 33.6% in textiles.

The region's agriculture produces 67,280 tons of fodder, 238,409 tons of cereals, and significant quantities of market gardening products, red meat, milk, white meat, and eggs. Additionally, it generates 6,229 tons of fishery products from five ports and 1,280 fishing fleets (Tunisian National Institute of Statistics[8], 2015).

The lagoon has an urbanized and industrialized shoreline. Moreover, it features 10 industrial zones spanning 250 hectares, with notable industrial activities are readily present, including heavy industries like SOTULUB and Bizerte Cement Factories employing over 45,858 people (located in the vicinity of Bizerte), dye works, and metallurgy (located in Menzel Jemil), making it one of the most threatened lagoons in Tunisia (Alves Martins *et al.*, 2015).

The Bizerte Lagoon has been used as the principal dumping place for water discharge directly or after primary treatment for several decades. However, it does not meet the standards set by the central government for used water treatment. The three wastewater treatment plants built in 1997 to treat the water before being dumped in the lagoon have decayed. Previous studies conducted in Bizerte (Barhoumi, 2014; Boukef *et*

[5] For more information, see: https://www.ins.tn/sites/default/files/publication/pdf/Estimation%20de%20%20la%20population%201er%20Janvier%202023.pdf.

[6] Represents approximately 187,000 in Bizerte center, almost 66,000 in Manzel Bourguiba, 31,000 in Manzel Jmil, and 21,000 in Manzel Abderrahmen. The total population of Bizerte was 600,012 inhabitants in 2023.

[7] https://www.ins.tn/en/statistiques/45.

[8] https://www.ins.tn/en/statistiques/45.

al., 2010; Toumi *et al.*, 2019) showed that the level of water treatment is low and the quality of treated water is non-compliant with discharge standards, particularly in terms of the levels of nitrate, phosphorus, polycyclic aromatic hydrocarbons, and heavy metals. These pollutants can be present in the atmosphere or the soil or especially dissolved in aquatic environments that are much more contaminated than others (Barhoumi, 2014). Moreover, the city of Bizerte has experienced atmospheric pollution due to industrial emissions in the region (Barhoumi, 2014), along with human population growth around the lagoon and maritime traffic that have increased wastewater discharge into the lagoon.

The lagoon is historically known for artisanal fishing activities, aquaculture, and, specifically, shellfish farming. The production from shellfish farming in the lagoon has decreased for over a decade (General Direction of Fishery Products and Aquaculture [DGPA] 2018) due to the rise in water temperature and the decrease in the level of dissolved O_2 (Bousbih[9], 2015).

2.2. *Data Collection: Choice Experiment-Based Survey*

This study used a DCE to investigate citizens' valuation of the benefits and the costs of restoration plans that EcoPact is considering implementing in the Bizerte Lagoon. A DCE is a quantitative research technique that presents individuals with alternative scenarios and asks them to state their preferred scenario (Hensher *et al.*, 2015). Several attribute levels describe each alternative scenario. Individuals' responses are then used to determine whether their preferences are significantly influenced by the attribute levels considered in the DCE. The responses are also used to determine the relative importance of the attributes. Individuals' WTP for the attribute levels of the alternative scenarios can also be estimated if a monetary attribute (e.g., the price or cost of each alternative) is considered in the choice experiment.

An initial and exhaustive list of attributes was prepared based on an extensive literature review on economic values of lagoons and wetlands (Hanley *et al.*, 1998; Brouwer *et al.*, 1999; Brander and Schuyt, 2004; Birol *et al.*, 2006; Christie *et al.*, 2006; Campbell *et al.*, 2008; Meyerhoff *et al*., 2009; Barhoumi, 2014; Dang *et al*., 2022; Pacifico *et al.*, 2024, 2025) to identify the most relevant attributes to consider in the choice experiment. The literature-based list of attributes and their levels was then refined using three focus groups (totaling 30 persons) of residents, experts, and scientists where the main objective is scoring the most relevant attributes according to the context, the urgent public intervention, and local priorities. This attribute selection and refinement process by focus groups is crucial for our choice experiment design, as it ensures that the attributes chosen are both relevant to the specific wetland or lagoon context and meaningful to the local population. Moreover, this participatory approach also helps to capture any unique local factors that might not be apparent from the literature review alone.

The attributes typically considered in such studies include environmental factors such as biodiversity and water quality and socio-economic aspects like fisheries production and recreational opportunities (Birol *et al*., 2006; Tsegaw, 2012; Dixon *et al.*, 2021; Pacifico *et al.*, 2024).

After the focus group discussions, the attributes are typically scored and ranked based on their perceived importance and relevance. This process helps narrow the list to a manageable number of attributes for the choice experiment, usually between 4 to 6 attributes (Bliemer & Collins, 2016). The final selection of attributes considered in this study were water quality, biodiversity, recreational facilities, reduced gas emissions, and the cost of improvement which represent a one-payment cost to be voluntary paid. A description of the attributes and their corresponding levels is displayed in Table 1 below.

Water quality, biodiversity, reduced gas emissions, and recreational facilities were defined as categorical attributes with three levels each.

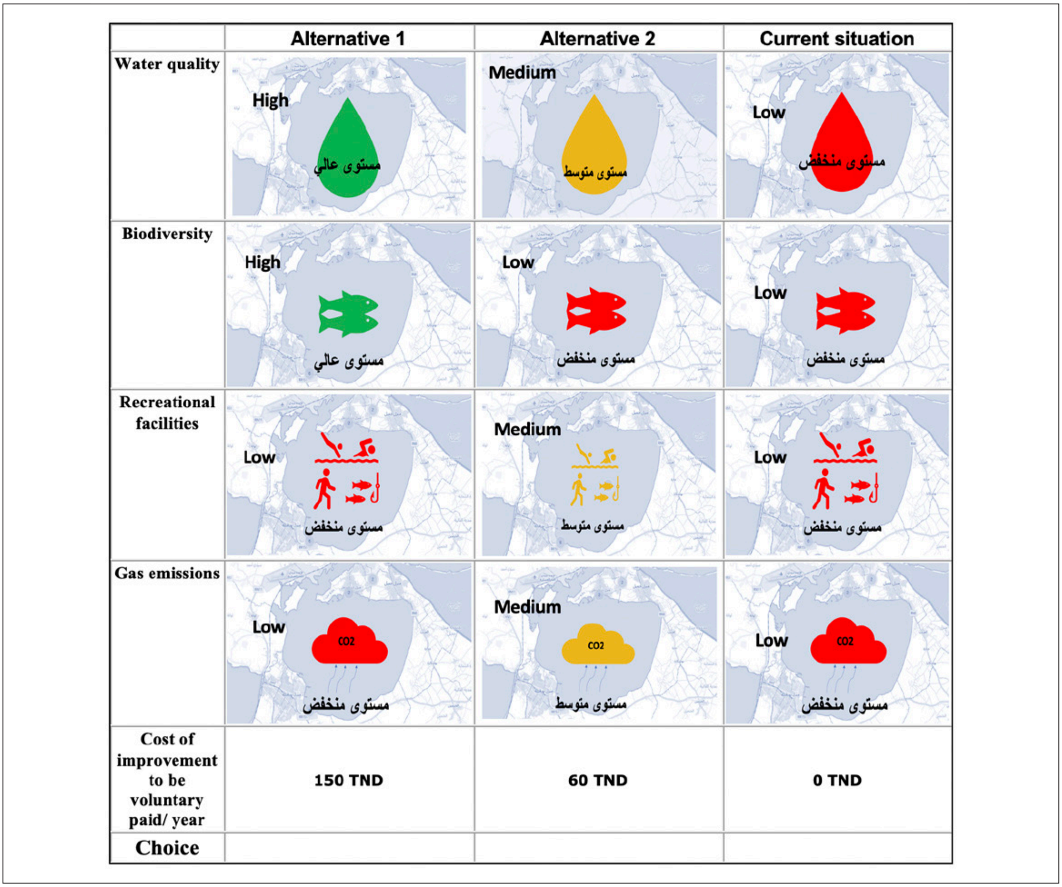
[9] Press at: https://inkyfada.com/fr/2015/07/27/bizerte-pollution-lac-peche-tunisie/.

Table 1 - Description of Attribute used in the DCE and Their Levels.

Attributes	*Attribute Levels*	*Variable Description in Model Estimation (Effect Coding)*
Water Quality	High (Green)	It refers to a high improvement level where water quality and clarity respond to the standards without a nasty smell and rehabilitated sanitation networks (1 = high water quality [green color], 0 otherwise).
	Medium (Amber)	It refers to a medium level of improvement where water quality, clarity, and smell improved compared to the current situation (1 = medium water quality [amber color], 0 otherwise).
	Low (Red)	It refers to poor water quality and clarity, with a nasty smell (–1 = low water quality [red color]).
Biodiversity	High (Green)	It refers to a high level of improvement where fauna (well-diversified species) and marine flora (nutritive algae) are diversified, valorisation of invasive species (1 = high biodiversity [green color], 0 otherwise).
	Medium (Amber)	It refers to a medium level of improvement where marine fauna and flora are more diversified compared to the current situation (1 = medium biodiversity level [amber color], 0 otherwise).
	Low (Red)	It refers to a situation where some species have disappeared while invasive species have appeared (–1 = low biodiversity [red color]).
Recreational Facilities	High (Green)	It refers to a high level of improvement where all activities are accessible (i.e., fishing, swimming, and walking) due to the development of the coastal infrastructure (1 = high recreational facilities [green color], 0 otherwise).
	Medium (Amber)	It refers to a medium improvement level where coastal infrastructure is moderately developed and at least one activity is possible (1 = medium recreational facilities [amber color], 0 otherwise).
	Low (Red)	It refers to a situation where the coastal infrastructure is not developed, and accessibility to activities is almost limited (–1 = low recreational facilities [red color]).
Decreased Gas Emissions	High (Green)	It refers to a high improvement level where air quality is good (filters installed), good visibility (i.e., almost clear emissions, decreased CO_2 emissions), and no smell (1 = high decreased gas emissions [green color], 0 otherwise).
	Medium (Amber)	It refers to a medium improvement level where average air quality (average CO_2 level in the atmosphere), average visibility (less gray emissions than before), and less smell compared to the current situation (1 = medium decreased gas emissions level [amber color], 0 otherwise).
	Low (Red)	It refers a situation with poor air quality is poor (significant CO_2 in the atmosphere does not meet discharge standards), poor visibility (gray emissions), and bad smell (–1 = low decreased gas emissions [red color]).
Voluntary Improvement Cost		TND[1] 0 (no payment), TND 30, TND 60, TND 90, TND 120 (40 EUR), TND 150 (continuous variable).

[1] *TND: Tunisian dinar.*

Figure 2 - Choice Example Cards.



Each was color-coded:[10] red for no improvement (i.e., the status quo), amber for moderate improvement, and green for high improvement. To further ease the understanding of the attribute levels and avoid confusion (Osman and Thornton, 2019), qualitative terms (i.e., low, medium, and high) were used to describe the traffic light color-coded levels (Fig. 2). Many studies supported the use of visual saliency instead of only including texts or values to avoid the hypothetical bias (Shr *et al.*, 2019; Delong *et al.*, 2021).

Respondents were invited to contribute voluntarily to support a five-year project through a one-time payment. We based our assumption on the belief that the improvement cost would be covered through voluntary payments. These contributions are likely more effective in Tunisia due to cultural norms and a social familiarity with charitable giving. Additionally, the proposed cost levels were informed by feedback from three focus groups, which helped refine the list of attributes considered for the questionnaire.

The combination of the five attributes and their levels resulted in 405 possible combinations (i.e., $3^{\wedge 4}$ * 5). Ngene software was used to generate a Bayesian D-optimal (i.e., fractional) design that allowed robust estimation of all main effects (ChoiceMetrics, 2018). The priors for the

[10] This study adopted the concept of visual saliency, where both images and text were presented to respondents. This approach aimed to mitigate hypothetical bias and prevent confusion by providing a clear and tangible representation of the attributes evaluated. Recent research by Netusil *et al.* (2023) and Shr *et al.* (2019) showed that the respondents strongly preferred attributes represented by both image and text.

fractional design were obtained from a pilot of 30 respondents. The final experimental design (D-error = 0.07) consisted of 18 choice cards, each comprising three alternatives – two pairs of hypothetical options of improvements and the status quo (SQ). The final design had three blocks (i.e., each respondent was presented with only six of 18 choice sets). An example of one of the choice example cards used in this study is shown in Figure 2.

The survey was designed with a structured approach, divided into four sections to ensure comprehensive data collection and accuracy. The first section introduced the study's framework, outlining its objectives and methodology while emphasizing the voluntary nature of participation. Participants were required to review and sign an informed consent form, which assured them of anonymity and clarified that the research had no commercial purposes. The second section focused on the choice task and began with a detailed explanation of the survey's context, objectives, and the importance of providing unbiased responses. To minimize hypothetical bias, reminders and "cheap talk" techniques were included. Respondents were then presented with randomly assigned choice cards, designed to enhance realism and reduce potential bias. Each choice question included three alternatives: two hypothetical improvement scenarios and a status quo (SQ) option. The first two alternatives were described using five key attributes detailed in Table 1, with variations across different choice questions, while the SQ option remained unchanged, reflecting the actual condition of the lagoon at the time of data collection. The final section gathered socioeconomic information from respondents to provide context for the findings.

The survey was conducted face-to-face in Bizerte between February and April 2023, engaging 371 citizens. However, 10 respondents were identified as zero protestors and were excluded from the final dataset based on the criteria[11] stated by De Jong *et al.* (2023) and Xu *et al.* (2020). As a result, the final data used in the analysis was based on the responses of 361 respondents.

2.3. *Econometric Modeling of DCE Data*

According to Hensher *et al.* (2015), the total utility derived by an individual n from choosing an alternative j is equal to the sum of two components, a deterministic component and an indeterministic component ε_{nj} assumed to be independent and identically distributed:

$$U_{jn} = V_{jn} + \varepsilon_{nj} \tag{1}$$

Assuming that the deterministic component of the utility is linear-in-parameter, equation (1) can be written as follows:

$$U_{njt} = \beta X_{njt} + \varepsilon_{njt} \tag{2}$$

where β denotes the K × 1 vector of unknown utility parameters and, X_{njt} represents the attribute levels.

Average respondents' preferences and WTP were estimated using the conditional logit model (CLM).

A Hausman test was performed to evaluate whether the IIA assumption holds; our test results indicated that this assumption does not hold, suggesting that the choices among alternatives are interdependent and necessitating alternative models that can account for this interdependence (See Table 2).

However, to investigate respondents' preferences and WTP heterogeneity[12] a latent class

[11] They choose the SQ in all the choice sets.

[12] The estimation of the Random Parameter Logit (RPL) model showed a non-significant price coefficient, likely due to the exponential function amplifying the standard deviation and leading to a low z-value. Using the "logitr" R package, we found that treating price as a random parameter complicated model convergence in willingness to pay (WTP) space. To assess the price parameter's impact, we tested several distributions, including normal and lognormal. We fixed the scale parameter and treated other parameters as normally distributed. However, assuming a constant price implies uniform sensitivity across individuals, which may bias WTP estimates by ignoring variations in price sensitivity.

model (LCM) was also estimated. In the LCM, respondents were grouped in a finite number of identifiable classes, allowing the respondents' preferences to be heterogeneous across classes but homogeneous within each class (Greene and Hensher, 2003; Sinha *et al.*, 2021).

In the LCM, the probability of individual *n* in class *c* choosing alternative *i* from a particular set of alternatives *J* was as follows:

$$P_{ns|c} = \frac{\exp(\beta'_c X n_i)}{\sum_{j=1}^{J} \exp(\beta'_c X n_{nj})} \quad (3)$$

where βs is the parameter vector of class *s* associated with the vector of explanatory choice attributes X_{ni}. Additionally, the analyst considered a classification model as a function of some individual-specific characteristics to determine the allocation of individuals to the *c* classes.

According to Greene and Hensher (2003), the probability that an individual *n* belongs to latent class *c* is given by

$$P_{n\in c} = \frac{\exp(\theta'_c Z_n)}{\sum_{C=1}^{C} \exp(\theta'_c Z_n)} \quad (4)$$

where z_{in} is the vector of respondents' socioeconomic characteristics, and θ is a set of parameters to be estimated. Moreover, the log-likelihood of the LCM can be expressed as follows:

$$\ln L = \sum_{n=1}^{N} \ln\left[\sum_{c=1}^{c} P_{n\in c}\left(\prod_{s=1}^{n} P_{ns/c}(j)\right)\right] \quad (5)$$

The WTP of an individual *n* who belongs to a latent class *c* for a given attribute *A* can be computed by dividing the estimated parameter ($\widehat{\beta_{A/c}}$) for *A* by the coefficient of the monetary attribute "Price" ($\widehat{\beta_{p/c}}$):

$$WTP = -2\left(\frac{\widehat{\beta_{A/c}}}{\widehat{\beta_{p/c}}}\right) \quad (6)$$

The ratio of the parameters is multiplied by 2 because all the non-price attributes are effect-coded (Rahmani & Loureiro, 2019).

Previous studies (Boxall *et al.*, 2002; Rahmani & Loureiro, 2019; Schaak *et al.*, 2020; Weller *et al.*, 2020) have used several criteria to guide the selection of the number of classes, but no consensus exists about the best criteria. The selection process used in this study considered multiple metrics, including the Akaike information criterion (AIC), the Bayesian information criterion (BIC), and the share of respondents in each class. Furthermore, the results' theoretical interpretability should be considered when choosing a solution. This study estimated LCM models with two, three, and four classes, while the LCM model with five classes did not converge. Therefore, we chose to present and discuss the results from the two-class LCM because, even though the three-class and four-class models had the lowest BIC values, all parameters for one of the classes in the latter two models were insignificant and had high standard errors, which made the computation of the WTP impossible (see Table 3).

Table 2 - Hausman Test to Test for IIA Assumption.

Hausman Test of Independence of Irrelevant Alternatives for sample			
Dropped Alternatives	X^2	*Degree of freedom*	*Probability*
Alternative 1	66.19	10	0.00
Alternative 2	48.31	10	0.00
Alternative 3 (SQ)	ND[1]	10	Could not carry out Hausman test for the IIA

[1] *Undefined.*

Table 3 - Metrics on the converged latent segment model.

Number of Classes	*Pseudo R-squared*[1]	*AIC*	*BIC*[2]
2	*0.43*	*2725.2*	*2862.1*
3	0.47	2584.6	2800.5
4	0.49	2506.4	2801.8

[1] *PseudoMcFadden R-square for both RPL models is >= 0.40. According to Bu* et al. *(2006) and McFadden (1973), in logistic regression, where the outcome variable is categorical, the Pseudo R-squared values help evaluate the proportion of variance explained by the model. They range from 0 to 1, with higher values indicating a better fit. A value of 0.2 to > 0.4 is generally considered a good fit for logistic regression models.*
[2] *BIC is calculated using the likelihood function of the model and penalizes models for having more parameters, thus favoring simpler models that explain the data well (De Jong* et al.*, 2023). AIC and BIC are always lower for higher number of classes.*

The final utility equation is presented as follows:

$$U_{in} = ASC_{SQ} + \beta_{1in} * \text{Biodiversity} + \beta_{2in} * \text{Recreational facilities} + \beta_{3in} * \text{Water Quality} + \beta_{4in} * \text{Gas emissions} + \beta_{5in} * \text{Cost} \quad (7)$$

where i = 1, 2, 3[13] for the three scenario alternatives, and n refers to the individual.

3. Results

3.1. *Respondents' Characteristics*

In Table 4 we show the comparison between the sample and population characteristics, revealing that the sample is representative of the Bizerte general population in terms of gender, secondary education[14] level and population aged >60. Approximately 60% of respondents have a monthly income of less than 1,500 Tunisian dinars (approximately less than USD 400[15]), which is considered low according to the National Institute of Statistics (INS, 2023).

3.2. *LCM Results*

Results from the LCM's estimation are displayed in Table 5. The LCM model splits respondent into two groups with distinct preferences based on their attitudes toward the status quo. Both groups support the lagoon's environmental restoration, but Class 1 prefers change (indicated by a negative sign), valuing the project's attributes and additional unmentioned benefits. In contrast, Class 2 supports the attributes while still favoring the status quo for other reasons.

Class 1, comprising 84.5% of respondents, strongly endorsed a restoration of the Bizerte Lagoon with a tangible improvement in water quality, the availability of recreation facilities, biodiversity, and a significant reduction in gas emissions from the factories near the Bizerte lagoon. This endorsement was evidenced by the negative and significant value of the preferences for the SQ, suggesting an inclination among members of this class to move away from the current situation. The results showed that Class 1 members preferred the restoration alternatives that provided a high level of improvement in all non-monetary attributes. Moderate improvement

Table 4 - Respondents' socioeconomic Characteristics.

Bizerte					
	Sample		*Population*		*p-value*
Female	184	0.51	298,200	0.50	<u>*0.63*</u>
Male	178	0.49	301,800	0.50	<u>*0.7*</u>
Age > 60	29	0.08	70,340	0.12	<u>*0.012*</u>
Age 18–59	333	0.92	319,260	0.53	*<0.01*
Primary educational level	147	0.40	187,512	0.33	*<0.01*
Secondary Studies Level	179	0.49	297,690	0.49	<u>*0.34*</u>
High educational level	23	0.06	68,186	0.12	*<0.01*
Income	361	1397.36[1] [mean] (SD = 867.88)	433,286[2]	< 1500[3] (400 $)	-

[1] 1397.36 TND = 450.76 $. [2] Active population in Bizerte. [3] According to the INS.

[13] It refers to the status quo (current situation).

[14] Some of the respondents did not declare their educational level.

[15] Where the average of personal annual expenditure estimated 5468 TND per year (1760$) without rent. a family of four estimated monthly costs are 7040$ according to the Tunisian National Institute of Statistics (March, 2021 and the average number persons per households is 5) https://www.ins.tn/en/statistiques/104.

Table 5 - Respondents' Estimated Preferences from the CLM and LCM.

	Conditional Logit Model		Latent Class Model			
Parameters	*All Respondents*		*Class 1*		*Class 2*	
Status Quo	-1.781 [(-1.931) _ (-1.631)]	***	-2.786 [(-3.006) _ (-2.566)]	***	1.548 [0.495_2.601]	***
Biodiversity Improvement						
Medium	0.309 [0.205__0.414]	***	0.277 [0.156_0.399]	***	0.128 [(-0.436) _0.693]	
High	0.388 [0.270_0.506]	***	0.644 [0.490_0.798]	***	0.598 [(-0.036) _1.232]	*
Recreation Improvement						
Medium	0.027 [-0.082_0.136]		0.100 [(-0.02) _0.228]		0.483 [(-0.116) _1.083]	
High	0.580 [0.473_0.686]	***	0.671 [0.538_0.805]	***	1.038 [0.423_1.654]	***
Water Quality						
Medium	0.219 [0.110_0.327]	***	0.227 [0.100_0.355]	***	0.935 [0.351_1.520]	***
High	0.736 [0.631_0.841]	***	0.984 [0.849_1.118]	***	0.756 [(-1.650) _0.137]	*
Gas Emission Reduction						
Medium	0.337 [0.229_0.446]	***	0.284 [0.156_0.411]	***	0.614 [(-0.317) _1.546]	
High	0.732 [0.623_0.841]	***	1.027 [0.874_1.180]	***	1.363 [0.585_2.142]	***
Cost of improvement	-0.020 [(-0.022) _ (-0.019)]	***	-0.023 [(-0.024) _ (-0.021)]	***	-0.026 [(-0.039) _(-0.013)]	***
Class Assignment Parameter						
Constant	NA		1.113 [0.534_1.691]	***	-	Fixed parameter
Gender: Female	NA		0.832 [0.052_1.613]	**	-	Fixed parameter
Age: Young adults	NA		0.951 [0.150_1.752]	**	-	Fixed parameter
Education: Primary	NA		-1.274 [(-2.20) _ (-0.342)]	***	-	Fixed parameter
Log-likelihood value	-1,599.3		-1,338.5			
Class share	100%		84.5%		15.5%	

****, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.*

[1] The values in brackets represent the confidence intervals of the estimated coefficients.

in biodiversity and water quality and a moderate reduction of gas emissions were also positively valued but much less than high improvement. This class was labeled "Pro-restoration."

Class 2 comprised 15.5% of respondents and exhibits a significant and positive preference for the high level of the attributes (save for water quality). However, the positive and significant coefficient for the status quo suggests that the members of this class prefer the current situation over a restoration for other reasons not explained by the attributes (to be discussed in the discussion part). Therefore, this class was labeled "Reluctant to Restore." The results also showed that Class 2 members were willing to support a restoration of the lagoon, especially if it resulted in highly improved biodiversity, water quality, and recreation facilities, with a high reduction in gas emissions.

Table 6 - WTP[1] of Bizerte Citizens for Lagoon Restoration in TND.

Parameters TND [Confidence Interval]	*Class 1: Pro-restoration (84.5%)*	*Class 2: Reluctant to Restore (15.5%)*	*Weighted Average[2]*
Biodiversity_Medium	24.07 (8.02) *** [13.55_34.59]	9.84 (3.28) [-33.13_52.82]	21.86 (6.83) *** [10.94_32.78]
Biodiversity_High	55.82 (18.60) *** [42.54_69.10]	45.75 (15.25) [-10.23_101.74]	54.26 (16.95) *** [40.06_68.46]
REC_Medium	8.68 [-2.36_19.73]	36.99 [-10.05_84.04]	13. 07 (4.08) [1.27_24.87]
REC_High	58.20 (19.40) *** [46.78_69.62]	79.46 (26.48) *** [31.21_127.70]	61.49 (19.21) *** [49.56_73.43]
WQ_Meduim	19.74 (6.58) *** [8.69_30.79]	71.58 (23.86) *** [19.42_123.74]	27.78 (8.68) *** [15.38_40.17]
WQ_High	85.26 (28.42) *** [73.94_96.58]	-57.86 [-132.93_17.20]	63.08 (19.71) *** [47.72_78.43]
GAS_Medium Reduction	24.60 (8.20) *** [13.49_35.71]	47.00 (15.66) * [-34.07_128.08]	28.07 (8.86) *** [12.84_43.30]
GAS_High Reduction	89.01 (29.67) *** [75.61_102.40]	104.31 (34.77) *** [37.52_171.10]	91.38 (28.55) *** [76.20_106.55]
Total WTP_High[3]	529.70 (165.58) *** [488.70_570.69]	53.20 [-45.86_152.27]	455.84 (142.45) [421.61_499.60]
Total WTP_Medium[4]	318.50 (99.53) *** [292.26_344.73]	46.96 [-18.42_112.34]	276.41 (86.37) [79.42_95.03]

****, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.*

[1] The values in parenthesis represent the converted value from TND to dollar while the values in brackets represent the confidence intervals of the estimated coefficients.

*[2] Weighted WTP average for an attribute level = (WTP of the concerned significant attribute level of Class 1 * 0.845 + WTP of the concerned significant attribute level of Class 2 * 0.155).*

[3] Corresponding to WTP for high levels of restoration, adding the ASC.

[4] Corresponding to WTP for medium levels of restoration, adding the ASC.

Interestingly, both classes exhibit similar sensitivity to the attribute cost, with values of (-0.023) and (-0.026). This suggests that differences in Willingness to Pay (WTP) are likely due to variations in preferences for non-monetary attributes and other factors not included in the model. In other words, respondents may favor the project because they anticipate benefits not explicitly mentioned among the attributes (Class 1), or they may recognize the value of the project's attributes but still prefer to maintain the current situation for other reasons (Class 2).

The WTP results (Table 6) further confirmed the findings. All WTP values were originally calculated in TND and subsequently converted to USD[16].The results show that members of Class 1 are willing to pay between TND 318.50 ($99.53) and TND 529.70 ($165.58) per year for respectively medium and high-impact scenarios. In contrast, members of Class 2 are unwilling to pay for both scenarios, with insignificant WTP for both medium and high-impact scenarios. To represent a representative average willingness to pay for both classes, a weighted average of WTP was calculated by combining their willingness to pay values with their respective frequencies or weights. The weighted average WTP for the high-impact scenario is TND 455.58 ($142.45) per year, while for the medium-impact scenario, it is TND 276.41 ($86.37) per year (see Table 4).

Regarding the profile of each class member, the results in Table 3 show that Class 1 members were more likely to be female and young respondents with higher education than those in

[16] 1 USD = 3.2 TND (current conversion, up to October 2024).

Table 7 - Total present Benefits values per Bizerte's Active Population.

	Class 1 (84.5%)		*Class 2 (15.5%)*		*Weighted*	
Active Population (No. of Citizens)	*Medium impact scenario (WTP/ Citizen)*	*High impact scenario (WTP/ Citizen)*	*Medium impact scenario (WTP/ Citizen)*	*High impact scenario (WTP/ Citizen)*	*Medium impact scenario (WTP/ Citizen)*	*High impact scenario (WTP/ Citizen)*
433,289[1]	318.50 ($99.53)	529.70 ($165.58)	NS	NS	276.41 ($86.37)	455.84 ($142.45)
WTP of Active Population per Year TND (USD)	138 million ($43.13 million)	229.5 million ($71.74 million)	NS	NS	119.7 million ($37.42 million)	197.5 million ($61.72 million)
NS: Insignificant						

[1] *See https://www.ins.tn/en/statistiques/111.*

Class 2. This finding was in line with previous studies on the profiles of sustainability-minded individuals. For instance, Plavsic (2013) and Ramstetter and Habersack (2020) found that female respondents were more likely to have pro-environmental attitudes and were more inclined to support "green" actions compared to male respondents. Meyer (2015) and Tianyu and Meng (2020) found that the surveyed adults' educational levels correlated with a greater awareness and understanding of environment-related issues and the importance of conservation efforts. Hence, individuals with higher education levels may have a deeper understanding of the benefits of project restoration and its impact on the environment, leading to a higher willingness to contribute financially. Elahi *et al.* (2022) found that young adults exhibited higher pro-environmental attitudes than older respondents.

This study serves, also, as a crucial opportunity to assess the economic viability of the Eco-Pact project by conducting a viability[17] analysis (Table 6)[18]. A comprehensive viability analysis allowed us to scrutinize the project's potential by comparing its costs to expected benefits (Birol *et al.*, 2006). The total cost of providing the project implementation is estimated at $67 million, equivalent to TND 214.74[19] million.

The weighted average WTP between the two classes was determined, as mentioned before, to allow for a comparison between the costs and expected benefits. Benefits were estimated by multiplying the weighted average WTP per Bizerte active population (433,286[20] active[21] inhabitants). Based on Table 7, Bizerte's active population's willingness to pay (WTP) was analyzed across different impact scenarios. For Class 1, which represents 84.5% of the population, the medium impact scenario results in a total WTP of $43.13 million per year, while the high impact scenario results in $71.74 million per year. In contrast, Class 2 (15.5% of the population) does not show significant WTP in either scenario. Considering the weighted average of both classes, the medium impact scenario produces a WTP of USD 37.42 million, and the high impact scenario produces USD 61.72 million per year.

In the high-impact scenario, the weighted

[17] The goal was to compare costs and estimated benefits to ensure the project can realistically achieve its objectives within the given constraints and conditions. With a viability analysis, decision-makers can make informed judgments about whether to modify the project.

[18] Bizerte statistics are available on Tunisian National Institute of Statistics (https://www.ins.tn/en/statistiques/111).

[19] According to 2025 current currency.

[20] We assume that only the population of Bizerte will benefit from the restoration. We are aware that Bizerte has many visitors during summer who can certainly contribute to the pollution while also benefiting from the restoration, so they also should pay. However, no statistics on the number of visitors was identified.

[21] According to the INS, active population refers to all the adults who work and pay taxes.

WTP (USD 61.72 million) is very close to the required project cost of USD 67 million.

As all study, this has also some limitations that must be considered when interpreting results. While we obtained positive WTP results, this exercise might have only captured some of the benefits stemming from lagoon restoration. Therefore, the voluntary nature of the payment commitment could lead individuals to show higher support or generosity, potentially inflating the WTP valuations. Moreover, free-rider engagements could further impact the accuracy of the estimations. Therefore, it is prudent to approach these estimations cautiously and adopt a conservative perspective. A sensitivity analysis for the viability study should consider both present and future values for a more realistic assessment to ensure its replicability.

3.3. *Discussion and Conclusions*

The study provides valuable insights into the heterogeneity of Bizerte residents' willingness to support the restoration of the Bizerte Lagoon and bear the expected cost (i.e., WTP). Two classes with distinct preferences were identified: "Pro-restoration" and "Reluctant to Restore," which underscores an interesting point. Both classes appreciated the presented attributes.

However, respondents in Class 1 are drawn to the project because they support both lagoon's environmental restoration and other benefits that are not explicitly included in the attributes. In contrast, respondents from Class 2 recognize the value of the project's attributes, as evidenced by their significant WTP for high-level attributes (e.g., TND 79.46 ($26) for REC_High and TND 104.31 ($34) for Gas_High reduction). Yet, they still prefer to maintain the SQ for other reasons, resulting in an insignificant WTP for the overall high or medium scenario.

The study presents also a contribution in a way that the the constant ASC_SQ emerged as the greatest contributor to the TEV. Moreover, it is a key driver of the high WTP observed in Class 1. Including ASC_SQ significantly elevates the value of WTP, indicating a strong desire to move from the status quo. In contrast, in Class 2, the influence of ASC_SQ, which must be deducted from the utility of the other attributes, on WTP significantly results in insignificant WTP values in both high and medium scenarios. In other words, while Class 2 respondents appreciate the benefits of the project's attributes, they are ultimately unwilling to pay for the overall high or medium-impact scenarios, likely due to factors not explicitly captured in the model. This suggests that their preferences are influenced by a combination of the project's attributes and other unobserved considerations. This may be because, despite they value the project they prefer to allocate additional resources to other priorities such as education and food, which are perceived as pathways to increasing their income, as observed by Whittington (2010). In a way that understanding citizens' social commitment and priorities is crucial when assessing ecosystem services, as it directly influences the effectiveness and sustainability of conservation efforts.

Despite facing economic challenges exacerbated by the global financial crisis, the sampling citizens' commitment to environmental conservation highlights the sense of shared purpose and collective action. This high WTP may be explained in several ways. First, the strong association between citizens and the lagoon produces a reasonable answer about both the expected WTP of Bizerte citizens. A recent study by Missaoui *et al.* (2023) revealed that in the context of the Bizerte Lagoon, fishermen are eager to contribute to its restoration to safeguard the cultural legacies of their port. Second, the level of awareness about environmental issues can significantly impact the citizens' willingness to contribute to the restoration of the lagoon, mainly when the lagoon plays a vital role in their livelihoods, such as fishermen and owners of tourist-related businesses. As part of the survey, a question was included to gauge respondents' awareness of the threats to the lagoon and their causes and consequences. The results revealed that 89% of respondents from Bizerte were aware of the irreplaceable nature of the lagoon within Tunisia's arid ecosystem, where water bodies are scarce and precious. The lagoon's ecological functions are not easily replicable by artificial means, making its preservation vital for environmental sustainability. This finding aligns with a study conducted by Nahar *et al.*

(2023) in Dhaka, Bangladesh, which emphasized that respondents with high environmental awareness exhibited a greater understanding of environmental laws and regulations, indicating a positive relationship between awareness and environmental concerns. Third, this finding may also be justified by the importance that respondents assign to recreational facilities where citizens are willing to contribute TND 58.20 ($19.40) (Class 1) to TND 79.46 ($26.48) (Class 2) for a high-impact scenario, representing the most preferred attribute. Hence, enhancing coastal infrastructure could serve as an asset for the citizens of Bizerte by allowing them to reclaim the values and activities they have lost due to pollution over time. Reviving activities such as swimming, artisanal fishing, and walking through improved coastal infrastructure would enhance the residents' quality of life while helping restore cultural and recreational practices that hold significance for the community. Moreover, the study highlighted the importance that citizens assigned to reducing gas emissions. They were willing to pay TND 89.01 ($29.67) (Class 1) to TND 104.31 ($34.77) (Class 2) to reduce the maximum of gas emissions.

The WTP results for Class 1, where members were willing to pay up to TND 55.82 ($18) to enhance biodiversity, align with comparative WTP analysis results from similar studies (Owuor *et al.*, 2019; Chen & Ting Cho, 2019) where citizens were willing to pay TND 73.6 ($23) to improve biodiversity. However, the findings regarding biodiversity in Class 2 were unexpected and differed from the existing literature. Specifically, biodiversity was not deemed important at the medium and high levels. People may be more focused on short-term, tangible results that they can see and touch immediately (O'Donoghue and Rabin 2000). Furthermore, drawing from López *et al.* (2007), non-economic motives for biodiversity WTP, such as familiarity and biophilia, may play a significant role. Individuals may be less inclined to contribute to biodiversity conservation efforts if they lack a personal connection or appreciation for nature. Thus, it may reflect how to increase in biodiversity awareness among citizens.

Results from the viability study, in the present value, suggest that voluntary payments could almost fully fund the project, assuming the population perceives a high benefit from the intervention, suggesting that the EcoPact project is almost viable only if the improvement is highly significant, which may be because respondents are willing to pay much more for the high-improvement scenario since it entails more substantial changes and interventions than the medium-improvement scenario. These interventions will likely result in more significant environmental, social, and economic benefits, such as improved water quality, enhanced biodiversity, and increased recreational opportunities.

The difference between the medium and high-impact scenarios is significant. For the medium impact scenario, the weighted WTP is only USD 37.42 million, far below the project cost. This highlights the sensitivity of the population to contribute based on their perception of the benefits. Suppose the perceived impact of the project is low or moderate. In that case, the funding gap will be much larger, affecting the project's viability or requiring additional funding sources such as government subsidies. Otherwise, governmental efforts will be needed to reduce project implementation costs and cover the required average investment and operational expenses so that aggregated WTP for medium level can cover the costs because medium improvements are more attainable and less costly than a high-impact scenario. Consequently, the medium-impact scenario may not recover its total costs without a government subsidy.

The article adds to the existing literature by providing new insights into the increasing public concern over the degradation of the Bizerte Lagoon's ecosystem, indicating a social demand for restoration. The results emphasize the substantial net benefits derived from both ecological and social aspects of restoring the Bizerte Lagoon in a way that by providing the economic values of ecosystem services, this study can serve as a baseline that policy-makers are based on to conduct the benefit transfer method and assess the TEV or precisely ecosystem services values in other similar locations. It can serve also as an input to assess the ongoing projects or research aiming to set best management for marine ecosystems such lagoons.

Successful implementation relies on harmonious collaboration between institutions and effective government involvement.

Research indicates that individuals place significant value on public goods and often demonstrate a willingness to contribute financially to their preservation. This finding suggests a strong potential for community support for public policies aimed at the conservation or restoration of natural spaces that provide essential ecosystem services. Moreover, citizens can play a pivotal role in financing these initiatives, which addresses a major challenge – financial constraints – often encountered in the implementation of public policies. These insights can be instrumental in designing effective programs; by ensuring they achieve a meaningful impact; we can enhance public support and engagement. For public authorities aiming to promote the protection of public goods, such as lagoons, it is crucial to understand how to effectively engage different segments of the population. Tailoring approaches for Class 1 and Class 2 citizens will be key to raising awareness and fostering a collaborative environment for conservation efforts. In this way, policies should emphasize the organization of campaigns to effectively raise awareness about environmental issues among older individuals using spoken local dialects to ensure accessibility and the ability to understand the technical terms for those with limited literacy skills and strengthen collaboration with non-governmental organizations to facilitate information-sharing and dissemination of environmental knowledge, as emphasized through the results obtained from Class 2. It is also crucial to maintain a solid foundation in environmental education for young students to ensure similar results in WTP for Class 1 and to achieve better outcomes for Class 2. Disseminating environmental education in schools can also be a solution. Furthermore, by teaching kids the environmental importance of the lagoon, they can grow up with greater awareness, which will make it easier to influence their behavior positively when they become adults. Tunisian government must supplement existing environmental legislation with regular monitoring of wastewater treatment plants and gas filtration to ensure that factories surrounding the lagoon comply with standard norms. Deviations from these norms must be met with appropriate penalties to deter non-compliance.

In conclusion, this enchanting lagoon holds immense significance not just for the residents of Bizerte but for the entire Mediterranean region. Its intricate connection to the sea underscores the importance of its restoration; by rejuvenating this vital ecosystem, we actively contribute to the preservation of the Mediterranean – a lifeblood for countless communities surrounding its shores. "This lagoon is more than a body of water; it is a sanctuary of ecological diversity and a source of cultural heritage, deeply intertwined with the lives of those who inhabit this beautiful coastal landscape".

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Suitability and tendencies of small-scale agricultural producers toward e-commerce: An in-depth interview study for evidence from a developing country

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Abstract

This study focuses on identifying the challenges faced by small family farmers and examining the potential of e-commerce for marketing agricultural products. It aims to observe the suitability and tendencies of small-scale agricultural producers toward e-commerce and to determine their readiness for this marketing method. Given the rising trend of e-commerce and digital marketing, this research holds significant importance for the agricultural future of a developing economy. Based on in-depth interviews with 27 farmers from 11 villages, our findings showed that small family farmers do not have infrastructure issues regarding e-commerce. However, their lack of knowledge about e-commerce, adherence to the existing system, and lack of trust in e-commerce are identified as the main obstacles to e-commerce implementation. This study contributes to the existing knowledge by offering a conceptual framework on e-commerce adoption that has five main elements regarding adaptation to e-commerce, namely (1) the obstacles they face, (2) the future of agricultural production, (3) marketing of agricultural products, (4) production problems, and (5) the nature of e-commerce.

Keywords*: Small Family Farming, E-commerce, Agricultural marketing, Conceptual framework, Developing Country.*

1. Introduction

Unfortunately, it is no longer possible to feed the world and make it sustainable using current methods for many reasons, such as growing populations, climate change, and air and water pollution. Thus, it is clear that a change is required in the world's food systems. Today, family-based agriculture constitutes 90% of the 608 million farms that perform world agriculture, and family businesses produce more than 80% of the world's food. Therefore, it can be argued that family farms are at the very center of change in food systems and constitute the most dominant agricultural model in the world (FAO, 2020). In addition, family farmers not only produce food but also fulfill environmental, social, and cultural functions, playing an influential role

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in conserving the world's biodiversity and sustaining communities and cultural heritage. These characteristics led the United Nations to declare 2019-2028 as the "Decade of Family Farming" in December 2017, providing an extraordinary opportunity for the international community to take a holistic view of family farming to realize significant transformations in current agriculture (FAO & IFAD, 2019).

According to the United Nations Decade of Family Farming (UNDFF) 2019-2028 Global Action Plan, family farming plays a key role in achieving the Sustainable Development Goals (SDGs). This is because some practices related to family farmers can serve some of the SDGs. For example, poor family farmers can move from subsistence to income generation opportunities in rural areas (SDGs 1, 10); family farmers can practice resilient and highly productive agriculture that creates income generation opportunities (SDG 2); they can provide inclusive rural services and contribute to regional development (SDGs 3, 4, 6, 7); they can enable diversified food systems that can create job opportunities in rural areas and positively impact rural–urban mobility, especially for youth (SDGs 8, 9); they can enable food systems that strengthen sustainable integration between urban and rural areas (SDG 11); and more (FAO & IFAD, 2019). In this context, the importance of small family farmers in both developing and underdeveloped countries cannot be underestimated.

In concurrence with sustainable development, family farming plays a crucial role in promoting rural development and addressing the challenges faced by rural environments and populations (Damke *et al*., 2021). Investment in small family farms is vital for improving access to financial services, strengthening market linkages, and enhancing productivity, thereby contributing to rural development (Purnawan *et al*., 2022). Empirical evidence suggests that engagement in non-farm livelihood activities can lead to more stable livelihoods for families compared to relying solely on farming for income (Asfaw *et al*., 2017). Furthermore, family farms have been a subject of interest in determining farm efficiency and productivity, with a focus on their superiority over corporate structures (Gorton & Davidova, 2004). Pluriactivity, viewed as an accepted aspect of family farming, has contributed to the integration of farm households into the general economy of both developed and developing countries (Brookfield, 2008).

As a part of the developing countries, the share of agriculture in Türkiye's GDP appears to have been declining steadily over the years, at a rate of 6.5% in 2022 (TÜİK, 2018). However, agricultural production still remains important to Türkiye, although its share is declining. The family workforce in agricultural production is 83.24%. This shows that agricultural activities in Türkiye are mostly based on family labor (Kan and Kan, 2020). Regarding world e-commerce figures, retail e-commerce sales amounted to approximately 5.2 trillion US dollars in 2021. It is estimated that this figure will increase by 56% in the coming years and reach approximately 8.1 trillion dollars by 2026 (Chevalier, 2023). In Türkiye, the e-commerce volume increased by 115.15% in 2023 compared to the previous year and reached 1.85 trillion Turkish liras (77.89 billion dollars) (Ministry of Trade, 2024). In the consumer goods category, an analysis of e-commerce data for January 2023 shows that global food expenditures totaled $244.0 billion, while in Türkiye, the figure was $411.9 million (Digital, 2023*: Turkey-DataReportal-Global Digital Insights*, n.d.).

In the context of e-commerce, there is a growing focus on evaluating the environmental implications and impact of e-commerce on various sectors, including agriculture and rural areas (Mangiaracina *et al*., 2015). Studies have indicated that e-commerce plays a significant role in increasing farmers' incomes, alleviating rural poverty, and promoting rural development (Lin, 2019). Additionally, the adoption of e-commerce has been linked to increased awareness and adoption of green farming techniques among farmers (Zhao *et al*., 2022). However, challenges exist in the adoption of e-commerce in agriculture, including delivery risks and the need for educational support to enhance farmers' understanding of new farming practices (Huda *et al*., 2022).

The role of family farms in the context of e-commerce is also evident, with evidence suggesting that family farms and those located in rural areas benefit more from the adoption of digital media advertising, highlighting the potential for e-commerce to support and enhance family farming activities (Chung *et al*., 2021). Furthermore, the participation of farmers in e-commerce has been shown to influence their income levels, with various factors such as gender, farm household differentiation, and self-employment experience playing significant roles in farmers' e-commerce participation decisions and income levels (Zheng *et al*., 2023).

E-commerce is thought to have benefits such as streamlining the agricultural value chain and reducing inefficiencies in the distribution of farm produce. Gomathy *et al*. (2021) stated that e-commerce and digital marketing are a rising trend in agriculture. Smidt and Jokonya (2022) stated that digital tools in agriculture can facilitate access to commercial markets by connecting farmers and buyers, positively impacting access to information and the ability to overcome spatial barriers. Digital tools can also facilitate the flow of agricultural information, enabling small-scale farmers to better understand their costs, improve decision-making, and access better financial resources. El Bilali and Allahyari (2018) pointed out that ICTs can improve rural livelihoods and increase agricultural and market knowledge by strengthening the connectivity of small-scale farmers in developing countries.

The rise of e-commerce offers new opportunities for small family farmers to connect directly with consumers (Tomic and Martinovic, 2014) and circumvent traditional market structures. Besides, some small family farms recognize the potential of e-commerce for improved income and market access (Kızılaslan and Unal, 2015; Rameshkumar, 2022). However, the unique characteristics of family farms, often characterized by limited resources (Sekyi, 2017), marketing difficulties (Mendonça *et al*., 2020; Ali *et al*., 2021) complex family dynamics (Savickiene and Miceikiene, 2018) and a focus on sustainable practices, raise important questions about their e-commerce adoption. Hence, there is a gap in these studies in terms of addressing the issue of e-commerce from the perspective of farmers. This study attempts to fill this gap in the literature by addressing the perspective of small family farmers on e-commerce, their tendencies in this regard, and the future of agriculture from the perspective of small family farmers. In line with this, this study is focused on the e-commerce adoption of small family farmers in a developing country and has developed a conceptual framework to understand the elements of e-commerce adoption for small family farmers.

This study contributes to the small business and e-commerce literature in three ways. The major contribution lies in the study's holistic approach to identifying key factors for e-commerce adoption for small family farmers. By identifying challenges, obstacles, and future directions, we provide important and novel evidence for small business owners, encouraging the implementation of digitalization and e-commerce strategies and practices in developing countries, particularly for family firms in agriculture. Another contribution of this study is its focus on the viewpoints of small family farmers in rural areas of a developing country. The adoption of e-commerce is likely to increase household income (Li *et al*., 2021), and the resilience of family businesses towards digitalization and the transition to e-commerce is quite low. Understanding the factors that influence a farmer's decision to participate in or forego online shopping for farm inputs is of great interest, given the growing proportion of e-commerce offerings in agricultural trade and the previously cautious behavior of farmers (Schwering, 2021). Thus, this study highlights the key facts by defining the key concepts and steps to improve small-family farmers, which will offer significant opportunities for all stakeholders. Finally, our findings can provide useful insights for policymakers to develop policies aimed at encouraging agricultural entrepreneurship in terms of e-commerce and digital marketing.

This article is organized as follows: In the first part of the study, small family farming and e-commerce are discussed in a theoretical context. Then, details on methods and analysis, as well as findings, are given. The last section draws conclusions and suggests future research.

2. Theoretical Background

2.1. *Concept, characteristics, and problems of small-family farming*

Although it is not easy to make a generally accepted definition of family farming, it is possible to say that the most important elements are the family labor force, family members make the decisions, a significant part of the income is obtained from agricultural activities, and there is no size limitation (Keskin *et al*., 2017). Family farming includes agriculture, forestry, fisheries, pastoral, and aquaculture production activities managed and operated by a family, including women and men, relying predominantly on family labor (FAO, 2014).

Farming families are a large and diverse group and are defined in different ways around the world, depending on cultural traditions and national criteria. Within this diversity, the FAO views family farming as "a set of family-based agricultural activities linked to many areas of rural development". FAO (2020) defines family farming as "a method of organizing production activities for agriculture, forestry, fisheries, pastoralism, and aquaculture managed and carried out by one family, based predominantly on family labor, including women and men."

Strengths of family farming include fast decision-making, consideration of future generations, resistance to crises, independence, high motivation, and family members helping in cases of high work intensity. Weaknesses include scarcity of capital, insufficient economies of scale, assumption of risk, inheritance difficulties, and general knowledge replacing expertise. The main problems of family farming include difficulties in obtaining resources and raw materials, aging of the population and children leaving the land, lack of and difficulties in accessing education and financial services, and little or no participation in price formation processes (Keskin *et al*., 2017). In Türkiye today, many small family farmers are forced to enter into institutional and non-institutional borrowing relationships to purchase production inputs (Keyder & Yenal, 2013; Önal & Özalp, 2018; Özuğurlu, 2011). Therefore, it is important to develop, train, and support family farms.

2.2. *Small Family Farming and E-Commerce*

Digital technologies are seen to play a significant role in facilitating commerce because of their capacity to lower transaction costs, provide better interactions between buyers and sellers, and increase business efficiency (Higón and Bonvin, 2023). Thus, digital technologies such as e-commerce may play a vital role for small family farmers to overcome the barriers they face in developing and sustaining their businesses. Technology will help farmers with various issues such as weather reports, market prices, information on new techniques, climate changes, crop suitability, etc., helping farmers to expand their agriculture in different ways (Gomathy *et al*., 2021). Applications of information technologies in agriculture have been made in farming, especially in areas such as precision agriculture and bioinformatics. However, e-commerce has been explored later because of the diversity and perishability of agricultural products, unlike industrial products (Geng *et al*., 2007).

However, it is possible to say that e-commerce has many benefits for farmers. E-commerce offers the opportunity to streamline the agricultural value chain and reduce inefficiencies in the distribution of farm produce. By weakening the large-scale control of intermediaries in the supply of agricultural products, farmers can sell their products to a range of buyers, including agribusinesses, retailers, restaurants, and end consumers. It also gives farmers access to new markets and adds transparency to the value chain. All of this leads to higher profits for farmers and reduced losses in the logistics of agricultural products due to shorter supply chains (Joiner and Okeleke, 2019). Moreover, with this method, farmers have more control over their own products, can get more accurate and instant feedback on the market, and can identify market needs more clearly.

Compared to nonfamily businesses, many family-owned businesses have recovered more quickly from the COVID-19 pandemic's shocks. A long-term perspective can help one tolerate shocks from the environment. The findings imply that when developing national financial assistance programs, the type of entrepreneurial organization and its governance must be taken into account, especially for businesses with distinct ownership and management structures (Miroshnychenko *et al*., 2024). Indeed, the impact of the COVID-19 pandemic on those engaged in family farming is significant. For example, in many countries, consumer demand for long-shelf-life food products and e-commerce has affected small family farms that do not have e-commerce applications. Lack of access to fruit, horticultural, and other perishable products during this period led to reduced demand and lower prices (Campolina *et al*., 2020). However, rather than the lack of production, this effect is caused by structural problems such as loss of income due to a lack of access to markets and inputs, a negative impact on the general economic structure, and a lack of social security. In this context, it is possible to conclude that past policies on family farming have been ineffective. A more effective family farming policy is required with these lessons learned in the new normal process. E-commerce and bringing family farmers together with digital marketing should also be included in these policies. It is possible to come across some studies on this subject around the world and in our country.

For example, Gomathy *et al*. (2021) mentioned that although farmers play a crucial role in the agricultural life cycle, the majority of them do not make sufficient profits from their crops because of market strategies, and despite all the hard work and patience shown to grow the crops, others get the real profit because of bad market conditions. Therefore, they stated that farmers should be given the opportunity to sell their products more easily on the digital platform. Smidt and Jokonya (2022), El Bilali and Allahyari (2018), and Tomic and Martinovic (2014) stated that digitally enabled marketing can help improve internal efficiency and competitiveness in markets. Digital tools in agriculture can facilitate access to commercial markets by connecting farmers and buyers, positively impacting access to information and the ability to overcome spatial barriers. Digital tools can facilitate the flow of agricultural information, enabling small-scale farmers to better understand their costs, improve decision-making, and access better financial resources. Government laws and the deployment of cutting-edge financial technologies haven't made commercial banks any less reluctant to deny credit to small and micro-family enterprises. On the other hand, digital credit improved small and microfamily companies' financial accessibility. Furthermore, even if it did not immediately raise their profitability, more funding from digital finance was favorably correlated with the operational and business expansion of small and micro-family firms (Wu *et al*., 2023).

El Bilali and Allahyari (2018) revealed that digital tools have far-reaching effects in terms of the transition to sustainability in food systems and provide new relationships between producers and consumers based on greater equity and transparency. It is also important to align digital solutions with local conditions and create a localized digital development plan to support small-scale farmers. Smidt and Jokonya (2022) also provide practices from developing countries, noting that challenges in digital technology adoption by small-scale farmers include low levels of education, low income, cultural inertia, and lack of relevant localized content in local languages in Sudan; language, poverty, and illiteracy in Nigeria; and inadequate knowledge due to lack of infrastructure, low literacy levels, lack of appropriate information services, and lack of technical competence in Kenya. Aksu and Gurbuz (2018) also stated that basic costs, distrust due to a lack of information, and trust in the traditional method are the three main barriers to e-commerce in the livestock sector in Türkiye. Kızılaslan and Ünal (2015) stated that e-commerce is not sufficiently developed in Türkiye due to reasons such as producers' unfamiliarity with e-commerce in the agricultural sector, a lack of trained personnel in this context, and technological inadequacy. Therefore, the role of the state and institutions in supporting small family farmers is of critical importance.

Rameshkumar (2022) discussed state policies on this issue in India and stated that most industries started selling their products digitally, and young agriculturists are ready to adopt digital marketing tools to market their products globally after the Digital India Movement. However, while the concept of digital marketing reaches all business sectors, it is less so in the agricultural sector due to lack of knowledge, security concerns, start-up costs, lack of digital tools, lack of infrastructure, fear of use, and farmers' lack of readiness to accept new methods. Similarly, Tomic and Martinovic (2014) also analyzed the current and potential situation in the Republic of Serbia regarding mobile technology applications in the agricultural value chain and stated that new internet-based technologies have made a significant difference in connecting people, sharing information, and negotiating prices and payments, but they need more time for people to accept e-commerce as a standard way of trading, especially on farms. Li *et al*. (2021) explained the reasons why e-commerce has not yet been determined as a standard method for farmers and the factors affecting farmers' participation in e-commerce sales platforms as internal and external factors. Internal factors include personal characteristics, family business characteristics, and psychological cognition. They indicated that farmers with higher resource endowments and e-commerce awareness are more likely to adopt e-commerce sales. Farmers' decision-making behavior is deeply embedded in the social structure of the village, with distinct community-type characteristics. Therefore, e-commerce training in the village area has a significant positive impact on the e-commerce sales behavior of both large- and small-scale farmers. Hence, it can be assumed that the enhancing effect of village-based e-commerce training on small-scale farmers is significant. Research conducted by the United Nations Development Programme (UNDP), Investing in Rural People (IFAD), and the Food and Agriculture Organization of the United Nations (FAO) with small-scale farmers in Türkiye found that the higher the level of education of the farmer, the more likely they are to sell their farm produce online. Therefore, there is a need to train farmers in the use of digital marketing tools (UNDP, 2022).

3. Materials and Methods

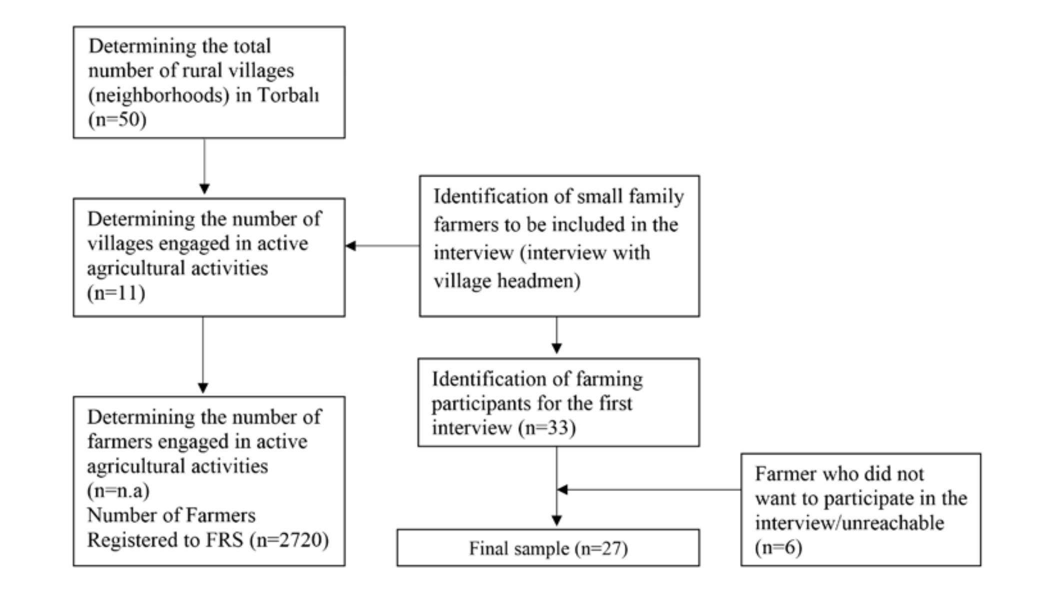
The data collection process was conducted using a semi-structured interview format that included questions on the demographic characteristics of small family farmers, methods and problems related to production, marketing, procurement, and their thoughts on e-commerce. In this context, the following questions were asked in the research:

- What types of problems do you experience during the production phase?
- How do you decide which crops to grow in the next season?
- Do you conduct market research?
- Who are the buyers of the products?
- Which inputs do you purchase? Do you have a problem with procurement of inputs?
- How do you set the price of your products?
- How are product sales collected?
- Can you predict how much you will earn?
- How are the collection, distribution, and storage of products carried out?
- Do you have the Internet?
- Do you have a social media account?
- Do you know anything about e-commerce?
- What do you think about e-commerce?
- What problems do you think you might face when you do e-commerce?
- What do you think about the future of agriculture in Türkiye?

These interview questions were developed by the authors on the basis of the literature review. The questions were also evaluated by two academics interested in marketing and e-commerce and two agricultural engineers before being finalized. Some questions have been revised in line with the suggestions. In addition, interviewers were encouraged to be flexible in asking additional open-ended questions to the main questions. These questions and the communication between the interviewees and the interviewers served to elicit detailed responses on small family farmers' problems related to production, marketing, and input supply, as well as their views on e-commerce.

Farmers' areas of agricultural occupation, the crops they grow, and the villages in which they reside provide the diversity of the sample. In this context, because no clear information was available, the headmen of 11 villages actively engaged in agriculture were interviewed. The selection of an appropriate sample size for qualitative research, especially for in-depth interviews, is a crucial factor that affects the validity and reliability of the results. The literature (Turner-Brown *et al*., 2018; Hennink *et al*., 2016;

Figure 1 - Diagram of the sampling process.



Guest *et al.*, 2020; Hennink and Kaiser, 2022; Squire *et al.*, 2024) substantiates the claim that a sample size of 9 to 30 participants is typically adequate for attaining data saturation, which refers to the juncture at which no new information arises from further interviews. Accordingly, 33 farmers who may be eligible for the scope of the research were identified together with the headmen (mukhtars) using maximum diversity sampling from purposeful sampling methods. Of these farmers, 4 did not want to be interviewed, and 2 could not be reached. As a result, the sample of the study consists of 27 farmers in total.

Face-to-face in-depth interviews were conducted with 27 selected farmers as the sample. During the interviews, farmers were given general information about the research and its objectives and asked to support the research. Each interviewee was interviewed for an average of 43 min (range 30-57 min). A diagram of the sampling process is shown in Figure 1.

4. Results

The sample consists of family-farmers who are at age between 22 and 70. One of them is female and six of them have at least high school level of education. The responses of the participants to the questions asked during the interview were noted simultaneously by three researchers, and the responses of some participants who gave permission were collected as audio recordings. After all interviews were completed, researchers independently coded the interview forms according to the main topics. Finally, another researcher checked the encryption forms and frames and created the final framework in the Maxqda program. The findings from the interviews were structured according to the final coding and illustrated with the specific statements of the interviewees.

The responses provided by the participants in the research were grouped under five themes: problems in production, marketing of agricultural products, e-commerce, e-commerce barriers, and future agricultural production. Under each theme, the responses given by the farmers were framed as follows by creating codes and sub-codes.

4.1. *Production-related problems*

As some of the farmers interviewed were involved in crop production, some in livestock production, and a small number in beekeeping, the responses to these questions were treated separately. According to the statements of farmers engaged in crop production, the biggest problems in agriculture are the increase in input prices and climate change. The high cost of inputs, especially the high prices of electricity, fertilizer, and diesel fuel, are among the problems that almost every farmer mentions. These problems are followed by a water shortage and the unavailability of labor and storage. In addition, some farmers stated that the fields are divided due to hobby gardens, which is a problem in production.

In terms of livestock breeding, the biggest problems are input costs (especially high feed prices), scarcity of pastures, climate change, and lack of labor and feed. In addition, the lack of hay in the country is among the problems mentioned. In the beekeeping sector, climate change, the use of pesticides, fraudulent practices in honey production, and the cost of transporting bees were highlighted as the main problems in honey production.

If we look at the common problems faced by all small family farmers, whether they are involved in crop production, livestock, or beekeeping, the biggest problems are input costs and climate change.

4.2. *Marketing of Agricultural Products*

In the interviews conducted with farmers in the research, the subject of marketing agricultural products was grouped under 5 codes: supply, buyers, market research, pricing, distribution, and stocking.

4.2.1. *Procurement*

Among the farmers participating in the research, those engaged in crop production purchase products such as fertilizers, pesticides, diesel fuel, seeds, and seedlings, while those engaged in animal husbandry mostly buy feed, hay, and medicines for animals, and beekeepers mostly buy sugar, hives, and protective medicines. Farmers in all branches of production stated that they provide the inputs they need mostly from the Agricultural Credit Cooperative and private enterprises. However, cotton and corn producers stated that traders provide all kinds of input (including diesel fuel and combine harvesters). The biggest problem experienced in the procurement process is stated as “high input costs.” Only one vegetable farmer (P15,58,M) stated that he could not always find the seeds he wanted, and even if he did, he could not buy enough.

4.2.2. *Purchasers*

The buyers of the products produced by the small family farmers participating in the research vary according to the products produced. Fig, grape, olive oil, maize, and cotton producers mostly sell their products to enterprises or intermediaries. Vegetable producers, on the other hand, stated that although they mostly give their products to intermediaries, market vendors also come and sometimes take their products to the market. They stated that they also sell products to final consumers, albeit very rarely, through the stalls on the edges of the fields. Farmers engaged in beekeeping stated that they mostly sell their products to final consumers. However, when all farmers are considered, it is observed that the biggest buyers of small family farmers’ products are intermediaries (11 people) and enterprises (8 people), and farmers prefer this system. This is because farmers sell their products wholesale to intermediaries and enterprises and receive their money in cash and in bulk. In connection with this issue, the farmers who participated in the interview were asked another question: “How do you find customers?”. Almost all of the farmers’ responses to this question were “we do not find customers; they find us; they come to the village for coffee; there is no problem in finding customers” (P12,50,M).

4.2.3. *Market Research*

One of the most important issues in marketing practices is market research. This is because it is important to know which products are most in demand on the market and what the competitive situation is in this respect. The data obtained from the research guides both the production and marketing activities of companies or professionals. Small-family farmers who participated in the survey were also asked whether they had conducted any market research while determining their products for the next period. However, corn and cotton producers, especially those who produce depending on the trader, stated that they do not conduct any research and produce what the trader wants. Apart from this, most farmers said that conversations with farmers in coffee houses, market prices, the demands of private companies, and the government's floor and ceiling prices influenced their future planting, but that they did not carry out any specific research. However, when farmers were asked how they decide which product(s) to produce in the next period and what was the most important factor in making this decision, those who grow figs, grapes, corn, cotton, and olives did not change, but most of those who grow vegetables stated that they divide the field and grow two or three types of vegetables in summer and winter, thus dividing the risk. Other farmers stated that "we plant according to our own minds (P2,70,M)", "we plant the crops that the farmers want (P6,53,M)", "we plant according to the seedlings we find (P12,50,M)". Here, it can be seen that the farmers who grow vegetables do not do any market research and plant crops either in response to the demands or on their own.

Pricing

According to the findings, three important factors, namely, the market, the state, and the stock exchange, come to the fore in determining the prices of all farmers' products. Price determination also varies according to the products produced by the farmers. For example, in the case of grapes and cotton, the agricultural exchange has an influence on the price; in the case of grains such as wheat and barley, the state has an influence on the price; and in the case of olive oil, the price is determined by the trader or other businesses, i.e., the buyer. Of course, the quality of the commodity also affects its price. For example, the acidity of olive oil is said to determine its price. The price of figs is generally determined by intermediaries.

The majority of farmers stated that they work in cash when collecting product prices. Apart from this, there are also farmers who work on an open account (P13,66,M) and farmers who say that they have to pay on credit (P2,70,M; P17,45,M; P6,53,M).

In connection with this issue, farmers were also asked whether they could predict how much they would sell and how much profit they would make at the beginning of the period. It was observed that all farmers gave negative answers to these questions. The farmers stated that agriculture depends on the climate and that they cannot predict the yield, so they cannot determine how much they will be able to sell or how much money they will be able to earn. The statements of some farmers on the subject are as follows:

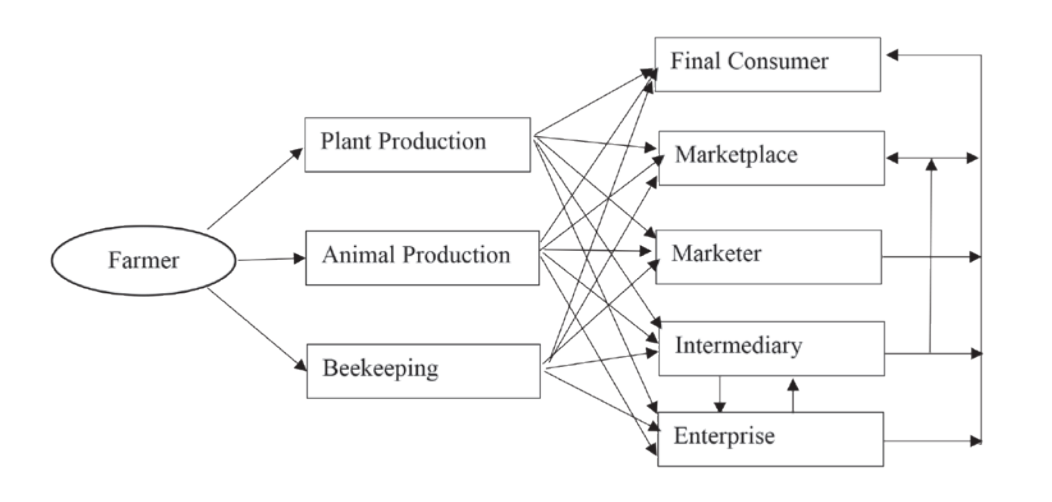
- *P6,53, M-You cannot know (predict), especially climate affects it a lot*
- *P7, 51, M-It is hard to make a prediction because we cannot predict the yield.*
- *P13,66, M-Expenses are clear, income is not.*
- *P15,58, M - You never know, last year I planted beans, I suffered a loss of 60.000 TL (approx. $4040/€3820).*
- *P16, 56, M-Climate is variable; therefore, forecasting is difficult.*

4.2.4. *Distribution and Storage*

The collection and packaging of the planted products vary according to the type of product. For example, some vegetable producers stated that the wholesalers themselves collect the products due to market law, while others said that they personally hire workers, collect and pack the products, and give them to the wholesaler or trader. Apart from this, it is observed that in maize and cotton, traders collect and store their own produce, and in olives and figs, farmers collect and store their own products.

The distribution of the products is also mostly done by intermediaries; the buyer comes to the farmer and picks up the products himself. However, beekeeping farmers distribute the products themselves, especially since their customers are final consumers. Some of the vegetable producers also stated that they do the distribution themselves as they sell their products in the market. Very few farmers engaged in animal husbandry stated that they themselves delivered the milk to the factory. In general, indirect distribution channels are preferred for agricultural products (Figure 2).

Figure 2 - Distribution chain of products.



4.3. *E-Commerce*

The use of the internet and information technologies in agricultural production is crucial. Therefore, the interviews with farmers also included questions on information technology infrastructure. The first of these questions is whether farmers have internet ownership or not. Only 3 farmers (P13,66,M; P23,67,M; P2,70,M) stated that they have no business with the internet, but their children do. The remaining 24 farmers have access to the Internet. In addition, only six of the farmers have Facebook, WhatsApp, and Instagram accounts. Considering that internet ownership is a necessity for e-commerce, farmers actually have internet infrastructure, which is the first step in technical terms.

Farmers were asked whether they had any knowledge about e-commerce and what they thought about it, and many of them emphasized that “trust” was essential. Only two people stated that they have little knowledge about e-commerce and that they are favorable to e-commerce:

- *Agriculturalists talked about Ditap, it is a good thing. When I entered the system, I saw my own product information, and I will use it (P5,47,M).*
- *Yes, we have online sales (P26,36,M).*

One participant gave a more neutral response: “*Trust is important; if there is a safe environment, it helps. If I feel this way, I can also do it” (P5,47,M)*. All the remaining participants (25 people) stated that they had no information on this subject and had a negative attitude toward it. The answers given by some of the participants in this group are as follows:

- *I don’t know about such things (P2,70,M).*
- *No, I don’t believe in e-commerce. They supposedly sold fields on the internet, and field prices flew (P3,60,M).*
- *I can’t do it (P4,63,M).*
- *No, I think it’s difficult to establish trust. When the buyer does not see the face of the goods, how will he buy them? (P6,53,M).*
- *I didn’t do it, I didn’t need to (P8,46,M).*
- *The other person will not see the goods; will I get my money? I have no confidence P1,51,M).*

As the answers of the participant farmers to the previous question were mostly negative, they were asked why they thought this way and what problems they might face if they engage in e-commerce. The common view of almost all 24 farmers who responded to this question is that they may experience a “trust” D problem. In addition, one of these 24 people stated, “*I don’t know enough*” (*P4,63,M)* and the other one stated, “*I don’t want to deal with it, this order is enough for me*” (*P9,59,M)*. Descriptive statistics with respect to respondents’ responses on e-commerce are reported in Table 1.

Table 1 - Discriptive statistics on e-commerce.

Theme	*Variable*	*Response*	*n*	*percent*
Intention to do e-commerce	Internet ownership	Yes	24	88,9
		No	3	11,1
	Social media account ownership	Yes	6	22,2
		No	21	77,8
	Knowledge on e-commerce	Yes	2	7,4
		No	25	92,6
	Main problem preventing e-commerce	Lack of trust	22	91,6
		Lack of knowledge	1	4,2
		Unwillingness to deal with e-commerce	1	4,2
E-commerce barriers	Internal	Lack of trust	24	88,8
		Inertia on the part of farmers	27	100
		Unsatisfactory e-commerce income	22	81,4
		Lack of knowledge	24	88,8
		Resistance to innovation	24	88,8
	External	Lack of support from government policies	25	92,6
		Organization	20	74,1
		Internal migration	27	100

4.4. *Obstacles*

Because of the interviews with farmers in the research, it is seen that there are two types of barriers to e-commerce that can be characterized as internal and external. Farmers' lack of trust in e-commerce, inertia on the part of farmers, unsatisfactory income from e-commerce, lack of knowledge about e-commerce, and resistance to innovation can be interpreted as internal barriers to the acceptability of e-commerce as an alternative way of agricultural marketing. In addition, it can be stated that government policies, organizations, and internal migration are external barriers to e-commerce. The inadequacy of the state's e-commerce incentives in terms of government policies can be given as an example. The characteristics of farmers, such as their low level of education, high average age, etc., reduce their technological literacy, and of course, this situation makes it difficult to adopt new methods. However, with the right organization, e-commerce transactions can be carried out from a single source and by experts. However, the problem of the organization of the farmers appears to be an external obstacle here as well. In addition, the migration of young people from rural to urban areas, who are much more tech-savvy and better educated, can be seen as another barrier to e-commerce. This is because the children of most farmers who participated in the interviews migrate from rural to urban areas either to study or work in factories and are not interested in agriculture.

4.5. *Agriculture in the Future*

It is confirmed by findings that agricultural production has decreased over the years due to high input costs in agricultural production, zoning of agricultural lands, wrong pesticides or irrigation, and many problems experienced in agricultural policies in Türkiye. Moreover, as seen above in the demographic characteristics of farmers, the young population is gradually leaving agriculture. For these reasons, farmers were also asked about their thoughts on the future of agriculture and whether they would continue agricultural production in the coming years. The responses of the farmers on the subject are as follows:

- *In the future, there will be no more farming; it will be finished (P3,60,M).*

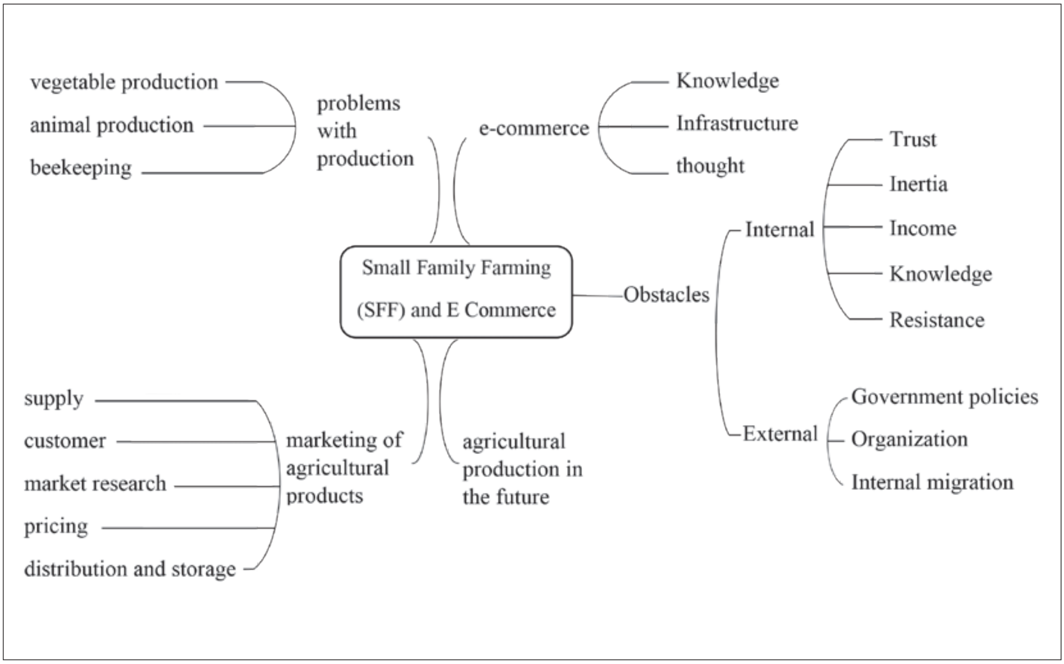
- *Children won't do farming (P5,47,M).*
- *I will quit this job when the children finish school. I will do it for 2-3 more years (P1,51,M).*
- *I will quit when I retire (P6,53,M).*

As can be seen from the answers given by the farmers, they have very negative thoughts about continuing agricultural production in the future. The most striking of these views is the view that "*In the future, farming will cease to exist*". The farmers stated that the earnings obtained from farming would not support a family, that children would not do this work due to both the earnings and the difficulty of the work, that the costs have already increased a lot due to the economic situation, and that this situation forces the farmer. They state that all of these will end agriculture in the future. This may lead to a significant food crisis in our country in the future, as well as many economic, social, and cultural problems. Only two farmers gave a positive response as "*I will do this job until I die*" (*P5,47,M; P8,46,M)*.

According to the findings, a framework for e-commerce adoption for small-family farmers is created and presented in Figure 3. The framework provides a holistic approach to the concept of e-commerce adoption.

The framework consists of five components. Production problems deal with the following stages of the value chain: from producers to end users. Along with both animal production and vegetable production, regional production, such as beekeeping, rises as a problem of agricultural production. Numerous reasons contribute to small family farmers' increasing production issues. These include the growth of industrial agriculture, limitations imposed by the market, inadequate infrastructure, and more general problems, including social protection and health concerns. In addition, the availability of family labor, financial availability, and the utilization of subsidies all have an impact on the productivity of small family farms. Additionally, the current conventional agri-food systems have an impact on small farms' competitiveness. As a result, in order to develop sustainable strategies for small family farms, it is necessary to reconstruct regional and local agri-food systems. From this point of view, e-commerce can be a solution to ensure sustainability and support the development of small family farms.

Figure 3 - Conceptual Framework of Small-Family Farming and E-Commerce Adoption.



E-commerce, on its own, stands out as an important element. There are factors arising from e-commerce itself that small family businesses in agriculture face in the adoption of e-commerce and the transition to e-commerce. These include themes such as the need for appropriate infrastructure, a lack of knowledge and awareness, and negative attitudes towards e-commerce. Thus, e-commerce needs to be investigated as an important trigger and obstacle for small-family farmers. On the other hand, there are two main obstacles facing small-family farmers in e-commerce. These can be classified as internal and external barriers. Despite its effects, such as creating new sources of income and reaching new markets, internal barriers such as lack of trust and resistance and external barriers such as government policies and migration are classified as barriers to e-commerce adoption. The marketing of agricultural products is the fourth component of e-commerce adoption. Small-family farmers in developing countries have a lot to gain from the marketing of agricultural products through the use of e-commerce, including greater sales, better financial results, expanded market access, simplified value chains, and better market research. Lastly, the future of agriculture has been asserted as the final component. Although many farmers stated that they are negative about the future of agriculture, e-commerce can be a salvation for small-family farmers.

5. Discussion

This study addressed the elements of e-commerce adoption for small family farmers. The majority of people engaged in farming are elderly and have a low education rate. It causes farmers to be far away from new information technologies used in agriculture. Instead of engaging in agriculture, young people mostly work in factories in cities for the minimum wage, engage in non-agricultural jobs, or migrate to different regions for education. Our findings support the observations of Petruzzella *et al*. (2020) that there is a need for the establishment of policies and various support mechanisms to support young entrepreneurs, facilitating access to credit facilities, and expanding cooperation between entrepreneurs and researchers. This situation is also related to the findings of Keskin *et al*. (2017), Smidt and Jokonya (2022), and Rameshkumar (2022) and raises concerns about the future of agriculture in developing countries.

The rise of production problems for small family farmers is a complex issue influenced by various interconnected factors such as market constraints, infrastructure, access to credit, gender-related attitudes, climate change, and decision-making processes. Addressing these challenges requires a multifaceted approach that considers the unique circumstances and needs of small family farmers. Our findings support the fact that agricultural extensionists have been identified as having a crucial role in improving the production systems of small-scale farmers through training and advisory services (Munyakazi *et al*., 2022). It is possible to say that climate change is one of the major problems in agricultural production and that high input costs affect production. Interestingly, this situation supports the results of the study conducted by Aksu and Gürbüz (2018) on the barriers to e-commerce in animal husbandry.

Our findings show that they do not have much difficulty finding customers and that the intermediaries come to the village coffee house and reach them. Therefore, it was observed that they did not make any efforts for product promotion or advertisement. As Smidt and Jokonya (2022) point out, inertia does not detach most farmers from the existing order. This situation, in fact, indicates that the majority of them do not get enough profit from their crops, as stated in the studies of Gomathy *et al*. (2021), and that despite all the hard work and patience shown to grow the crops, the real profit is received by others. The farmer both complains about this situation and allows it. This shows that e-commerce can play a vital role for small-family farmers to enhance their vision and motivation to reach larger markets.

COVID-19 pandemic has had a strong impact on online food shopping service demand. This has increased the variety of products offered on e-commerce platforms and raised the possibility of increased sales concentration on niche products, as well as the growing consumer attraction of online platforms (Chang & Meyerhoefer, 2020). Furthermore, it has been discovered that e-commerce adoption increases farmers' income, especially in areas with greater rates of e-commerce adoption. This suggests that small family farmers may benefit financially from e-commerce adoption (Li *et al*., 2021). Moreover, the impact of e-commerce adoption on small enterprises' performance has been emphasized, highlighting the role of e-commerce in improving the performance of small enterprises (Lestari *et al*., 2021). In line with these studies and our findings, to contribute to the literature, we have asserted that small-family farmers in developing countries need to be motivated to adapt e-commerce to their businesses faster and more widely in order to make more profit and reduce their dependence on intermediaries. This may be achieved by determining and implementing policies by both public administration and local authorities. In line with Han and Li (2020) who have emphasized the significance of supportive institutional frameworks for e-commerce adoption by highlighting the function of improved institutional mechanisms for e-commerce in lowering perceived risk and fostering adoption preparedness, our findings support the need for exact policies for the use of e-commerce. This is also consistent with the results of Miroshnychenko *et al*. (2024), who asserted that policies for financial aid can be utilized to encourage and boost family-owned businesses' adoption of resilience-fostering strategies. Furthermore, based on our findings, we agree with Wang *et al*. (2022) in highlighting the fact that it has been demonstrated that e-commerce advertising encourages farmers to use organic fertilizers, which enhances product quality and promotes sustainable agricultural development.

Contrary to the studies of Smidt and Jokonya (2022) and Rameshkumar (2022), there is no problem in Türkiye in terms of both internet access and e-commerce infrastructure. Nevertheless, similar to Chen *et al*. (2022), our findings are parallel with providing evidence in favor of government spending on rural infrastructure to promote the growth of e-commerce. However, farmers generally have a negative view of e-commerce, with the effect of age and education. Our findings have shown that there is a lack of knowledge and awareness about e-commerce adoption. Their lack of knowledge about e-commerce, their loyalty to the existing order, the ease of this habitual order for them, and their distrust of e-commerce are among the barriers to e-commerce. This situation is also found in the studies of UNDP (UNDP, 2022), Kızılaslan and Ünal (2018), Aksu and Gürbüz (2018), Keskin *et al*. (2017), Rameshkumar (2022), and Li *et al*. (2021).

Our findings are consistent with the findings of relevant studies that have shown that the adoption of e-commerce by small and medium enterprises (SMEs) in developing countries has become increasingly important (Rahayu and Day, 2015). Furthermore, the perceived e-readiness factors in e-commerce adoption have been identified as crucial in developing countries, emphasizing the importance of readiness for e-commerce adoption (Molla and Licker, 2005). Thus, e-commerce is one of the most efficient ways of achieving sustainable development for small-family farmers in developing countries. In line with our findings, Su *et al*. (2021) also found that, in rural China, the adoption of e-commerce has been found to impact farmers' participation in the digital financial market, indicating the broader influence of e-commerce adoption on financial inclusion in rural areas.

6. Conclusion

Although family farming has been extensively studied in previous research, prior literature has scantly addressed the adoption of e-commerce by small family farmers. According to our findings, it is clear that it will not be possible to solve marketing problems without solving the basic problems related to agricultural production. On the other hand, it is possible to infer that the farmers do not want to break away from the existing order due to the fact that one of the biggest problems in the value chain of agricultural production is the high number of intermediaries between producers and consumers. Intermediaries lead to higher prices for agricultural products for the final consumer. The farmer, who does the actual work, has the lowest profit share in this chain, and such a long distribution channel leads to product waste. However, it is seen that the farmers who participated in the interview, although they complained about this situation, were also satisfied with selling the products in cash and wholesale. The fact that the farmers have an elderly population and a low level of education perhaps creates an incentive to protect the existing order and creates anxiety about innovations. Unfortunately, all this will put our country's future agricultural production in trouble. It is necessary to find a solution to the structural problems in production and marketing. Certainly, the solution to these problems will not be possible without conscious state policy and support.

7. Implications, limitations, and further research

Small family farmers need to be supported for their survival and future; new methods need to be taught; and they need to gain a structure that can keep up with new technologies and systems. Explaining e-commerce to small family farmers in the field research and explaining that this method can be an alternative way in agricultural marketing can be considered a practical contribution of the study. Most of the farmers who participated in the interview stated that production has become increasingly difficult from year to year; therefore, they will not continue production, they cannot make a living with the income obtained from agricultural production, and their children will not do this work. Therefore, the view that "in the future, there will be no more farming" is the most common among farmers. This statement and thought are perhaps the most important focus of the research that has not appeared in the literature. In addition, the framework is a theoretical contribution of this research to the literature.

The research also has some suggestions for institutions and organizations such as the state, local governments, NGOs, and universities in practice in terms of e-commerce as an alternative to current agricultural marketing practices for small family farmers and the future of Turkish agriculture. The state and relevant institutions should provide sufficient incentives for agriculture to be an income-generating endeavor with the right policies and direct young people to agriculture. This is because the aging population will not be able to do this job in the future, and young people will not want to do this job in the existing order. Government regulations should prioritize the establishment of collaborations between farmers and e-commerce platforms as well as mobile applications to develop sustainable sales and marketing strategies that enhance income generation. In particular, with the support of local-level associations such as chambers of commerce, commodity exchanges, artisans' associations and agricultural cooperatives, trade entry mechanisms can be established and made available to family farmers who need them. Moreover, while the importance of agricultural activities is increasing due to the world's growing nutritional needs, Türkiye, despite its great agricultural potential, will suffer a huge loss of income. Therefore, the future of Turkish agriculture lies with young farmers. In order to attract young farmers, policies that improve the institutional framework for entrepreneurship by making it easier for startups to access support, funding and expertise, may be installed. With the joint initiative of the public sector and universities, programs can be developed to inform young farmers about innovation. As Petruzzella *et al*. (2020) state, the implementation of innovative pedagogical methodologies, particularly those that emphasize open innovation and design thinking, is paramount in nurturing young farmers' entrepreneurial aspirations and cultivating their aptitude for innovation.

In terms of e-commerce, the characteristics of young people, such as their predisposition to technology, being open to innovations, and being educated, can enable them to develop themselves more easily in this field. Young people who see state support with the right policies at their backs will have the chance to find markets more easily and directly at home and abroad, thanks to e-commerce. It will contribute to the employment of the young population in developing countries, regional development, and supporting sustainable development goals. Therefore, the government can increase production and marketing incentives for young farmers. Policies can be developed to ensure the supply of inputs such as fertilizer, diesel, and seed to young farmers at affordable costs. Universities can include e-commerce courses in the curricula of agriculture-related professions such as agricultural engineering and train young people in the marketing of agricultural products through e-commerce as well as their production. Initiatives to incorporate e-commerce into agriculture must also address the socio-economic inequalities intensified by the digital divide. Improving rural digital literacy and offering extensive e-commerce training programs will be essential for facilitating equitable participation. Policies must focus on developing inclusive educational content that provides practical tools and resources for farmers, enabling them to succeed in a progressively digital marketplace.

Local governments and district agricultural directorates can organize various events with the local community for the online purchase of agricultural products produced only in their region at certain times of the year. The repetition of such practices at certain times of the year can serve both the sale of regional agricultural products and sustainability. Moreover, when all the problems of small family farmers are taken into account, it becomes clear how important it is to organize. This requires practices by state and local governments to facilitate organizing. In conclusion, a comprehensive government strategy focused on developing supporting infrastructure, increasing digital literacy and expanding economic accessibility can significantly increase the participation of small family farmers in e-commerce. Emphasizing these areas can improve economic resilience and sustainable agricultural practices, thereby advancing food security and rural life.

The biggest limitation of this study is that it was conducted during and immediately after the COVID-19 pandemic. Therefore, interviews with farmers who could not fully recover from the pandemic were very difficult. In addition, the long distances between villages created problems in terms of both cost and time.

Since the research was conducted only in the Torbalı district of İzmir, it is not possible to generalize the results obtained to Türkiye. Therefore, in future studies, more regions active in agriculture in Türkiye should be included in the study. In addition, more accurate results can be obtained with a mixed data collection method using both quantitative and qualitative studies.

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Creating a business model for Farmers' Organizations in Tunisia: Lessons learned to strengthen and support their activities

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Abstract

Farmers' organizations have become a central element in agricultural policies and have established themselves as key partners in development programs in developing countries. This study aims to create a business model for Melyane Mutual Agricultural Services Company (SMSA) in northeastern Tunisia. This business model will define, on the one hand, the necessary resources (financial, technical, human) to realize its future projects and demonstrate their viability, and, on the other hand, the strategies to overcome existing constraints while leveraging local resources and creating sustainable activities. Semi-structured interviews and detailed surveys were thus conducted with the SMSA board of directors and its members. The business model, developed and validated by SMSA members, provides a clear strategy for income-generating activities to be implemented and investments to be made in the short and medium term. The development of SMSAs should therefore be integrated into a territorial development approach that focuses on enhancing local resources, with members leveraging their artisanal skills. Furthermore, considering the challenges SMSAs face in terms of effective management and visibility, their activities should be reinforced with a mechanism for technical assistance and support.

Keywords: *Producer's Organization, Melyane SMSA, Constraints, Business model, Territorial approach.*

1. Introduction

It is now acknowledged that Farmers' Organizations (FOs) play an active role in the progress of developing countries, with a multiplication of their numbers and an increase in the dynamics of their federation (Bizikova *et al.*, 2020; Ma *et al.*, 2023). Considered key partners in agricultural policies and development programs, FOs act as essential intermediaries between rural communities and institutional actors, facilitating access to markets, extension services and management of common natural resources (Luo *et al.*, 2020; Krishnan *et al.*, 2021; Minah, 2022).

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While some FOs have achieved significant technical and economic results, others are "running on fumes" and their success depends largely on their ability to establish links with funding agencies to secure technical and financial support (Bizikova *et al.*, 2020; Chen *et al.*, 2023). That is why institutionalized mechanisms must be put in place to effectively promote FOs. These mechanisms should primarily address the challenge of access to funding, as FOs' members need access to credit, and the organizations themselves require resources to sustain their activities (FAO, 2019; Hintz *et al.*, 2021; Iyabano *et al.*, 2022).

In this context, the Business Model Canvas (BMC) has emerged as a relevant tool to address these challenges. By providing a structured framework to analyze and design business models, the BMC enables FOs to identify key resources (land, agricultural equipment, technical knowledge, human resources), value propositions (productivity improvement, market access, food security), customer segments, and revenue streams, thereby strengthening their sustainability and growth potential (Osterwalder and Pigneur, 2010; Gertler and Wolfe, 2002). For FOs, which often operate as fragile structures with limited business management skills, the BMC offers a practical approach to overcome financial constraints, improve operational efficiency, and foster innovation by demonstrating the long-term viability of a farmers' organization. Furthermore, the BMC can help FOs leverage local resources and establish strategic partnerships with donors and development agencies to create sustainable economic activities, in line with broader development objectives (Sivertsson and Tell, 2015; Atuahene-Gima and Amuzu, 2019; Krishnan *et al*., 2021).

In Tunisia, the post-2011 Revolution period has seen a renewed interest in cooperatives and FOs as levers for socio-economic development (El Haddad, 2020; Gherib, 2021). However, access to finance remains a major obstacle, limiting their growth and impact (Soltani and Mellah, 2023). This highlights the urgency of using innovative tools such as the BMC to strengthen the organizational and financial resilience of FOs.

The literature on FOs indicates that there have been few recent studies addressing this research gap. To tackle the challenges faced by smallholders, particularly financial ones, it is essential to develop business models that are viable for smallholder collectives.

The main objective of this study is to assess the potential of a Mutual Agricultural Services Company (SMSA) in the governorate of Zaghouan (north-eastern Tunisia) and to identify the key factors influencing its expansion. By applying the BMC framework, the study aims to define the necessary resources (financial, technical, human) for the growth of the SMSA, to demonstrate the feasibility of its expansion and to propose solutions to the existing constraints. This approach not only addresses the immediate challenges of the SMSA, but also provides a replicable model for other FOs seeking to strengthen their sustainability and impact. Through this perspective, the study contributes to the broader debate on the role of FOs in rural development and the importance of innovative economic tools to achieve their objectives.

2. Conceptual framework

2.1. *Mutual Agricultural Services Company (SMSA) in Tunisia*

SMSAs are agricultural service cooperatives established by farmers to pool services and address various needs related to their agricultural activities. Operating under a cooperative structure enabling commercial activities, SMSAs offer essential services to their members, thus contributing to the improvement of production management and the optimization of their agricultural operations. According to the Law No. 2005-94, enacted on October 18, 2005, SMSAs are defined as "companies with variable capital and shareholders that operate in the field of services related to agriculture and fishing" (JORT, 2005, p. 2683).

In 2022, there were 390 SMSAs. The total number of SMSA members in Tunisia stands at 40,128 cooperators, representing a membership rate of 8.8% among farmers. Of these, only 4.3% are in good standing, 23% have ceased their activities, 20.9% face various difficulties, and 43.9% are active but in a rather average situation (Belhaj Rhouma et Ahmed, 2018).

The members of SMSAs must be farmers, fishermen, or agricultural service providers, and they must carry out their activities within the SMSA's intervention territory. The regulatory framework also governs the operating rules of the Board of Directors, which consists of 3 to 12 members elected for a term of 6 years. For a General Assembly to be valid, at least one-quarter of the SMSA members must be present. Additionally, the presidency of the board must be held by a farmer or fisherman actively engaged in their profession, with the necessary academic qualifications to carry out the tasks assigned to them (Giguère, 2016).

These SMSAs have the following missions: providing the inputs and services necessary for agricultural and fishing activities, guiding and supporting their members to increase the productivity and profitability of their farms and improve product quality, and marketing agricultural products, including collection, storage, packaging, processing, transportation, and export (JORT, 2005).

2.2. *Business Model Canvas (BMC)*

The concept of a Business Model has gained prominence since the 1900s as tool for communicating business ideas to potential investors within a limited timeframe (Zott *et al.*, 2011). According to Teece (2010), a BMC is defined as "the way in which the company delivers value to customers, persuades them to pay that value, and converts those payments into profits". The BMC thus seeks to outline how an organization defines its strategy through the activities and services it provides in the market, the revenues it generates, the costs it incurs, and how it integrates its production chain within a value network (Osterwalder and Pigneur, 2010; Dewitte and Lecocq, 2016). The concept of value is central to a business model and has been expanded from economic value to include environmental and social value, reflecting the need for the BMC to align with the ecosystem in which the organization operates (Schaltegger *et al.*, 2012; Mentink, 2014).

The BMC is now a widely used conceptual tool for organizations, both agricultural and non-agricultural, at all stages of their life cycle helping them implement a more relevant and adapted business model (Scuotto *et al.*, 2020; Santini *et al.*, 2023). It serves as a support tool for understanding how an organization operates and creates value for its stakeholders (Baden-Fuller and Morga, 2010; Teece, 2010). Consequently, the BMC not only focuses on the organization itself but also involves the stakeholders who interact with it.

Moreover, the BMC is highly useful for exploring potential innovations within the organization, employing an inside-out approach to help managers align their activities and relationships in designing the organization's strategy (Trigkas *et al.*, 2020). Additionally, these business models represent either the current or future state of organizations, offering simple and easy-to-understand configurations of aspects related to their operational mode (Gregurec *et al.*, 2021).

The BMC has been applied in numerous cases within the agricultural sector, including agritourism development, strategic planning for agricultural cooperatives (the subject of our research work), the expansion of renewable energy, and irrigation extension services (Benjaminsson *et al.*, 2019; Trigkas *et al.*, 2020; Zanjirchi *et al.*, 2020; Santini *et al.*, 2023).

The BMC takes the form of a 9-box matrix containing interconnected elements: customer segments, value proposition, distribution channels, customer relationships, key activities, key resources, key partnerships, cost structure, and revenue streams. This matrix helps to identify the organization's competitive advantages, strengths, and the resources required to achieve its objectives and perform its core activities (Osterwalder et Pigneur, 2010; Clark *et al.*, 2012).

3. Materiel and methods

3.1. *Specificities of the Melyane SMSA*

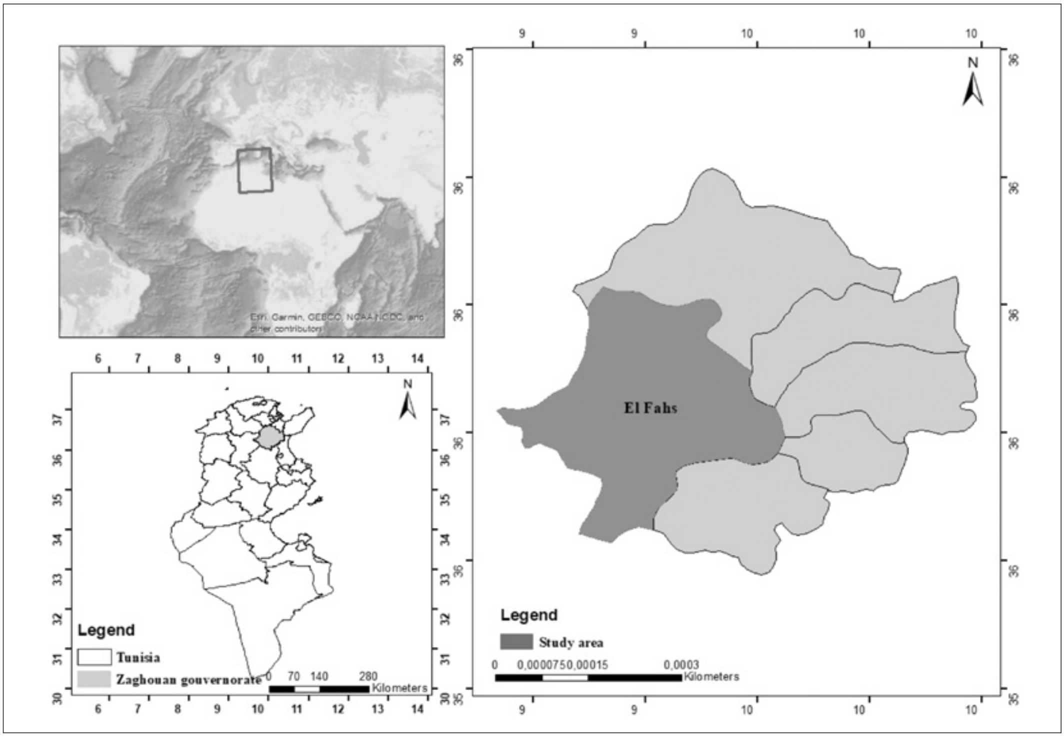
The governorate of Zaghouan has a total of 131 FOs, including 4 SMSAs and 127 GDAPs. The majority of GDAPs (84%) focus on managing water resources, including irrigation and drinking water. The others (3%) consist of rural women specialized in adding value to local products (such as the distillation and extraction of aromatic and medicinal plants-AMP, handicrafts, and *Oula* products like spices). Although SMSAs are fewer in number, their activities are limited to the distillation of AMPs, the sale of animal feed and the rental of agricultural equipment.

We chose to focus our work on the *Melyane* SMSA, located in El Fahs delegation (Figure 1). El Fahs delegation has significant agricultural potential, with a usable agricultural area of 74,500 ha and abundant hydraulic resources, including deep aquifers, hill lakes, and dams. The cropping systems are dominated by field crops, combined with livestock (such as sheep and cattle), arboriculture (such as olive, almond, apple, and apricot trees), and market gardening. However, small and medium-sized farmers are facing difficulties in making their farming systems profitable due to the surge in input prices (such as fertilizers, pesticides, and animal feed) in recent years, the lack of availability of agricultural equipment, and the near-absence of technical and financial support from public officials.

To improve their socio-economic situation (increased income, access to basic services) and advocate for their interests with institutional actors, farmers in Elfahs, with the support of the regional agricultural administration (Regional Agricultural Development Commission-CRDA), decided to establish the Melyane SMSA in 2014. The SMSA currently has about 68 members, primarily small and medium-sized farmers from the region. The association operates on a cooperative economic model, purchasing agricultural inputs in bulk on behalf of its members to benefit from economies of scale and reduced costs. These inputs, which include animal feed (such as soybean meal, corn, hay bales, etc.), phytosanitary treatments, fertilizers (such as ammonium nitrate and diammonium phosphate), and fuel, are then distributed to members at more affordable prices compared to market rates. Additionally, the SMSA offers rental services for agricultural equipment such as tractors and plows, further helping its members reduce operational costs and improve productivity.

The *Melyane* SMSA was one of the FOs selected by the African Development Bank as part

Figure 1 - Location of the El Fahs Delegation-Governorate of Zaghouan (Elaboration by the authors, 2024).



of a project aimed at developing and promoting agricultural sectors in the Zaghouan governorate, initiated in 2022, to benefit from technical and financial support through the creation of a BMC. This selection was made based on well-defined criteria, including the regularity of general assemblies, the absence of internal conflicts, and the level of member involvement. It is also important to note that our decision to study this SMSA was influenced by the members' motivation to engage in new activities and the active participation of women.

3.2. *Methodological approach*

To achieve the objective of this research, we adopted a progressive methodological approach that includes the following steps.

3.2.1. *Data collection*

Initially, semi-structured interviews were conducted with agricultural administration officials at both the regional level (CRDAof Zaghouan) and the local level (Territorial Extension Unit – CTV of El Fahs), as well as with members of the SMSA board of directors (president, treasurer, technical director). The objectives of this phase were to collect initial data on the *Melyane* SMSA (such as founding objectives, activities, resources, and constraints), identify the target population (members and board members), and prepare detailed surveys. This exploratory phase is crucial as it provides an opportunity to highlight the key elements of our research.

These interviews were conducted between March and April 2023 through detailed qualitative and quantitative surveys with the SMSA board of directors and its members. The data collected will serve as the basis for developing a business model in a subsequent phase. In total, we interviewed three board members (50% of the total composition) and 37 members (55% of the total membership). Additionally, the initial surveys with the board of directors were designed to thoroughly characterize the SMSA in terms of its resources, current and future activities, budget situation, and operational constraints.

For the second survey with members, the sample was selected in collaboration with the SMSA President and officials from the Zaghouan CRDA. Selection criteria included the members' level of involvement in the SMSA, their activities, future perspectives (such as activities, investments, and projects), and gender aspects (women and youth). These surveys will allow us to assess the socio-economic situation of the interviewed members (including age, education level, professions, etc.), their level of affiliation with the SMSA in terms of roles and involvement, as well as their short- and medium-term perceptions and suggestions regarding the challenges facing the SMSA.

3.2.2 *SWOT analysis*

The data collected from interviews and surveys conducted with members and board members facilitated the development of a SWOT matrix (Strengths, Weaknesses, Opportunities, Threats), a strategic tool commonly used by organizations, particularly in the case of SMSA *Melyane*. Furthermore, conducting a SWOT analysis provides a solid foundation for preparing a BMC and developing a clear strategy by enabling both an internal diagnosis (such as skills, competencies, and technology) and an external diagnosis (such as customers, suppliers, competition, and market trends), supporting the necessary decisions for the long-term progress of the SMSA (Teoli *et al*., 2019; Stefan *et al*., 2021).

The analysis of internal factors focuses on the key strengths and weaknesses of SMSA *Melyane*, as well as its current conditions (such as resources, activities, and budget situation). Strengths refer to the advantages and socio-economic benefits inherent to the SMSA, specifically what it offers primarily to its members and secondarily to its clients (non-members), enhancing its attractiveness. Weaknesses highlight areas that need improvement. External factors address the future implications of opportunities and threats. Opportunities refer to positive external factors available to the SMSA (such as financing, legal frameworks, and technical support) as well as the broader environment in which it operates. Threats encompass competitive market dynamics, technological challenges, regulatory hurdles, and financial obstacles faced by the SMSA.

The resulting SWOT matrix was then discussed and validated with the SMSA members as part of a participatory process aimed at encouraging their active involvement in the development of their community.

3.2.3. *Development of the Business Model Canvas (BMC)*

The data collected from the surveys and the resulting SWOT analysis enabled the development of the BMC for SMSA *Melyane*. This BMC is designed to outline how the organization defines its promotion strategy by leveraging the activities and services it offers to its members while integrating its production chain into a broader value network (Osterwalder and Pigneur, 2010).

Furthermore, the successful development and implementation of the BMC would be a significant milestone for the SMSA, demonstrating that it has made considerable progress in clearly defining its objectives and identifying its specific needs. This achievement would, in turn, lay a solid foundation for improved resource management and targeted technical support. Both are essential for enabling the SMSA to increase its capacity to generate stable income and attract external funding. Although these outcomes are still prospective at this stage, they are a natural progression of the work done during the BMC development process. If realized, these results would strengthen the SMSA's ability to generate lasting socioeconomic impacts across the region.

In light of this, the BMC outlines the strategic elements needed to expand SMSA's activities. It presents a clear pathway toward economic sustainability, while also addressing the region's unique social and environmental challenges. However, it is important to emphasize that these potential benefits depend on the successful implementation of the BMC and the SMSA's ongoing commitment to achieving its objectives.

Given that the BMC was structured and developed through consultation with stakeholders and local beneficiaries within a participatory framework (Crispim *et al*., 2021), it was subsequently discussed and validated with CRDA officials in Zaghouan and the president of the SMSA. This process enabled the formulation of policy recommendations for the development of these rural communities.

4. Results

4.1. *Strategic diagnosis of Melyane SMSA: SWOT analysis*

A comprehensive strategic diagnosis was conducted for *Melyane* SMSA, focusing on both internal and external factors influencing its operation and development through a SWOT analysis. The main elements are detailed below in Table 1.

4.1.1. *SMSA internal diagnosis: Strengths and weaknesses*

The internal diagnosis examines the environment and internal factors of SMSA *Melyane*, including its resources, capacities, and constraints in institutional, social, and economic terms. This analysis identifies and evaluates key strengths and weaknesses that shape the organization's current state (Table 1).

I. Strengths

At its inception in 2014, the *Melyane* SMSA started with just 12 members. Over the years, this number has grown significantly, reaching 68 members by 2023, making a fivefold increase. This growth reflects the strong interest and commitment of farmers in the region to engage with the cooperative structure and improve their socio-economic situation. Moreover, the technical and financial support provided by the donors (such as training and agricultural equipment) played a crucial role in motivating the members to get actively involved.

Rural women are actively participating in this SMSA, both in decision-making roles as members of the Board of Directors and in various activities as ordinary members. The Board of Directors consists of 6 members, one of whom a woman (an agricultural engineer) serves as the treasurer. Additionally, 53% of the members are women engaged in dairy cattle farming with small herds (an average of 3 cows), as well as in family poultry farming and as vegetable crops (such as lettuce, fennel, and broad beans). The presence of women is, therefore, crucial, as they are an active and significant force in agricultural production and contribute to the family income through their agricultural and non-agricultural activities (such as weaving, pottery, and transformation of agricultural products).

Various actors, including public institutions, donors, NGOs, research institutes, and private sector, have provided institutional, financial, and technical support to this SMSA, thereby ensuring its long-term sustainability. The collaborative nature of these partnerships highlights the openness of SMSA *Melyane*—both its members and the Board of Directors—to the broader institutional environment, emphasizing its ability to maintain productive relationships. Specifically, the National Institute of Field Crops (INGC), a state actor with a mission to contribute to food security by increasing yields of cereals and related crops (such as legumes and fodder), has provided technical assistance (such as seeding techniques, use of appropriate inputs, crop rotation, pesticides, and phytosanitary products) to members.

Although the CRDA of Zaghouan faces financial and logistical resource constraints, it has provided valuable administrative support to the SMSA. This support has been particularly evident in assisting with general assemblies, facilitating the election of Board Members, and supporting budget management. Despite being somewhat limited by material constraints, this support has been crucial in the organization and structuring of the SMSA.

The Food and Agriculture Organization of the United Nations (FAO) contributed 25,000 Tunisian Dinars (TND) (1USD=3.14 TND in 2025) to equip the SMSA premises and purchase office supplies (such as computers, administrative supplies and furniture). In addition, the International Center for Agricultural Research in the Dry Areas (ICARDA) provided mobile phones to 30 women to support them remotely whenever necessary, mainly through message exchanges (alerts on agricultural risks, market opportunities, demonstrations).

The SMSA currently offers free product delivery during critical periods, such as livestock or crop diseases, ammonia and seed shortages, at competitive prices. One of the main advantages is the option of installment payments for members. This service not only helps reduce production costs by eliminating transportation fees, but it also lowers prices compared to private input suppliers in the region.

II. Weaknesses

More than half of the SMSA members (59%) own small family farms (less than 5 ha). Only 6% of members are tenants or beneficiaries of State-owned land with agricultural technicians cultivating State land under long-term contracts (15 years). In addition, some members (23%), particularly women, do not own land and instead raise livestock, including sheep and cattle, on rented land. The small size of family farms and the lack of land ownership limit farmers' ability to achieve economies of scale, making investments in modern technologies and agricultural equipment expensive and difficult to make profitable.

An SMSA has a social capital, which consists of all its shares and evolves over time based on the issuance of new shares, contributions from new members, or additional investments. For the *Melyane* SMSA, the number of shareholders is 40 farmers, in 2023, (59% of the members) participating with an amount of 50 TD/share. Thus, the social capital is relatively low, amounting to only 4,000 TD. Most shareholders (70%) purchased only one share, while Board Members bought between 8 and 16 shares, valued at 400 to 800 TD. Note that shareholders hold a stake in the SMSA's capital and actively participate in its financial and strategic management. While members benefit from the services offered by the SMSA, participate in general meetings, and vote on matters concerning its operations, they do not have a vote in major decisions related to its financial management or strategic direction.

The revenues of SMSA *Melyane* come from two sources: membership fees and the sale of agricultural products (such as animal feed, phytosanitary treatments, fertilizers). The annual turnover is limited to 20,000 TD (2022). However, these sources remain insufficient to meet the growing needs of the SMSA for its development. According to 95% of the surveyed members, the main challenge faced by the SMSA is financial. This situation can be attributed to two main factors: first, some members do not pay their membership fees but continue to benefit from the services offered by the SMSA (42.5% of the surveyed members); and second, there is a risk of a decline in agricultural activity, particularly due to climate change and market fluctuations. Consequently, the main expenses (such as rent for the premises, electricity, water, etc.) are covered by the board members, and the SMSA's assets are very limited, consisting primarily of office and computer equipment, along with a truck used for deliveries to members. Furthermore, the absence of a clear strategic vision, particularly a BMC, for the SMSA impacts its promotion and limits its ability to explore new opportunities to diversify its activities and generate revenue, such as through partnerships, grants, or income-generating initiatives.

4.1.2. *External diagnosis of SMSA: Opportunities and Threats*

The external diagnosis examines the environment in which the SMSA operates, aiming to identify both available opportunities and various threats (such as competitive, regulatory, financial, climatic, etc.) (Table 1).

I. Opportunities

The SMSA Melyane is faced with several opportunities that promote its evolution and development. First of all, the existence of development and support programs for FO's, particularly the Agricultural Sector Development and Promotion Project in the Zaghouan Governorate, funded by the African Development Bank (ADB). The project aims to support FO's through targeted training programs (such as administrative and budgetary management, communication techniques, etc.) and the provision of equipment (such as distillation equipment, incubator, etc.). However, the ADB, like most donors, requires that the SMSA have a clear strategic vision and develop a BMC before providing technical and financial support.

In addition, several national and international institutions (such as INGC, ICARDA, and FAO) collaborate with SMSA *Melyane* through formal agreements and conventions concerning the activities of her members (including cereal crops, forage crops, cattle breeding, etc.).

Regarding the financial environment, Investment Law No. 2016-71 of September 30, 2016, which aims to promote investment and encourage the creation and development of businesses. It offers several advantages for the establishment of SMSAs, such as a 55% subsidy on the purchase of agricultural equipment, storage infrastructure, or innovative technologies.

Furthermore, the Tunisian Solidarity Bank provides loans for financing SMSAs repayable over 10 years and at an interest rate of 5%.

II. Threats

The development of SMSA Melyane faces several major threats, the most significant of which is the rural exodus of young people to the capital (Tunis) or coastal regions in search of better economic opportunities. This rural exodus is particularly exacerbated in the El Fahs region, where unemployment and poverty rates remain very high. As a result, the availability of agricultural labor (farmers and workers) is impacted, posing a serious threat to the sustainability of the SMSA.

Another threat is the limited participation of young people in the SMSA *Melyane*. Currently, 40% of the members are between the ages of 55 and 75, while only 10% are under 35. This age distribution could present a challenge, as older farmers may be less inclined to collaborate or embrace new practices.

The third major threat is climate change. El Fahs delegation, like the rest of the country, is increasingly vulnerable to climate risks, including rising temperatures, irregular and decreasing. These challenging conditions threaten agricultural production and, therefore the viability of the SMSA *Melyane*.

Finally, there is the issue of the national and, in particular, the international market, on which Tunisia is heavily dependent. Certain sectors, such as the dairy industry, rely on imports for most of their dairy cows and concentrated feed, while the poultry sector depends on imported chicks and feed.

Table 1 - SWOT analysis of the *Melyane* SMSA (Our results, 2023).

	Strengths	*Weaknesses*
Internal factors	• Fivefold increase in membership since inception (from 12 members in 2014 to 68 members in 2023). • Significant presence of women who represent 53% of the members (2023). • Partnerships with institutional environment (FAO, ICARD, INGC, CRDA of Zaghouan). • Medium to high levels of education (secondary or higher) among board members. • Strong interpersonal relations and absence of social conflicts. • Proximity of products and their availability during critical periods (such as ammonia and seed shortages), coupled with free delivery and flexible payment.	• Small size of family farms (59% of members) and lack of land ownership (23% of members). • The social capital is relatively low, amounting to only 4,000 TD (2023). • Activities and services limited to the sale of animal feed, phytosanitary treatments, fertilizers and fuel. • Financial deficit and inability to cover main expenses (such as rent for the premises, electricity, water, etc.). • Low annual turnover (20,000 TD in 2022). • Absence of a clear strategy and business model. • Limited knowledge among members and board members regarding tax and financial incentives related to SMSAs.
	Opportunities	*Threats*
External factors	• Access to funding and development of specific support programs for FOs (ABD). • Collaboration with national and international institutions (INGC, FAO, ICARDA) through formal agreements and conventions. • Collaboration with regional and local agricultural authorities. • Financial incentives: Investment Law n° 2016-71 of September 30, 2016, such as 55% subsidy on the purchase of agricultural equipment or innovative technologies. • The Tunisian Solidarity Bank provides loans for financing SMSAs repayable over 10 years and at an interest rate of 5%.	• Migration and rural exodus of young people. • Limited involvement of young people (40% of members are between 55 and 75 years old, and only 10% under 35). • Risks associated with climate change. • Heavy dependence on international markets for agricultural inputs.

The elements drawn from the internal and external diagnostics showed the absence of a clear strategy to successfully carry out its activities and services and make sustainable decisions.

4.3. *Development of a Business Model Canvas for SMSA Melyane*

The surveys and SWOT analysis conducted enabled the creation of a BMC for SMSA *Melyane* (Table 2), highlighting both the current activities and the new initiatives proposed in collaboration with its members. Upon completed, the BMC was discussed and validated through consultations with officials from the Zaghouan CRDA and the SMSA president.

The primary activities and services of the SMSA include the sale of animal feed, phytosanitary treatments, fertilizers, and fuel. Since its establishment in 2014, these activities have remained limited in scope. To strengthen the financial situation of SMSA *Melyane* and create employment opportunities in the region, especially for women and youth, additional initiatives have been proposed. These initiatives will emphasize the utilization of local resources and the preservation of traditional know-how.

According to officials from the Zaghouan CRDA, these new activities will be funded by the ADB and the Special Fund for Agricultural Development (FOSDA), which supports agricultural development through grants aimed at

Table 2 - Business Model Canvas (BMC) for *Melyane* SMSA (Our results, 2023).

<table>
<tr><th>Key partners</th><th>Key activities</th><th>Value proposition</th><th>Customer relationship</th><th>Customer Segments</th></tr>
<tr>
<td rowspan="3">Private
• Veterinarian
• Microfinance organizations
• Banks

Public
• INGC
• CRDA Zaghouan
• CTV El Fahs

Development
• ICARDA
• FAO
• ABD</td>
<td>• Sale of animal feed, fertilizers and phytosanitary treatments
• Equipment rental (tractor, combine harvester, manure spreader, etc.)
• Aromatic and medicinal plants:
- Set up of a nursery: 10,000 plants
- Technical monitoring and control
- Distillation and extraction
- Marketing
• Range chicken breeding (150 to 300 chickens per member):
- Technical monitoring and control
- Support for the marketing
• Milk collection center: capacity 1000 liters/day
• Training and support:
- Administrative and financial management
- Communication skills
- APMs extraction and distillation
- Conduct of poultry farming
• Computer space for members' children</td>
<td rowspan="3">• Provide inputs at the right time and at the right price
• Very qualifying training courses
• Agricultural equipment rental service
• Marketing service of essential oils
• Farm chicken marketing service</td>
<td>• Free shipping
• Ease of payment
• Participation in training and awareness days
• Visit to members for technical monitoring and control</td>
<td rowspan="3">• Farmer members and users
• Collectors, retailers, herbalists, processors</td>
</tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr>
<td>• Human resources
- Executive board :6 members
- 1 driver for delivery
- 2 Agricultural counsellors
- Marketing Manager
- 1 Veterinarian
• Material resources
- A truck
- Office equipment
- Extractors and distillers
- Local
• Financial resources
- Working capital</td>
<td>• Direct and free delivery
• Social networks (Facebook page)
• Marketing platform
• National agricultural and agri-food fairs (SIAT, SIAMAP, PAMED)
• Sale in the premises of the SMSA</td>
</tr>
<tr><th colspan="2">Cost structure</th><th colspan="3">Income structure</th></tr>
<tr>
<td colspan="2">Start-up cost: 500,000 TD
• Accounting software
• Training material
• Distillation equipment
• Incubator
• Milk collection center
Cost structure
• Purchase of seeds: 10%
• Purchase of phytosanitary treatments: 7%
• Purchase of fertilizers: 7%
• Purchase of fuel: 15%
• Purchase livestock feed: 24%
• Veterinarian: 3%
• Wages: 20%
• CNSS[1]: 3%
• Local rent: 5%
• SONED[2]: 3%
• STEG[3]: 3%</td>
<td colspan="3">• Membership of members (5%)
• Sales of inputs (13%)
• Animal feed sales (20%)
• Sale of fuel (10%)
• Training contribution (5%)
• Rental of agricultural equipment (12%)
• % on the sale of PAMs products (15%)
• % on chicken and egg sales (8%)
• % on sales to the milk collection center (12%)</td>
</tr>
</table>

[1] Social Security, [2] Charges for the use of water, 3Charges for the use of electricity.

promoting added value and fostering regional development. The first activity to be developed is the Aromatic and Medicinal Plants (AMP) sector (such as rosemary, thyme, mint, lavender, and verbena), where demand in the local market is growing. This activity involves establishing a nursery specialized in the production of AMPs, with an initial capacity of 10,000 plants. It will also include value-added processes (such as drying, distillation, and extraction) as well as the commercialization of a range of finished products, including floral waters, essential oils and dried plants. This will allow members to engage in the AMP sector at every stage, both as producers of plants and as sellers of finished products.

The second activity to be developed is family poultry farming. Currently, 40% of the members are already engaged in this activity, raising small numbers of chickens, ranging from 15 to 100. These members are mainly housewives and young women, both educated and uneducated, seeking employment opportunities. For many, poultry farming provides a vital source of income to cover household and personal expenses while also allowing them artisanal know-how, particularly for those with limited financial resources and land. The goal is to promote this activity by incorporating chick production and free-range chicken farming, as well as creating a branded label for marketing. The target is for each member to raise an average of 150 to 300 chickens.

To ensure the economic profitability of SMSA Melyane's activities, they should be reinforced with technical assistance and support mechanisms. Members will receive training in pasture management and forage production for their flocks, the extraction and distillation of AMP, as well as poultry farming techniques, including incubation, feeding, chick rearing, and marketing. Additionally, to guarantee effective management of the SMSA, the board of directors will undergo training in administrative and financial management, communication techniques, and conflict resolution, board by field experts.

Women are increasingly becoming key actors in the success of FOs, contributing significantly to production, representation, and decision-making. In this context, the final proposed activity, in collaboration with the members, involves creating a computer space within the SMSA premises for members' children. This initiative will not only provide optimal working conditions for the members but also ensure their availability for various SMSA activities (such as meetings, general assemblies, training sessions, and awareness days).

The various activities of the SMSA require the provision of financial, material, and human resources to generate high added value and achieve sustainable competitive advantages. First, the human resources of the SMSA will be strengthened by the addition of two agricultural extension workers, including an engineer to provide technical support to members, a marketing manager to promote AMP products, and a veterinarian to improve animal husbandry practices. Second, in terms of material resources, the SMSA will be equipped with distillation and extraction equipment for AMPs. Additionally, administrative and financial management software is also essential to ensure effective management of the SMSA. Finally, to support dairy farmers, establishing a milk collection center with an initial storage capacity of 1,600 liters per day will be essential, serving 80 dairy farmers (both members and users).

The various activities of SMSA *Melyane* should address the needs of different customer segments, prioritizing members while also considering the needs of users (non-members). These customer segments also encompass other stakeholders involved in the value chains, including collectors, retailers, herbalists, and processors engaged in family poultry farming and the valorization of AMPs.

To enhance its services, SMSA *Melyane* is currently offering free delivery of inputs and animal feed at affordable prices, along with flexible payment options for members. Additionally, to facilitate information sharing, boost membership, and strengthen its brand image, the SMSA plans to promote the distribution of AMP products and poultry farming supplies through social media and a dedicated marketing platform.

The SMSA operates with a defined cost structure and revenue structure. The cost structure includes all expenses related to value creation and covers costs associated with key resources, activities, and partnerships. It is important to note that the start-up of the proposed activities for SMSA *Melyane* will require an investment of 500,000 TD to acquire necessary equipment (for training, distillation, and incubation), establish the milk collection center, and install accounting software. These activities will be funded by the ADB (60%), FOSDA (30%), and member contributions (10%) (Table 2).

The revenue structure outlines all cash inflows generated by the various activities of the SMSA. It identifies the sources of income and explains how the SMSA plans to generate revenue from its services and products. Notably, over half (60%) of the cash inflows will come from the sale of animal feed, inputs, fuel, and farm equipment rentals. Additionally, the SMSA will generate 35% of its income from the sale of AMP products, poultry products (chickens, eggs), and the milk collection center. However, member dues will account for only 5% of total revenue.

It is important to note that these revenues are recurring but are subject to certain conditions, including price fluctuations, climate changes, water resources, and the availability of inputs.

5. Discussion

The results indicate that, although the SMSA *Melyane* has certain strengths, it faces significant challenges that hinder its ability to serve as a true partner in rural development. To effectively fulfill its role and remain relevant to its members, the SMSA must develop a clear strategy and vision that incorporates the key elements essential for its promotion.

The strengthening of SMSAs and FOs, in a broader sense, is closely linked to the enhancement of local resources (such as AMPs, local breeds, traditional varieties, etc.) and the promotion of high value-added local products, often perceived as typical or organic. This approach aligns with territorial development strategies. It enables the effective and sustainable exploitation of local potentials by enhancing artisanal know-how, thus strengthening and energizing the development process (Apostolyuk *et al.*, 2020; Ibrouk and Raoui, 2022).

The promotion of these activities aims to generate additional jobs across the various stages of the sector (supply, production, processing, distribution, marketing), thereby improving and diversifying income sources for vulnerable social groups, such as youth and women (Callois, 2016). These findings are also supported by Gillero *et al.* (2022), who demonstrated that cooperation among farmers acts as a lever for implementing practices, enhancing economic value, and promoting access to strategic local resources.

Moreover, strengthening local resources and traditional knowledge in agricultural strategies plays a key role in enhancing resilience to the impacts of climate change. Traditional agricultural practices, tailored to local conditions and often more environmentally sustainable, provide better responses to climate-related hazards while preserving biodiversity (Apostolyuk *et al.*, 2020; Ouerghemmi *et al.*, 2024).

Technical support is essential for SMSAs to ensure their sustainable economic and social development, including the promotion of gender equality (Quisumbingn *et al.*, 2015 Kinikli and Yercan, 2023). This support encompasses areas such as production, management, productivity improvement, and the adoption of sustainable agricultural practices. For technical support to be effective, it must be accessible to all members of the SMSA, including the most vulnerable (Sapbamrer and Thammachai, 2021; Mushi *et al.*, 2022). This was confirmed by El Badri *et al.* (2023), who demonstrated that entrepreneurial support acts as a catalyst for the development of rural cooperatives in Morocco, helping them to improve their skills and overcome inherent challenges. Similarly, Garnevska *et al.* (2011), through a case study of cooperatives in China, demonstrated that these cooperatives could become more effective by improving members' management skills and their understanding of the legal and regulatory framework governing cooperatives.

The strengthening of SMSAs is closely linked to their understanding of the institutional environment and their financial capacity, enabling them to become autonomous and create favorable conditions for their representation and sustainability (Chaves and Monzón, 2019). To achieve this, board members should not only enhance their leadership skills but also deepen their commitment to the organization, fostering a spirit of innovation and openness to ensure its long-term viability (Mishra and Sharma, 2022). This was similarly observed by M'Barki and Schmitz (2023) in their study of farmers' cheese cooperatives in Morocco, which highlighted how weak governance, a lack of collective spirit, and legal gaps have hindered the promotion of cooperatives. Moreover, the presence of competent leaders and the active participation of members are crucial for the sustainable development of agricultural cooperatives, as they ensure strategic governance and the continuous mobilization of human and material resources. Garnevska *et al.* (2011) confirmed in their study of agricultural cooperatives in northwestern China that strong leadership and continuous member participation in activities such as management, decision-making, production, and marketing are key factors for their successful development.

Access to markets remains a significant challenge for SMSAs, especially in promoting local products. While SMSAs can add value by processing agricultural products and accessing larger markets, this often requires investments in infrastructure, management capabilities, and the fostering of an entrepreneurial spirit. In this context, promoting short marketing circuits strengthens the local economy by providing producers with direct and more profitable business opportunities, while also contributing to the reduction of logistical costs (Callois, 2016; Gillero *et al.*, 2022; Ibrouk and Raoui, 2022).

6. Conclusion and political implications

Since the 2011 Revolution, which marked Tunisia's transition to democracy and the implementation of new legislation on the freedom of association, the role of cooperatives, particularly SMSAs, has been increasingly strengthened. These organizations can contribute to boosting production and income, facilitate the sharing of knowledge and expertise, and improve access to resources and services.

However, SMSAs face various obstacles, including limited market access, difficulty accessing bank credits and scarce financial resources, as well as a lack of training and support. Moreover, the absence of a clear strategy within many SMSAs represents an additional challenge. Without a solid strategic vision and clear objectives, SMSAs struggle to direct their actions and coordinate their efforts. To this end, developing a Business Model Canvas in collaboration with SMSA members and the board of directors could promote SMSAs and facilitate sustainable investment decision-making. This approach aims to secure funding from stakeholders (such as donors and NGOs) while establishing solid governance and fostering partnerships with local authorities and development institutions. This BMC should primarily reflect market trends, member needs, and funding or innovation opportunities for the SMSA. The development of this BMC aims to go beyond traditional approaches to managing SMSAs in Tunisia, offering pathways for their adaptation to current challenges and positioning them as key players in sustainable rural development. These improvement pathways, coupled with inclusive partnerships and government support, could transform SMSAs into engines of economic, social, and environmental growth for rural areas in Tunisia could play a key role in the sustainable structuring of SMSAs. It is crucial that the public policies implemented encourage the integration of SMSAs into incentive mechanisms to encourage private companies to collaborate with them through partnership contracts or research grants or crowdfunding.

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Agricultural producer support and production relation: Panel data evidence from selected countries on agricultural wheat crop

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JEL codes: C23, H71, Q18

Abstract

The study's main purpose is to analyze the effect of wheat producer support on wheat production using panel data methods. The primary independent variable of interest is wheat producer support, and the secondary variables of interest are wheat harvested area, previous period price of wheat, and previous period production of wheat. Panel data include 352 observations from selected 16 countries between 2000 and 2022. All the data are annual and retrieved from the OECD official website. The main finding of this study is that wheat producer support has a positive effect on wheat production. This finding reveals that agricultural support increases agricultural production for wheat crops. The findings indicate that countries should give importance to producer support policies in agriculture and develop new support policies. The secondary findings of this study show that wheat harvested area, previous period price of wheat, and previous period production of wheat have a positive effect on wheat production. The study has significant consequences for the Mediterranean countries, which have a considerable share of world wheat imports during and after the analysis period.

Keywords: *Agricultural policy, Producer support, Subsidies, Wheat production, Panel data analysis.*

1. Introduction

Food systems embrace the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption, and disposal (loss or waste) of food products from agriculture (including livestock), forestry, fisheries, and food industries (Von Braun *et al.*, 2021). Many factors affect the food system in a country. These include market fluctuations, changes in agricultural policies at the national and international level, use of technology, trade conditions, and biophysical properties (such as the presence of water resources, soil quality, carrying capacity, pests, and diseases) (Kurukulasuriya & Rosenthal, 2013). Dimitri and Rogus (2014) stated that the behavioral factors that reflect individuals' food choices could be another factor that can be added to the above factors. However, main-

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ly in the 2000s, climate change has been added to these factors. Climate change and its consequences are the phenomena that all countries face. Agriculture is the food system's primary sector. It is most affected by climate change due to its production structure (Trentinaglia *et al.*, 2023). This situation has led to the formation of literature on the effects of climate change on agriculture (Gregory *et al.*, 2005; Reddy *et al.*, 2013; Wheeler & Von Braun, 2013; Saranga *et al.*, 2024). On the other hand, human nutrition is closely related to grain consumption: wheat, corn, and rice are the three main pillars of human nutrition (Soto-Gomez & Perez-Rodriguez, 2022). Wheat, corn, and rice, which are cereals that provide a significant portion of human nutrition, are among humanity's most important food sources and will continue to be staple foods with the estimated increase in the global population (Aktaş Çimen, 2025). Commodity supplies such as wheat, corn, and rice are important to many countries. They are essential to meet the needs of people living in countries where these commodities are not produced or produced in sufficient quantities. Ensuring the population's food security is one of the primary challenges of the agricultural sector (Harbouze *et al.*, 2024). The issue of access to and availability of food on a global basis is known as food security (Lacirihnola *et al.*, 2015). On the other hand, agricultural production risk affects food availability (Chavas *et al.*, 2022). Food insufficiency has serious consequences. For example, food insufficiency in African societies causes illness and even death. Therefore, ensuring food safety is essential. In summary, this study focuses on agriculture, the priority sector of food systems, and agricultural policies, among the factors affecting food systems, especially agricultural support policies.

Agricultural support policies are an essential mechanism that countries' governments can use to develop the agricultural sector and ensure its sustainability and food security. Agricultural policies affect productivity growth and environmental performance (Lankoski & Thiem, 2020). The development and growth of the agricultural sector will significantly contribute to the country's economy by increasing production, providing employment opportunities, and providing foreign exchange inflows to the country through the growth of export-oriented foreign trade. Agriculture is a sector that has a vital role in economic development. Agriculture provides inputs (or raw materials) to sectors such as industry and services. It is of primary importance for the growth of other sectors of the economy. The agricultural sector provides employment. The agricultural sector helps reduce poverty and raise incomes for the people who live in rural areas and work mainly in farming. This importance increases significantly in countries where the income source of a significant part of the population is agriculture. The agricultural sector also provides a source of foreign currency for the country's economy by exporting agricultural products. In this context, Johnston and Mellor (1961) summarized the contributions of agricultural growth and productivity to economic development in five points: (i) Providing increased food supplies, (ii) enlarged agricultural exports, (iii) transfers of workforce to nonagricultural sectors, (iv) contributions to capital formation and, (v) increased rural net cash income as a stimulus to industrialization. Today, for many countries, agriculture needs to grow to sustain economic growth in the long term.

The agriculture sector is also of social importance. People are fed by the agricultural products that are produced. Ensuring adequate food supply is essential to all societies. With the rapid increase in agricultural trade worldwide, the dependence on international trade to meet food needs has increased (Porkka *et al.*, 2013). This situation causes the fluctuations in international agricultural markets to spread more rapidly to domestic markets. The increase in volatility in agricultural markets makes low-income countries especially vulnerable regarding food security. (FAO, 2010; Ceballos *et al.*, 2017; Bekkers *et al.*, 2017; Gutiérrez-Moya *et al.*, 2021). For most developing countries, food security depends on agricultural product imports. MENA (Middle East and North Africa) countries highly depend on food imports (OECD – FAO, 2018). For example, while the cereal import dependency ratio for low-income economies was 25.9% in 2022, it was 57.5% in North African countries (FAO, 2024).

On the other hand, agriculture is more fragile as a sector with more risks and costs from natural conditions than other sectors. Besides, it includes more seasonal activities. Drought, floods, decrease in water resources, increasing uncertainty in climate, length of season, and increase in precipitation caused by global warming and precipitation increase in soil erosion led to a decrease in agricultural production and an increase in the prices of farm products, creating a food security problem.

Agriculture is a sector where the state intervenes due to its social importance. Agriculture support policies in many countries actively promote food production and reduce hunger and poverty (Zhang *et al.*, 2022). Although state intervention in many sectors has decreased due to the liberalization policies that started in the 1980s, state intervention in agriculture continues for the development of the agricultural industry in both developed and developing countries. In addition, the search for sufficient and safe agricultural production to meet the worldwide population growth keeps agricultural support policies on the agenda. The agricultural sector is a sector that requires support due to its structure and strategic importance.

Agricultural support policies influence production patterns, farming practices, and input use and thus can have significant environmental impacts (Lankoski & Thiem, 2020). Though agricultural supports differ in country practices regarding their types and scope, they are concepts integrated with the agricultural sector. Countries provide different levels of support, from public expenditures to farmers (Ruzsikova, 2019). Some countries subsidize their agricultural producers more significantly, and some countries provide less support from public resources. While the agricultural support in middle- and high-income countries and regions is relatively high, in low-income countries, the level of support is low or even negative (Zhang *et al.*, 2022). According to the classification made by the Organization for Economic Cooperation and Development (OECD), the state's agricultural supports comprise producer, general service, and consumer support. Among these stated supports, producer supports are the most critical (Baliño *et al.*, 2019; OECD, 2023). In this context, in the 1990s, when discussions on the reform of the international agricultural trade system began, the type of support that was taken as the basis for evaluating national support was producer support (Kirsten *et al.*, 2000). Since producers are the main determinants of agricultural activities among these supports, the field studies after that date observed that producer support was the focus point (e.g., Helm & Van Zyl, 1994; Kirsten *et al.*, 2000; Chintapalli & Tang, 2021; Koetse & Bouma, 2022). Therefore, it is essential to determine the effects of producer support on the development of agriculture.

In the context of the above explanations, the study's main purpose is to analyze the effect of wheat producer support on wheat production using panel data methods. Wheat was examined as an essential agricultural product in this study because it has importance for several reasons: (i) Wheat is one of the first domesticated plants in the world and is among the plant foods widely grown and consumed today, (ii) it provides one-fifth of the world's total calorie and protein supply, (iii) it is one of the most widely produced primary crops in the world, and (iv) twenty-five percent of worldwide wheat production is exported. With this rate, wheat is the most traded grain in the world (Erenstein *et al.*, 2022).

This study makes many contributions to the literature in terms of being a study that only deals with (i) an essential agricultural product such as wheat, (ii) analyzing wheat producer supports (producer single commodity transfers), (iii) using a panel data set consisting of a selected group of countries, (iv) its findings for a selected group of countries and, (v) its consequences for the Mediterranean countries. Besides these, due to the nature of panel data methods, the fact that they work with many observations considered cross-sectional and time dimensions has enabled the subject to be addressed from a different perspective with more information.

The rest of this study was organized as follows: The next section covers the theoretical framework of agricultural support policies. Section three was composed of the literature review. In section four, applications were given. The last section contains the conclusion.

2. Agricultural support policies

The agricultural sector is much more exposed to uncontrollable risk factors, such as natural conditions, than other sectors. These risk factors in the agricultural sector require governments to be more responsible for keeping farmers in the agricultural sector and ensuring adequate food supply (Vigani *et al.*, 2024). This situation leads to agriculture being one of the sectors where government intervention is required. State interventions, on the other hand, consist of agricultural support and regulations. Agricultural support, also the subject of this study, is the most critical intervention tool.

There are different opinions on agricultural support, primarily based on theoretical ideas and the development levels of the countries. In theory, the proponents of classical and neo-classical economics are opposed to state intervention in agriculture and other sectors due to the ideology of this movement. For example, economists with neo-classical thought have addressed the state's role in agriculture and stated that state intervention in agriculture in developed and developing countries leads to severe market distortions (Vyas, 2022). In comparison of the developed and developing economies, it is seen that there are different practices in agricultural support. In the case of advanced economies, it is observed that with economic growth, the gap between the incomes of farmers and urban workers widens as the demand for nonagricultural goods and services increases faster than the demand for agricultural products. In addition, farmers in developed countries face higher labor costs than producers in developing countries, and they need help to compete.

For this reason, the farmers' lobby's demand for various concessions and subsidies increases in developed countries. With a high income level, governments in these countries can meet the needs of farmers because the subsidies given to farmers include only a tiny part of the country's budget and can be easily covered. Farmers are better organized and able to express their demands better in these countries.

On the other hand, farmers are poor, uneducated, and unorganized in the case of developing countries. Therefore, they are unable to express their demands and protect their interests. As a result, while agriculture in developed countries earns 'rent' due to state interventions, it becomes difficult for agriculture to earn rent in developing countries. At this stage, governments tend to appease industrial workers and urban consumers at the expense of the agricultural sector. In other words, developing countries' governments tax the agriculture sector. Therefore, government interventions in developed and developing countries distort markets, leading to misallocation of resources and loss of productivity. This means government intervention is not good because markets function better without them. The above views have been criticized from various angles. These criticisms are explained on the following grounds:

- Especially in developing countries, there need to be more efficient markets to allocate resources appropriately. The initial conditions for the efficient functioning of markets, such as equal access to productive resources, ease of entry, and symmetry in information, need to be more present in developing countries. In other words, 'market failures' and 'market losses' are common in developing countries (Vyas, 2022).
- In addition, other justifications for government intervention are that uncontrolled market forces do not improve food security, pose some challenges and that governments are under political pressure to increase and stabilize farmers' income (Helm & Van Zyl, 1994).
- In both developed and developing countries, governments intervene in the agricultural sector to respond to political-economic pressures with support such as trade policies or price support for certain agricultural products to develop agriculture (CGIAR Research Program on Policies, Institutions, and Markets (PIM), 2021).
- The increase and diversification of numerous socio-economic and bio-physical factors affecting food systems and, thus, food security has increased the importance of government interventions in this sector. Adaptation to changing conditions and results for sustainable agriculture requires a connection with incentives (Piñeiro *et al.*, 2021).

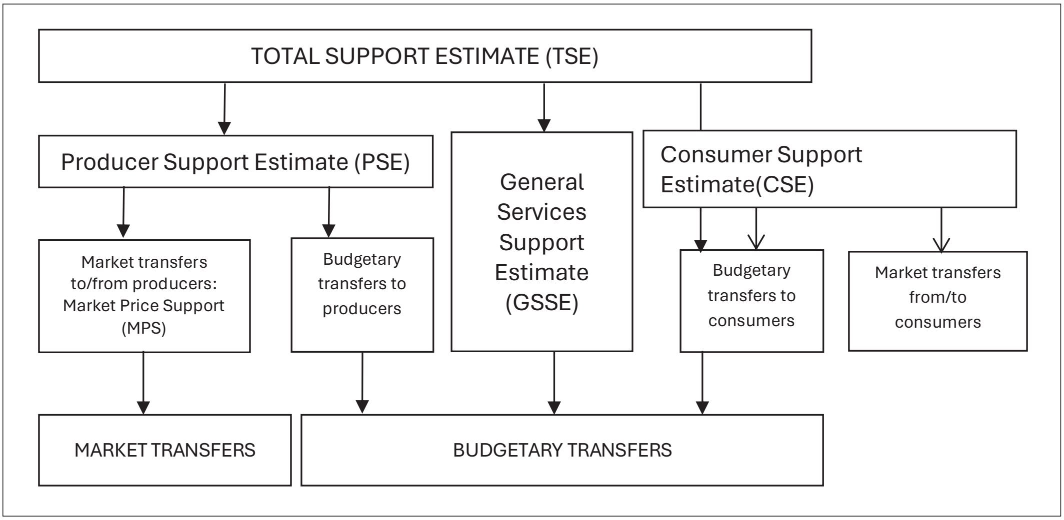
- On the one hand, the importance of agricultural products for individuals and the fragility of agricultural production due to many factors necessitate government support. Climate change is one of these factors. Climate change has increased the fragility of agriculture much more and made government support more necessary. Climate change imposes additional financial burdens on farmers, such as crop yields, the possibility of extreme natural events, and investments in new technologies compatible with climate change. Support is especially mandatory for producers to meet these costs (Kurukulasuriya & Rosenthal, 2013).

Within the framework of these debates, for much of the 1990s, discussions about reforming the international agribusiness system were dominated by issues related to domestic agricultural policy and, more specifically, levels of local support to farmers. Afterward, agricultural policies have maintained their importance in every period until today and still have an essential place.

As general government support, the support given to the agricultural sector shows diversity. On the other hand, researchers and international official organizations classify these supports according to various criteria. For example, Piñeiro *et al.* (2021) divided incentives into four groups. The first is market-based incentives. These economic incentives include changes in input and output prices, income transfers, or other cash or in-kind incentives provided to agricultural producers. The second is non-market incentives. Non-market incentives are a broad group of non-market-based mechanisms, such as technical assistance and technology transfers, to improve environmental sustainability. The third is regulatory measures, which are general rules or specific actions implemented by government agencies, private businesses, and organizations to improve environmental and economic outcomes. These supports include certifications given in the agricultural sector and environmental laws and standards. The fourth is cross-compliance incentives. They are payments made directly from the budget: subsidies, depending on farmers' compliance with fundamental environmental standards or keeping the land in good agricultural and ecological conditions (Piñeiro *et al.*, 2021). Another example is the classification of the OECD, which is one of the leading official organizations working on agricultural support within the scope of this framework. In the classification made by the OECD, the support provided by the state to agriculture is classified into three groups, as is seen in Figure 1.

These groups are (i) Producer Support, (ii)

Figure 1 - Structure of agricultural support indicators.



Source: OECD, 2023, p. 82.

General Services Support, and (iii) Consumer Support. Consumer support, similar to producer support, covers transfers from the market and budget to consumers of agricultural goods (OECD, 2023). General service support includes expenditures benefiting the agricultural sector rather than directly to individual producers. Producer supports cover all supports given to agricultural producers.

Producer supports are also divided into two. The first is market price support (MPS). MPS represents transfers from taxpayers and consumers to agricultural producers in the form of domestic market prices that are higher than international reference prices due to domestic and foreign trade policies. It involves implicit transfers from consumers to producers by creating a price gap between domestic market prices and border prices for specific agricultural commodities (Vos *et al.*, 2023). MPS will be positive if product prices are higher than reference prices. Conversely, negative MPS is formed. The second is transfers from the budget to producers. The source of these transfers is transfers from taxpayers. Budget transfers consist of direct payments and forego budget revenues. Tax concessions can be given as an example of foregone budget revenues. Farmers pay indirect taxes not only on the income they receive but also on their agricultural inputs. These subsidies, which include the various taxes farmers pay and the subsidies they receive, go beyond market prices. Because these supports also affect farmers' production decisions. This indicator is more complex than other supports. Some of the supports within this scope include indirect income transfer in the form of payments and tax concessions given directly to the producer. In the agricultural sector, producers and consumers look at prices and other factors such as subsidies, tax deductions, and exemptions. These factors change the expectations of producers and buyers (Baliño *et al.*, 2019).

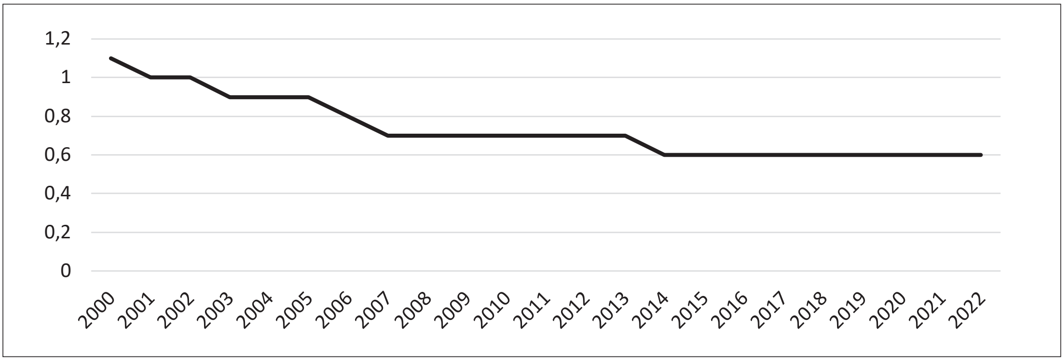
Producer decisions are the main determinants of agricultural production. Producer support is the most important type of support in all economies among these supports. Producer supports also consist of cost and minimum price supports. Cost subsidies to producers should be at a level that covers at least part of the planting costs incurred by farmers. Minimum price support occurs in real terms when the market price of crops is below the minimum price set by the government. Minimum price support may have different applications. The most common of these supports is when the government gives a difference to farmers if the current market price for the products is below the market price determined by the government in advance (Nan *et al.*, 2023). Among the producer supports, the supports that directly affect production decisions are the MPS provided by commercial measures and the supports provided to outputs (Laborde *et al.*, 2021).

Producer support varies from country to country. For example, a study covering 54 countries conducted by the OECD shows that the weight of support given to the producers varies from country to country. OECD reported that Australia had the lowest producer support among OECD countries in 2023 (OECD, 2023). Moreover, the distribution of agricultural support as an average for the 2020-2022 period shows that 74% of the total support was given to the producers individually, either directly from government budgets or indirectly through MPS. In this distribution, the share of general service support was 12.5%, and consumer support was 13.5% (OECD, 2023).

Baliño *et al.* (2019) note that when considering the types of support provided to producers, although MPS has decreased in most OECD countries, total agricultural support remains relatively high due to subsidies and other transfer payments. This situation increased nominal agricultural support in OECD countries in the 2000s (see Figure 2).

Following Figure 2, it is seen that the share of total agricultural subsidies in GDP has steadily declined from 2000 to 2007. Between 2007 and 2013, it generally continued in the same course. This share declined again in 2014. It continued in the same course in the following years. The decline in state support in the 2000s was due to the World Trade Organization's (WTO's) neo-liberal agricultural policy proposals, especially for developing countries. Similarly, in the Uruguay Round, the abolition of support mech-

Figure 2 - Evolution of total support to agriculture in OECD (% of GDP).



Source: OECD, 2023, p. 84.

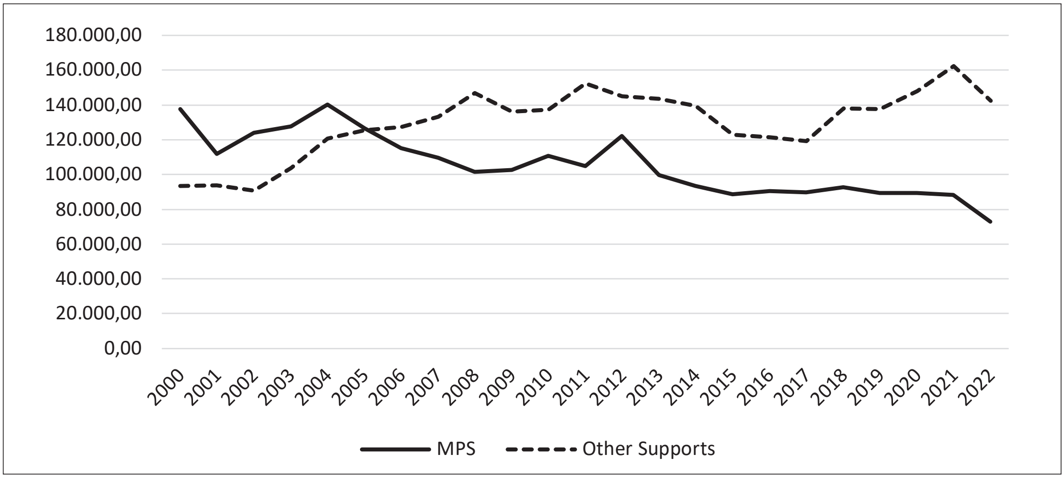
anisms that disrupt the free-market system was an issue on the agenda (OECD, 2001). However, the lack of fiscal incentives is considered in many countries as a significant obstacle to the agricultural regime change necessary for sustainable agriculture to solve the problem of food security. European Union (EU) countries such as the Netherlands are at the forefront of these countries (Vermunt *et al.*, 2020). Developing economies have tended to tax local agricultural sectors, while developed economies have subsidized their farmers. This trend began to change in the 1980s when developing economies ended most of the taxes on agriculture and subsidies that supported industry as part of their structural adjustment policies. In addition, although developed countries have taken border measures to protect agriculture, developing countries have reduced direct price support to reduce price distortion in international markets for the benefit of agriculture. (Baliño *et al.*, 2019). All these developments have created a situation that is against developing countries. Developing countries already have structural problems, such as unstable economies and incomplete infrastructure. Because in a large part of these countries, rural areas are often marginalized and lack essential services, rural development is a crucial aspect of overall development efforts. In addition, constraints such as lack of access to technology, inputs, and markets are often the dominant agricultural elements in these countries (Trentinaglia *et al.*, 2023).

Although developed countries have some commitments to free trade, they can get more priority for protecting their agriculture. For example, support for farmers accounted for one-third of farmers' incomes in the United States in 2000, half in the EU, and two-thirds in Japan (Kannan *et al.*, 2000). However, climate risks to food security are even more significant for poor populations and tropical regions. Wealthy populations and temperate zones not near restrictive thresholds for food availability, access, use, or stability are less at risk (Brown *et al.*, 2015). Another significant change in the 2000s is the change in state support types within themselves. In many OECD countries, MPS to producers has decreased, while direct support to producers has increased (see Figure 3).

In many OECD countries, market price support to producers has decreased, while direct support to producers has increased. In some countries, such as Australia, market price support was removed in 2000 (OECD, 2023). When the MPS given to producers in OECD countries is compared with other supports, it is seen that MPS were higher than other supports until 2005, but their support share decreased after this year (see Figure 3).

Although there have been decreases in MPS, the weight of these supports continues in some countries (Canada and Colombia). When EU and OECD countries are evaluated in general, it is seen that this type of support is decreasing. For example, in EU countries, MPS for producers declined from 46% in 2000-02 to 16% in 2020-22 (OECD, 2023). As with other supports, the

Figure 3 - Market price and other supports to agriculture in OECD (Millions of US Dollars).



Source: OECD official web site. https://data.oecd.org.

share of subsidy payments made directly from the budget and support in the form of tax concessions has increased. In the 2000s, the most crucial fiscal policy instrument for agriculture in EU countries was payments made directly from the budget (Sinabell *et al.*, 2009).

For incentive policies to be successful, some issues must be taken as a basis. First, when designing a policy, the number of incentives used should often be directly linked to the number of desired outcomes. For example, it would be a mistake to expect an economic incentive for a specific outcome, such as soil health, to achieve an additional result, such as increases in productivity. Secondly, prerequisites for implementation should be considered, including an understanding of the impact of the policy and the selection of appropriate institutions and mechanisms. Conditions include audit mechanisms to ensure implementation and a net knowledge of the sustainability of the incentive. Third, when assessing the effectiveness of incentives, one should consider the trade-off between economic and environmental consequences and, if possible, social ones. Incentives must be large enough to motivate a change in manufacturing practices (Piñeiro *et al.*, 2021). At the same time, state support has a cost in terms of the budget. This support should not be unsustainable. For example, a study conducted in India stated that the current level of subsidy is an untenable financial burden for the state (Sharma & Gulati, 2005).

3. Literature

There are theoretical and empirical studies on agricultural support policies in the related literature. One of the early studies conducted by Johnston and Mellor (1961) discussed the role of agriculture in economic development. Gulati (1989) measured the level and spread of input subsidies in Indian agriculture during the 1980s. The study covers four primary inputs of modern agriculture: fertilizers, irrigation, electricity, and credit. The study revealed that total input subsidies created approximately 17% of net added value for India, and irrigation supports constituted more than 70% of the total input support. Helm and Van Zly (1994) analyzed the support given to producers in the agricultural sector in South Africa with data for the period 1988/89 to 1993/94. Analysis results showed that agricultural support increased steadily. In addition, it was stated in the study that market price support is the most significant component of domestic support and contributed about 48% of total support during the last four years of the analysis. In another study by Helm and Van Zyl (1995), South Africa's agricultural support was compared with that of some selected countries in the developed world. Researchers stated that except for Australia and New Zealand, South Africa had a relatively low degree of support compared to the other selected developed countries. The OECD has published a cross-nationally comparable data set on agricultural support since 1986 and has made it available since 1998 (Park & Jensen, 2007). The availability of such data has paved the way for studies in this field. On the other hand, it has been observed that some academics, such as Kirsten *et al.* (2000), have published publications criticizing and updating the OECD's calculations.

The number of studies in this field has increased relatively in the post-2000 period. Recent studies addressing different aspects of the subject are as follows: Frandsen *et al.* (2003) studied the impact of eliminating or decoupling at the individual member-state level in the European Union and non-member regions of liberalizing domestic support in the EU. Researchers found that the existing domestic support payments in the EU are indeed coupled with production, affecting production decisions and distorting international trade with adverse effects on the export potential of developing countries. Koo and Kennedy (2006) analyzed the changes in the distribution of social welfare among consumers and producers in both exporting and importing countries resulting from reduced subsidies. Researchers stated that their theoretical analysis indicates that domestic and export subsidies distort the trade flows of agricultural goods from exporting countries to importing countries. Piñeiro *et al.* (2021) investigated much-needed evidence about the effects of different incentives on farmers' adoption of sustainable agricultural practices and the expected agricultural, economic, and environmental consequences of such interventions. The study's findings show that incentives that provide financial benefits are better adopted in the short term. Chintapalli and Tang (2021) examined the effects of credit-based MPS in stimulating production. Researchers found that high MPS cannot improve the farmer's income, and the net benefit of market price support may be harmful. Koetse and Bouma (2022) analyzed whether support packages consisting of public and private payments would effectively promote a regime change in agriculture and how payments could further increase this effect. In the Netherlands, a significant sample of farmers producing crops and dairy products was taken as a basis. According to the analysis results, the importance of offering policy packages consisting of mixed incentives was emphasized to encourage farmers to adopt environmentally inclusive agricultural practices. It is also stated that the combination of incentives is more effective than individual incentives alone. Sun *et al.* (2023) investigated incentives and conditions that can enable adopting climate-change-adaptive technologies in agriculture. To this aim, they developed an evolutionary game model to analyze the behavior of local governments and farmers to encourage them to use technologies compatible with climate change. According to the study's findings, incentives in the form of subsidies and cost-sharing to be given to farmers increased the use of these technologies. Nan *et al.* (2023) evaluated the impact of three different strategies, namely cost subsidy, minimum price subsidy, and term contracts, on farmers, consumers, and society. In this search, alternative tools were examined, considering the burden of state support on the budget. The study's findings are that cost subsidies provide superior advantages for farmers and society when there is minimal uncertainty about harvest yield. When this is not the case, farmers benefit more from prospective contracts rather than relying on government subsidies. These results suggest that policymakers must design subsidy policies tailored to specific agricultural contexts to ensure optimal benefits for all stakeholders. Trentinaglia *et al.* (2023) conducted an empirical study of 115 developing countries covering 2010-2020. The results show that international aid to agriculture, especially climate change adaptation aid, positively affects agricultural productivity growth. Researchers also found that countries with higher climate preparedness benefited the most from aid. In contrast, countries that were highly vulnerable and heavily dependent on the agricultural sector benefited equally less from the aid received. Mgomezului *et al.* (2024) evaluated the efficiency of input subsidy programs given to farmers for the Malawi economy. The SWOT analysis showed that most smallholder farmers are unproductive despite the government's efforts to increase yields through subsidies. Following the finding that large farmers are more productive, the study reviewed models to increase agricultural production. Vigani *et al.* (2024) showed that higher intensity of common agricultural policy subsidies reduces spending on the risk management toolkit, which means that the income stability capacity of direct payments can be an alternative to risk management and can be a substitute between policies for EU countries.

On the other hand, recent studies that address the issue in the context of the relationship between agricultural support and production are as follows: Aktaş *et al.* (2015) analyzed twelve countries (US, EU, Australia, Brazil, China, South Africa, Israel, Canada, Mexico, Russia, Chili and Türkiye) panel data using annual data from 1995 to 2010 from the OECD database. Researchers concluded that price and input support increased agricultural output. Işık and Bilgin (2016) examined the relation between total agricultural production and market price and other supports for Türkiye using annual data for 1986-2015. Researchers found that the given supports positively influenced agricultural production. Vozarova and Kotulic (2016) studied the dependence of agricultural production and subsidies in Slovakia. The research results showed that annual gross agricultural production and the volume of subsidies strongly correlate with Slovak agriculture. Yıldız (2017) analyzed the effects of agricultural support on an agricultural production level for Türkiye using data from 2006-2016. The research results showed a long-term relationship between agricultural support payments made from the central government budget and agricultural production level. Zampa and Bojnec (2017) studied the relationships between subsidies and financial performance in Slovenia. Researchers reported that subsidies have a positive impact on financial indicators. Akyol (2018) analyzed the relationship between agricultural incentives and agricultural value-added between 2000 and 2016 in five developing countries (Türkiye, South Africa, Mexico, China, and Brazil). In this analysis using the panel data, researchers found that increased agricultural incentives positively affected the agricultural value added. Koç *et al.* (2019) studied the effects of government support and credits on Turkish agriculture. Researchers found the positive effect of agricultural credits on agricultural value added. On the other hand, researchers reported that they found a negative effect of government support on agricultural value added. Baştan and Songül (2019) investigated the impact of agricultural support on the value of agricultural production for six products (wheat, maize, cotton, rice, beef, veal, milk, and poultry) on OECD and selected countries using annual data for 2006-2017. Researchers concluded that support positively affects agricultural production value but is ineffective regarding animal production. Igberi *et al.* (2020) investigated the relationship between agricultural output and government spending on agriculture in Nigeria between 1987 and 2015. Researchers found a positive and significant long-run relationship between these variables. Önder and Şahin (2020) studied the relationship between agricultural production and subsidy policies in Türkiye from 2000 to 2020. They concluded that the subsidy policies had a positive effect on agricultural production. Canbay (2021) studied the effect of agricultural support on crop production in Türkiye between 1995 and 2018 with the obtained data from the OECD. Researcher reported that agricultural support in Türkiye positively affects short- and long-term crop production. Sağdıç and Çakmak (2021) studied the relationship between agricultural subsidy payments and agricultural production in Türkiye for the quarterly data between 2006 and 2019. Study results showed that agricultural subsidy payments have a long-term effect on the level of agricultural production in Türkiye. Agyemang *et al.* (2022) studied the effect of increased agricultural input subsidies on agricultural productivity in Ghana. Researchers found that agricultural productivity increases as farmers' level of agricultural input subsidy increases. Oğul (2022) examined the relationship between agricultural subsidies and agricultural production in Türkiye with quarterly data between 2006 and 2021. Researcher concluded that agricultural subsidies increase agricultural production in the long term. Bulut and Bayraktar (2023) investigated the effect of deficiency payment and land-based direct support given to eleven crop products in Türkiye on the production amount for 2002-2019 with the panel data method. Researchers determined that the supports subject to the research positively affected production. Yang *et al.* (2023) investigated the impact of agricultural subsidies on grain production in China. Research findings showed that agricultural subsidies in major grain-producing regions have significantly increased rural household grain yield. Özşahin *et al.* (2023) analyzed the data of six developing countries (China, Russia, Brazil, Indonesia, Mexico, and Türkiye) obtained from the World Bank and OECD from 2002-2018 by panel data method. Researchers found a positive statistically significant relationship between agricultural support and agricultural value added. Liu *et al.* (2024) studied the effects of agricultural subsidies on the technical efficiency of agricultural production technology and factor input for China. Research findings indicated that agricultural subsidies have substantial impacts and increase the technical efficiency of the production process.

4. Application

The method is briefly explained in this section. Afterward, the econometric model and data are described. The last section includes the estimation results.

4.1. *Method*

Time series, cross-section, and panel data are the types of data that are generally used for empirical analysis (Gujarati, 2003). In the time series data, the observation values of a variable are measured by its change over time. In cross-sectional data, observation values of a variable are measured from different cross-sectional units (e.g., countries, cities, or firms) in the same period. Panel data involves a cross-sectional N and a time series T dimensions (Hsiao, 2003). Panel data are repeated observations on the same cross-section (Cameron & Trivedi, 2005). A panel data set offers a certain number of advantages over traditional pure cross-section or pure time series data sets (Matyas & Sevestre, 1996): (i) Because of the number of observations *NT* is more than time series and cross-section data, more reliable estimates are produced, and more sophisticated models are tested with less restrictive assumptions, (ii) because of the structure of panel data in two dimensions, independent variables are less likely to be highly correlated and panel data sets alleviate the multicollinearity problem, (iii) panel data sets make it possible to identify and measure effects that are not detectable in pure cross-section or pure time series data and, (iv) the use of panel data may eliminate or reduce estimation bias. The panel data observations can be denoted on the variables X and Y as X_{it} and Y_{it} where the first subscript i refers to the individual being observed and the second subscript t refers to the date at which observed (Stock & Watson, 2007). The data set is called a balanced data set when the same periods are available for all cross-section units, and in other cases, it is called an unbalanced panel data set (Wooldridge, 2002).

The most restrictive model is called a pooled model that specifies constant coefficients (Cameron & Trivedi, 2005):

$$y_{it} = \alpha + x'_{it}\beta + u_{it} \quad i = 1, \dots, N, \quad t = 1, \dots, T. \tag{1}$$

Here, Y_{it} is a scalar dependent variable, is a kx1 vector of independent variables, and u_{it} is a scalar error term. A variant of the pooled model is the fixed effects (FE) model that permits intercepts to vary across cross sections while slope parameters do not is as follows:

$$y_{it} = \alpha_i + x'_{it}\beta + u_{it} \quad i = 1, \dots, N, \quad t = 1, \dots, T. \tag{2}$$

Here, α_i are random variables potentially correlated with the independent variables that capture unobserved heterogeneity across cross-sections. The significance of the cross-section effects is tested against a pooled model with the redundant fixed effects test. The null hypothesis is that cross-section effects are insignificant, which implies that the pooled model is the appropriate specification. The alternative hypothesis states that cross-section effects are significant, which implies the FE model with cross-section effects is the appropriate specification. On the other hand, the significance of the period effects can also be tested similarly. In this case, α_t are random variables potentially correlated with the independent variables that capture unobserved heterogeneity across periods.

The other variant of this model, called the random effects (RE) model, assumes that the unobservable cross-sectional effects (α_i) are random variables distributed independently of the X independent variables (Cameron & Trivedi, 2005, p. 700). That is, they have no covariance ($Cov(\alpha_i, X) = 0$). If there is covariance between them ($Cov(\alpha_i, X) \neq 0$), then the basic assumption is violated for the RE model, and it cannot be used. The Hausman test is applied to test this issue. The null hypothesis is $Cov(\alpha_i, X) = 0$, implying that the RE model is appropriate. The alternative hypothesis is $Cov(\alpha_i, X) \neq 0$, implying that the FE model is appropriate.

4.2. *Econometric model and data*

The study's primary purpose is to analyze the effect of wheat producer support (*WPS*) on wheat production (*WP*) using panel data methods. So, WP_{it} is the dependent variable, which is wheat production in the current period, and WPS_{it} is the primary independent variable of interest, which is wheat producer support in the current period. Secondary variables of interest that may have an impact on the dependent variable in this relationship are as follows: Wheat harvested area in the current period (WHA_{it}), previous period price of wheat (WPR_{it-1}), and previous period production of wheat (WP_{it-1}). In line with the Nerlove (1956) supply response model, previous period production quantity and price were included in the model as explanatory variables as it was also used in several studies (e.g., Albayrak 1998; Özkan *et al.*, 2011; Haile *et al.*, 2016). The functional relationship put forward for this purpose in the closed form is as follows:

$$WP_{it} = f(WPS_{it}, WHA_{it}, WPR_{it-1}, WP_{it-1}) \quad (3)$$

This functional relation can be expressed in the open form as the following pooled model form of the panel data model:

$$WP_{it} = c + \beta_1 WPS_{it} + \beta_2 WHA_{it} + \beta_3 WPR_{it-1} + \beta_4 WP_{it-1} + u_{it} \quad (4)$$

Here, the subscript "*i*" indicates the countries (16 countries), and the subscript "*t*" indicates the period (2000-2022). All variables were measured annually and retrieved from the OECD official website in June 2024. Each one of the variables has 352 observations. The data set included the following countries: Argentina, Brazil, Canada, India, Israel, Japan, Kazakhstan, Mexico, Norway, Russian Federation, Switzerland, Türkiye, Ukraine, USA, South Africa and China. While selecting the countries in this data set, the selection was made by determining the countries whose data on the variables to be used in the analysis were available. The panel data set allowed panel data regression inferences to be made using all the numerical information. All estimations were made in the Eviews program.

Wheat production dependent variable was measured in thousands of tons, and wheat producer support independent variable was measured in millions of US dollars. Producer single commodity transfers were used as a wheat producer's support indicator. The OECD defines producer single commodity transfers as the annual monetary value of gross transfers from consumers and taxpayers to agricultural producers, measured at the farm gate level. The producer's single commodity transfers refer to the total support given to manufacturers. In other words, the producer's single commodity transfers consist of market price support, product-based budget, and other transfers. The secondary independent variables of interest were measured as follows: The wheat harvested area was measured in thousand hectares, the previous period price of wheat was measured as US dollars per ton, and the previous period production of wheat in thousands of tons. The economic expectations are as follows:

- As wheat producer support increases, wheat production is expected to increase. Therefore, the economic expectation regarding the coefficient of the WPS_{it} variable is positive ($\beta_1 > 0$).
- As the wheat harvested area increases,

wheat production is expected to increase. Therefore, the economic expectation regarding the coefficient of the WHA_{it} variable is positive ($\beta_2 > 0$).

- As the price of wheat in the previous period increases, wheat production is expected to increase. Therefore, the economic expectation regarding the coefficient of the WPR_{it-1} variable is positive ($\beta_3 > 0$).
- As the previous period of wheat production increases, wheat production is expected to increase. Therefore, the economic expectation regarding the coefficient of the WP_{it-1} variable is positive ($\beta_4 > 0$).

4.3. *Estimation results*

The following steps were applied in the analysis, and summarized results were achieved:

- Step 1: The pooled model, FE model with cross-section effects, and FE model with period effects were estimated separately.
- Step 2: Cross-section and period effects were tested separately against a pooled model with redundant fixed effects tests. The FE model with cross-section effects was found to have appropriate model specifications.
- Step 3: The FE model was tested against the RE model by using the Hausman test, and it was found that the basic assumption that $Cov\ (\alpha_i, X) = 0$ is violated for the RE model. Then, the FE model found an appropriate model specification. Moreover, Breusch-Pagan and Honda Lagrange Multiplier (LM) tests were also used to test random effects.
- Step 4: The EGLS method (cross-section SUR) was applied to obtain more reliable estimates for the FE model.
- Step 5: The normality of residuals was tested with the Jarque-Bera test. Cross-sectional dependence of residuals was tested with Breusch-Pagan LM and Pesaran CD tests. Residuals were found to be normally dis-

Table 1- Pooled, one-way fixed effects with cross-section and period effects estimations.

Models / *Coefficients*	*Model 1*	*Model 2*	*Model 3*
	Pooled OLS	*One-way fixed effects with cross-section effects*	*One-way fixed effects with period effects*
Constant	-2294.548 (0.0015)	-14131.27 (0.0000)	-2307.258 (0.0040)
Independents			
WPS_{it}	0.249897 (0.0056)	0.266961 (0.0045)	0.241194 (0.0088)
WHA_{it}	0.420406 (0.0000)	2.537085 (0.0000)	0.406927 (0.0000)
WPR_{it-1}	6.511865 (0.0036)	14.42092 (0.0006)	6.593556 (0.0097)
WP_{it-1}	0.895755 (0.0000)	0.554427 (0.0000)	0.900166 (0.0000)
Statistics			
R^2	0.983056	0.988281	0.984242
$\bar{R}^2$	0.982861	0.987611	0.983033
F	5033.020 (0.0000)	1473.637 (0.0000)	814.4613 (0.0000)
RMSE	4534.515	3771.019	4372.963
SSR	7.24E+09	5.01E+09	6.73E+09
Akaike	19.70523	19.42171	19.75200
Schwarz	19.76011	19.64124	20.03738
Hannan-Quinn	19.72707	19.50907	19.86556
DW	2.546771	1.984865	2.530932

Note: In parenthesis, p-values are given.

tributed, and no cross-sectional dependencies were found.

The pooled model, one-way fixed effects with cross-section model, and one-way fixed effects with period effects model were initially estimated. The estimations are given in Table 1 above:

In these models, all coefficients are statistically significant at the 5 percent significance level (p-value < α=0.05). Also, in each of these models, the p-values of F statistics show that the models are statistically significant (p-value < α=0.05). When the coefficients of determination (R^2) are examined, it is seen that the model with the highest explanatory power is Model 2. When the RMSE, SSR, Akaike, Schwarz, and Hannan-Quinn criteria are examined, with the smallest criteria values, Model 2 appears to be the most appropriate. Although Model 2 is a proper model to evaluate the above statistics, a formal test must be performed to decide whether the cross-section effects and period effects are essential. The redundant fixed effects test results for both cross-section and period effects are given in Table 2

The p-value for the period effects shows that the period effects are insignificant (p-value ≥ α=0.05). However, the p-value for the cross-section effects shows that the cross-section effects are significant (p-value < α=0.05), which means that the FE model with cross-section effects is a better model specification than the pooled model. Therefore, Model 2 appears to be the appropriate model at this stage. However, whether the effects are fixed or random should be determined. For this purpose, the estimation results are given in Table 3.

In these models, all coefficients are statistically significant at the 5 percent significance

Table 2 - Redundant fixed effects test statistics.

Statistics / *Effect Tests*	*F- Statistics*	*Chi-square Statistics*
Cross-section Effects	9.869699 (0.0000)	129.798550 (0.0000)
Period Effects	1.168192 (0.2772)	25.539249 (0.2246)

Note: In parenthesis, p-values are given.

Table 3 - One-way fixed effects and random effects with cross-section estimations.

Models / *Coefficients*	*Model 2*	*Model 4*
	One-way fixed effects with cross-section effects	*One-way random effects with cross-section effects*
Constant	-14131.27 (0.0000)	-2294.548 (0.0002)
Independents		
WPS_{it}	0.266961 (0.0045)	0.249897 (0.0011)
WHA_{it}	2.537085 (0.0000)	0.420406 (0.0000)
WPR_{it-1}	14.42092 (0.0006)	6.511865 (0.0006)
WP_{it-1}	0.554427 (0.0000)	0.895755 (0.0000)
Statistics		
R^2	0.988281	0.983056
$\bar{R}^2$	0.987611	0.982861
F	1473.637 (0.0000)	5033.020 (0.0000)
RMSE	3771.019	4534.515
SSR	5.01E+09	7.24E+09
DW	1.984865	2.546771

Note: In parenthesis, p-values are given.

Table 4 - Hausman test results.

Test \ Statistic	Chi-square Statistic
Cross section random	140.899819 (0.0000)

Note: In parenthesis, p-values are given.

Table 5 - Lagrange Multiplier (LM) tests for random effects.

Test \ Dimension	Cross-section	Time
Breusch-Pagan	1.251492 (0.2633)	0.161360 (0.6879)
Honda	1.18701 (0.1316)	0.401696 (0.3440)

Note: In parenthesis, p-values are given.

level (p-value < α=0.05). Also, in each of these models, the p-values of F statistics show that the models are statistically significant (p-value < α=0.05). When the coefficients of determination (R^2) are examined, it is seen that the model with the highest explanatory power is Model 2. When the RMSE and SSR criteria are examined, all statistics show that the model with the smallest value is Model 2. According to these criteria, the most appropriate model is Model 2. Although Model 2 is a proper model to evaluate the above statistics, a formal test must be performed to decide whether the fixed or random effects are essential. The Hausman test result for this evaluation is given in Table 4.

The p-value for the Chi-square statistic shows that the null hypothesis is rejected (p-value < α=0.05). This means a covariance exists between unobservable cross-sectional effects (α_i) and the X independent variables ($Cov(\alpha_i, X) \neq 0$). So, the FE model is the appropriate model specification.

Breusch-Pagan LM test and Honda LM test results are given in Table 5.

These results showed that the null hypothesis is not rejected for all cases above p-value ≥ α=0.05). This means that there are no random effects.

The EGLS method (cross-section SUR) was applied to obtain more reliable estimates for this model. The estimation results are given in Table 6.

Table 6 - One-way fixed effects estimation with cross-section SUR.

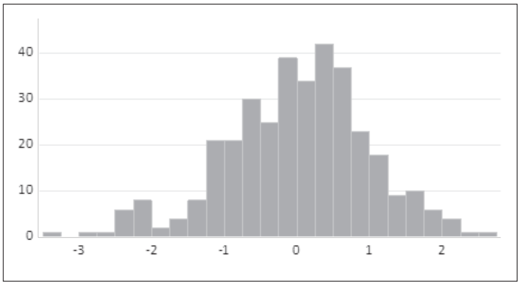
Coefficients \ Model	Model 5
	One-way fixed effects with cross-section effects SUR
Constant	-14252.87 (0.0000)
Independents	
WPS_{it}	0.285657 (0.0000)
WHA_{it}	2.603259 (0.0000)
WPR_{it-1}	13.54233 (0.0000)
WP_{it-1}	0.544437 (0.0000)
Statistics	
R^2	0.995485
$\bar{R}^2$	0.995226
F	3852.393 (0.0000)
RMSE	0.988676
SSR	344.0730
DW	2.025793

Note: In parenthesis, p-values are given.

All the coefficients are statistically significant at the 5 percent significance level in Model 5 (p-value < α=0.05). Also, the p-values of F statistics show that the model is statistically significant (p-value < α=0.05). The coefficient of determination (R^2) shows that independent variables collectively explain approximately ninety-nine percent of the total variation of wheat production. Durbin-Watson (DW) statistic equal to 2.02 shows no first-order serial correlation. In the end, Model 5 is acceptable. Moreover, the normality and cross-sectional dependence of residuals for Model 5 were also tested.

The histogram of the residuals is similar to the normal distribution shape, which is bell-curved (See Figure 4). The formal normality test for the residuals, the Jarque-Bera test, was performed, and the statistics were found to be 7.377 with a probability of 0.024. The null hypothesis that the residuals are normally distributed is not rejected at a 1 percent significance level (p-value ≥ α=0.01).

Figure 4 - Histogram of residuals.



Note: The vertical axis represents frequencies, the horizontal axis represents residuals.

Table 7 - Residual cross-section dependence test.

Test	*Statistic*
Breusch-Pagan LM	5.906081 (1.0000)
Pesaran CD	0.115304 (0.9082)

Note: In parenthesis, p-values are given.

Breusch-Pagan LM test and Pesaran CD test results are shown in Table 7.

The null hypothesis is not rejected, meaning there is no cross-sectional correlation dependency between residuals.

5. Conclusion

The study's main purpose is to analyze the effect of wheat producer support on wheat production using panel data methods. Due to the peculiar properties of panel data, it covers both cross-sectional and time dimensions. The main finding of this study is that wheat producer support has a positive effect on wheat production. This finding reveals that the higher agricultural support, the more the commodities produced (Park & Jensen, 2007). Agricultural subsidies aim to increase total production capacity and preserve national food security (Liu *et al.*, 2024). So, this finding also reveals that agricultural support, in line with its purpose, makes wheat production advantageous for producers and encourages producers to increase wheat production.

The secondary findings of this study show that wheat harvested area, previous period price of wheat, and previous period production of wheat have a positive effect on wheat production. The finding of a positive impact of the harvested area variable reveals that production will increase as the harvested area increases. In this context, the Heckscher-Ohlin theory of international trade, which includes views on the advantage of harvested area, predicts that countries with abundant land relative to labor will have a comparative advantage in agricultural production (Park & Jensen, 2007). Moreover, Cong (2022) suggested in a study related to land rights that improving the stability of land rights would generally be beneficial to increasing farmers' agricultural production efficiency as a policy recommendation. The finding of a positive effect of the previous period price variable indicates that the cobweb theorem is valid in wheat production. According to the cobweb theorem, current period production is a function of the past period price for products that take time to produce and require at least one period to change production after the production plan is made (Poitras, 2023). The finding of a positive effect of the previous period production variable indicates producer inertia caused by crop rotation costs that may arise due to the adaptation of product-specific land and other inputs to a different product (Haile *et al.*, 2016). However, it takes more than a year for wheat producers to fully adjust their production decisions according to external shocks (Albayrak, 1998).

The findings above indicate that countries should give importance to producer support policies in agriculture and develop new support policies. Policymakers should take these considerations into account when planning future wheat production. Because the agricultural support policy ensures food security and increases farmers' income, agricultural-related public expenditure improves total factor productivity and agricultural output (Zhang *et al.*, 2022). In this context, it is undeniable that agriculture, as mentioned in the previous sections, has many economic and social benefits and that agricultural support should be given importance and planned well. Studies on wheat show that countries less dependent on imports are less affected by volatility in international markets (Guo & Tanaka, 2019; Luo & Tanaka, 2021; Gutiérrez-Moya *et al.*, 2021). Therefore, increasing food self-sufficiency through agricultural support policies will improve food security by stabilizing local prices.

The main finding of this study (increasing agricultural support increases agricultural production) has indirect consequences for Mediterranean countries. Namely, increasing production enables foreign trade by enabling countries that meet their needs to sell their surplus products abroad. Thus, the wheat demands of importing countries are met. Therefore, these wheat productions are essential for the imports of Mediterranean countries.

According to our calculations using data from the official OECD website, the total wheat production of the relevant countries in the analyzed period (2000-2022) constitutes approximately 62% of the world's wheat production. On the other hand, according to our calculations using the data on the Food and Agriculture Organization (FAO) official website, the average share of the countries located on the Mediterranean coast in world wheat imports for the period 2000-2022 (average value of 23 years) is 28%. These important wheat-importing Mediterranean countries are Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Montenegro, Morocco, Palestine, Slovenia, Spain, Syrian Arab Republic, Tunisia, Türkiye.

According to our rankings using data from FAO statistics, in the world wheat import rankings in 2023, Egypt ranks second with approximately 3.77 billion dollars (5.1% of total wheat imports), Turkey ranks fourth with approximately 3.75 billion dollars (4.7% of total wheat imports), Italy ranks fifth with approximately 3.1 billion dollars (4.2% of total wheat imports), Spain ranks sixth with approximately 2.8 billion dollars (3.8% of total wheat imports), Algeria ranks tenth with approximately 2.1 billion dollars (2.8% of total wheat imports), and Morocco ranks eleventh with approximately 1.91 billion dollars (2.5% of total wheat imports). These 6 Mediterranean countries, among the world's 11 largest wheat importers, realized roughly 24 percent of world wheat imports in 2023. This rate is approximately one-fourth of world wheat imports and contains a significant amount.

When the literature is examined, it is seen that most studies focus on individual countries in reviewing the relationship between production and support. For instance, Vozarova and Kotulic (2016) studied Slovakia, Zampa, and Bonejic (2017) studied Slovenia, Igberi *et al.* (2020) studied Nigeria, Canbay (2021) studied Türkiye, Agyemang *et al.* (2022) studied Ghana, and Yang *et al.* (2023) studied China. However, although there are studies on country groups such as Aktaş *et al.* (2015), Akyol (2018), Baştan and Songül (2019), and Özşahin *et al.* (2023) in the literature, they seem to be few. In addition, this study differs from the mentioned country group studies in terms of the countries, periods, and variables used. Besides, the findings are consistent with similar studies in the literature (Aktaş *et al.*, 2015; Akyol, 2018; Baştan & Songül, 2019; Özşahin *et al.*, 2023) analyzing the relationship between agricultural support and production for country groups.

This study has some limitations. First, only one cereal crop (wheat) was used in the study. Other cereal crops, such as rice and corn, which are important sources of nutrients, can be considered for future studies. Secondly, in the study, 16 countries were analyzed collectively using panel data analysis methods using panel data including both cross-sectional and time dimensions. In future studies, other techniques, such as time series analysis, can be considered to investigate the functional relationships mentioned. Thus, analyzing countries individually and making inferences on a country basis will be possible. Third, the study is limited to 16 countries' panel data since the data was obtained within the existing countries' framework. In the future, if data for other countries are measured and made public by the OECD, analyses including those countries will be possible. Thus, it will be possible to make inferences about other country groups with panel data analysis as in this study. Fourth, this study used wheat production as the dependent variable and producer single commodity transfers as the primary independent variable. Other variables may be considered for future studies. For instance, the yield variable can be used as the dependent variable. While other types of support can be used, variables such as fertilizer, irrigation, and capital indexes can also be considered. Moreover, temperature change can also be used as the secondary independent variable.

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Environmental efficiencies in the European Union Fisheries Sector with a focus on CO_2 emissions

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Abstract

This study examines the EU fisheries sector's environmental efficiency based on CO2 emissions from marine gas consumption. We utilize the European Commission's Scientific, Technical, and Economic Committee for Fisheries (STECF) dataset compiled over the period spanning 2013 to 2022. We evaluated environmental efficiencies employing the Tone Slack-Based Measure (SBM) with an undesirable output approach. The analysis involves two models: one assessing the environmental efficiency based on the live weight of landings as the good output and CO_2 emissions as the undesirable outcome, and the other model focusing on revenue derived from fishing activities as the good output and CO_2 emissions as the undesirable outcome. The EU fishery sector's environmental efficiency averages 0.712 based on live weight landings and CO2 emissions, while it increases to 0.831 when considering fishery revenue instead of live weight landings. Results show that it is feasible to reduce CO_2 emissions from fishing activities ranging from 24.6% to 26.2%. Some countries, such as Latvia, Lithuania, Netherlands, Poland, and Estonia, demonstrate exemplary environmental efficiencies with perfect scores.

Keywords: *Fishing sector, European Union, CO_2 emissions, Environmental efficiency.*

1. Introduction

Carbon dioxide (CO_2) is a greenhouse gas that traps heat in the atmosphere, contributing to global warming and climate change (IEA, 2023a). The world's industrialization and rapid economic growth have led to a sharp increase in CO_2 emissions (Krátký *et al.*, 2024). These emissions result from various human activities, including burning fossil fuels, producing materials, farming, and fisheries (Krátký *et al.*, 2024). Oil and gas production, transport, and processing resulted in 5.1 billion tonnes (Gt) CO_2 equivalent in 2022 – just under 15% of global energy sector GHG (greenhouse gas) emissions (IEA, 2023b). Fuel usage is among the most significant factors. In the fishing sector, fuel use requires taking necessary precautions regarding environmental damage. While continuing to generate revenue from fishing operations such as landing amount, developing methods to reduce the volume of CO_2 emissions is essential. Reducing GHGs remains an international priority for reducing the ecological and social impact of climate change (UN, 2015).

Global energy-related CO_2 emissions grew by

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0.9% or 321 Mt in 2022, reaching a new high of over 36.8 Gt[2]. The primary sources of CO_2 emissions were coal (42%), oil (30%), and natural gas (25%) (Ritchie & Roser, 2020; IEA, 2023b). There is an opportunity to reduce the impact of CO_2 released as a result of production activities. For example, technologies for capturing and using CO_2 that can be transformed into advanced biofuels (such as methane, ethanol, and butanol), chemicals (such as urea, methanol, and formic acid) or building materials (including inorganic and organic carbonates) through various chemical, electrochemical, photochemical or biochemical processes (Anonymous, 2023).

The EU ranks fourth in the world in fish production, accounting for approximately 3.1% of global production, behind China, Indonesia, and India. 80% of the production comes from fishing, while 20% comes from aquaculture (Anonymous, 2020). The Common Fisheries Policy (CFP) is the management tool for the EU's fisheries and aquaculture, adopted at the Union level and implemented in each member country. The CFP aims to ensure that fishing and aquaculture are environmentally, economically, and socially sustainable while providing a healthy food source for EU citizens and ensuring a fair standard of living for fishing communities. The EU is developing policies to ensure that fishing practices do not harm the reproductive capacity of fish populations (Anonymous, 2020).

1.1. *Objective*

This study aims to analyze the volume of CO_2 emission resulting from the consumption of marine gas oil, in calculating the environmental efficiencies (or eco-efficiencies) of European Union (EU) countries in the fisheries sector. The analysis will lead to stakeholders in the fisheries sector having a better understanding of their environmental impact. Understanding the relationship between energy usage and CO_2 emissions can facilitate more efficient resource management practices in the fisheries sector, thus reducing environmental impact. By identifying areas where energy consumption can be reduced or optimized, fisheries can operate more efficiently and sustainably. The EU's policies aim to reduce fishing sector emissions through sustainability, climate action, and a low-carbon transition, promoting energy efficiency, renewables, and resource management. This study supports these efforts by evaluating marine gas oil consumption and CO_2 emission efficiencies, providing empirical insights for policy development, resource optimization, and alignment with the EU's Blue Growth Strategy while highlighting the competitive edge of low-emission fisheries.

1.2. *Literature Review*

While several studies have assessed environmental efficiency in fisheries, they primarily focus on economic performance, resource utilization, or sustainability without explicitly incorporating CO_2 emissions as an undesirable output. Research on carbon emissions in fisheries primarily investigates emission trends, policy implications, or mitigation strategies. However, these studies do not integrate environmental efficiency modeling to quantify the extent to which emissions can be reduced while maintaining fishery output. The study bridges this gap by employing the Slack-Based Measure (SBM) approach, which explicitly accounts for undesirable outputs in efficiency assessments. By addressing this gap, our research provides a novel contribution to the field, offering empirical insights that inform both policy and industry stakeholders on optimizing resource management and reducing the environmental footprint of the fisheries sector in the EU.

Shirazi *et al*. (2020) assessed the environmental efficiency of airline companies with undesirable output, greenhouse gases emission (Shirazi & Mohammadi, 2020; Cui & Li, 2016) while Ozkan *et al*. (2016) measured efficiency with undesirable output in cement sector in Turkey (Ozkan & Ulutas, 2016). Miran *et al*. (2025) measured the environmental efficiencies of milk specialized farms in the European Union concerning CO_2 emissions using the Tone Slacks-Based Measure (Tone-SBM) with undesirable outputs method and conducted country-level analyses (Miran & Güngör, 2025). Wang *et al*. (2017) measured environmental efficiency across ten different coastal fishing regions in China and analyzed the influential factors (Wang & Ji, 2017). Zhou *et al*. (2007) presented a novel approach to measuring environmental performance using non-radial DEA methodology (Zhou, Poh & Ang, 2007). Their research highlights the significance of integrating pollutants into the conventional DEA framework to generate a standardized environmental performance index. Focusing on non-radial efficiency measures, the study provides a comprehensive environmental performance analysis, as demonstrated through a case study involving OECD countries. Li *et al*. (2020) stated that efficiency analysis of fishery output is crucial for sustainable management (Li, Jeon & Kim, 2020). This study evaluates the productivity of fisheries in China's coastal regions using the DEA-Malmquist index. Moreover, the study identified the need for improved technological efficiency in coastal fisheries production by examining input and output indicators over six years. The findings underscore the importance of informed development planning and policy measures for enhancing the regional fishery industry in China's coastal areas. Fare *et al*. (2007) evaluated the issue of unwanted by-catch and excess harvesting capacity in fisheries management is addressed (Fare, Kirkley & Walden, 2007). Their study examined four approaches, primarily employing data envelopment analysis (DEA), to estimate and assess both capacity and technical efficiency in production activities involving desirable and undesirable outputs. Through an analysis of data from fishing vessels operating in the northwest Atlantic Ocean's Georges Bank, the study highlights the challenge fishing vessels face in reducing undesirable outputs without compromising desirable outputs. Okeke-Ogbuafor *et al*. (2024) discussed that climate-smart fisheries policies play a crucial role in balancing CO_2 emissions reduction with food security, particularly in regions like Sierra Leone (Okeke-Ogbuafor *et al*., 2024). Their study emphasized the complementary relationship between CO_2 emissions reduction and food security, suggesting that both objectives can work in tandem to promote sustainable development in coastal fisheries (Okeke-Ogbuafor, *et al*., 2024). Du *et al*. (2021) assessed the efficiency level of marine ranching and its ecological implications is essential for achieving a balance between economy and ecology (Du, Jiang & Li, 2021). This research proposes a comprehensive index system and employs the Super-SBM model to measure Marine Ranching Ecological Efficiency (MREE) in Shandong Province, China. The research identified key factors contributing to efficiency loss in marine ranching and underscores the importance of efficient resource allocation and habitat conservation in ecological management. Durgun (2019) assessed the environmental efficiency level of small-scale fishing activities in the research area as which is low (Durgun, 2019). In the study, fishers were categorized into distinct segments based on their values, attitudes, and job satisfaction, followed by a comparative analysis across different fisher groups. Furthermore, the study examined the relationship between fishers' psychographic attributes and environmental efficiency. Alongside demographic and fishing-related characteristics, environmental efficiency was influenced by their values, environmental attitudes, perspectives on sustainable fishing, job satisfaction, and behavior, with undesirable outputs identified as bycatch and plastic waste. Alsaleh *et al*. (2023) pointed out that marine waste poses critical threats to coastal economies and marine sustainability, impacting tourism, fisheries, and shipping (Alsaleh, Wang & Nan, 2023). According to this study, the fisheries sector is a significant contributor, with production strongly associated with increased marine waste, particularly in affluent EU14. Moreover, the study revealed a significant positive correlation and demonstrated a strong association between fishing output and carbon sink decline across most quantiles. This analysis was conducted using an innovative approach – the method of moments quantile regression – which incorporates a fixed factor across 27 European nations.

1.3. *Data and Methodology*

The data used in this study were sourced from the Technical and Economic Committee for Fisheries (STECF) of the European Commission (STECF, 2023) for the period 2013-2022, a recognized authority in fisheries data analysis. The dataset, provided by EU Member States for the 2022 Economic Report, includes economic and production data by national totals and segments, covering fleet profitability and fish processing.

The study employs the approach of Tone Slacks-Based Measure (SBM) with undesirable outputs (Tone, 2003). Tone (2001) developed the Slacks-Based Efficiency Measure (SBM), which enables the calculation of efficiency values by utilizing slacks (Tone, 2001).

The primary reason for using the Tone SBM approach is its ability to explicitly handle undesirable outputs, such as CO_2 emissions. The Tone SBM approach offers greater flexibility in assessing environmental efficiency by explicitly considering both desirable and undesirable outputs (Tone, 2003). This method allows for a more nuanced evaluation of performance, especially in sectors where the impact of undesirable outputs (e.g., CO_2 emissions) is a significant concern. In contrast, classic parametric models may require complex adjustments to address such issues adequately (Tone, 2003).

Data Envelopment Analysis (DEA) is a robust methodology for computing the efficiencies of a defined number of decision-making units (DMUs). A DMU is referred to as any homogeneous structure, such as firms, businesses, or production facilities, that produces similar outputs from similar inputs (Coelli, Rao, ODonnell, & Battese, 2005). Data Envelopment Analysis (DEA) utilizes linear programming methods to construct a non-parametric efficiency frontier. The frontier formed by efficient units also facilitates the calculation of expected targets for other units. Assuming that there are *N* production units, each utilizing *K* inputs to produce *M* outputs, the input matrix (*X*) would have dimensions *K*×*N*, and the output matrix (*Y*) would have dimensions *M*×*N*. The radial linear programming model of Data Envelopment Analysis (DEA) for this scenario can be defined as follows:

$\min_{\theta,\lambda}\theta,$

st. $-y_i + Y\lambda \geq 0,$

$\theta x_i - X\lambda \geq 0,$

$\lambda \geq 0$

where θ is a scalar representing efficiency, λ is N×1 dimensional vector of constants (Miran, 2021). Production aims to obtain beneficial products that meet human needs through input transformation. Data envelopment analysis measures the ability to determine the optimal levels of inputs and outputs in production and assumes that both inputs and outputs are good. In other words, DEA assumes that all inputs and outputs are "desirable" and will not harm anyone or anything. However, it is possible for the inputs used in production and the outputs obtained to have harmful characteristics for nature and humans. Alongside desired and market-oriented products, unwanted or harmful by-products such as environmental pollutants or hazardous waste may also be generated. The Tone undesirable output-oriented slack-based model has been utilized in accordance with the purpose of the study (Tone, 2003). This model explicitly incorporates undesirable outputs, like pollution or waste, into the efficiency analysis. Unlike input-oriented or output-oriented models, it doesn't prioritize either inputs or outputs. It considers proportional improvements in both while accounting for undesirable outputs.

The general representation of the Tone undesirable output-oriented slack-based model is as follows (Tone, 2003):

$$Z_{min} = t - \frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{x_{io}}$$

Subject to:

$$t + \frac{1}{s_1 + s_2}\left(\sum_{r=1}^{s_1}\frac{S_r^g}{y_{ro}^g} + \sum_{r=1}^{s_2}\frac{S_r^b}{y_{ro}^b}\right) = 1$$

(good and undesirable outputs)

$x\lambda + S^- = tx_{io}$ (inputs)

$y^g\lambda - S^g = ty_o^g$ (good outputs)

$y^b\lambda + S^b = ty_o^b$ (undesirable outputs)

Where:

t: a coefficient greater than 0

m: Number of inputs

S_r^g: Slack of the r^th good output

S_r^b: Slack of the r^th undesirable output

y_{ro}^g: Level of the r^th decision unit's good output

y_{ro}^b: Level of the r^th decision unit's undesirable output

x_{io}: Use of input for the r[th] decision unit
S_i^-: Slack of the i[th] input
s_1: Number of good outputs
s_2: Number of undesirable outputs

In this model, each DMU is characterized by its consumption of inputs, production of desirable outputs (e.g., products), and generation of undesirable outputs (e.g., pollution or CO_2 emission). The model introduces slack variables for both inputs and outputs. Positive slacks in inputs indicate potential reduction, while negative slacks in desirable outputs represent potential expansion. Undesirable outputs are minimized through negative slacks. The model calculates an efficiency score for each DMU based on the proportional reduction of inputs and undesirable outputs while potentially expanding desirable outputs. DMUs are compared to the efficient frontier formed by the best-performing units. Those with scores of 1 are considered efficient, while others have scores lower than 1, indicating inefficiency.

The objective function of the Tone Undesirable Output-Oriented Slack-Based Model is not directly minimizing an efficiency score like traditional DEA models. Instead, it focuses on minimizing a weighted sum of proportional slacks associated with inputs and undesirable outputs. The model utilizes slack variables that represent the potential for proportional reduction in inputs and undesirable outputs. These slacks are expressed as a percentage of the original input or undesirable output values. The objective function minimizes a weighted sum of these proportional slacks. This means the model attempts to simultaneously: Lowering the proportional slack associated with each input indicates a potential for input reduction without compromising efficiency; minimizing the proportional slack for undesirable outputs signifies potential reduction in their generation. The weights assigned to each slack variable reflect their relative importance. For example, a higher weight for an undesirable output slack might emphasize its criticality in the efficiency assessment. Therefore, the objective function of aims to find the most proportional reduction in inputs and undesirable outputs for a given DMU, considering their relative weights. This approach allows for a non-radial and non-oriented evaluation of efficiency, focusing on proportional improvements across all dimensions.

The environmental efficiency of the fishery sector in the European Union countries was first analyzed using Tone Slacks-Based Measure (SBM) with undesirable outputs (Tone, 2003) considering both live weight of landings and fishing revenue as good outputs and a undesirable output of CO_2 emissions from energy consumption in fishing sector. The first model assesses efficiency based on live weight of landings, representing biological productivity and fisheries capability, while the second model focuses on fishing revenue, reflecting economic performance. A single integrated model could introduce bias, as variations in fish pricing, species composition, and market conditions might obscure the true efficiency drivers. By analyzing these models separately, we provide clearer insights into whether inefficiencies stem from biological, operational, or economic factors, enabling more targeted policy recommendations. This approach aligns with established environmental efficiency methodologies (e.g., Tone, 2003), ensuring robustness and interpretability in our findings.

Subsequently, effective non-discretionary factors for each environmental efficiency were analyzed in depth using the truncated regression method.

Environmental Efficiency Models

In a typical data envelopment model, specific inputs are considered to produce a particular output. The inputs and outputs that can be used in DEA depend on the specific research question and the data available. This study was carried out with two outputs, one good and the other bad, and five inputs. Thus, there are two different environmental efficiency models, one with the good output as live weight of landings and the other with the good output as fishing revenue.

Good outputs:

In data envelopment analysis (DEA) studies related to fisheries, the most frequently utilized output variables are the quantities, live weight of landings, or value of landings and the gross revenues derived from fishery activities (Ceyhan & Gene, 2014; Pascoe *et al*., 2013; Pipitone & Colloca, 2018; Felthovena & Paul, 2004). In this study, the good outputs are actual annual fishery revenues and the live weight of landings. The Tone *Slacks-Based Measure (SBM) with undesirable outputs* employed in this study for the EU fishery comprises two outputs: live weight of landings and fishery revenue. It involves five inputs contributing to the generation of the outputs.

One of the main outputs is the real fishery revenue of EU countries, deflated to 2012 prices, which is calculated as follows:

Fishery output = Gross Value of Landings (€)
+ Revenue from leasing out quota (€)
+ Lease/rental payments for quota (€)
+ Other revenue (€)

The other good output represents fishery output generated by EU countries the live weight of landings (tonnes). The live weight of landings in fishery refers to the total weight of the fish or seafood caught by fishermen and brought to shore, measured while the catch is still fresh and has not undergone any processing or removal of parts such as guts or scales. It represents the actual weight of the catch as it is landed, including both target species and any by-catch. This metric is vital in fisheries management and research, providing insights into the overall catch volume and composition.

Undesirable output:

The undesirable output variable is CO_2 emissions due to the energy consumption of marine gas oil. It is assumed that consuming 1 liter of marine gas oil produces 2.77539 kg of CO_2 (UNFCCC/Secretariat, 2021).

Inputs:

Some standard inputs and outputs used in fisheries research include vessel size, engine power, crew size, and fuel consumption (Reid & Squires, 2022; Squires & Grafton, 1996; Squires & Ruseski, 2009; Kirkley, Squires, & Ivar, 1995; Fare, Grosskopf, Kirkley, & Squires, 2020). This study includes the following inputs by EU countries:

- Energy consumption - marine gas oil (liter)
- Fishing days (count)
- Total vessel capacity (tonnes)
- Engaged crew (count)
- Real operational costs (€)

The input of operational cost is calculated as follows:

Operational cost = Personnel costs (€)
+ Energy costs (€)
+ Consumption of fixed capital (€)
+ Other non-variable costs (€)
+ Other variable costs (€)
+ Repair&Maintenance costs (€) - Subsidies (€)

Data transformation and sufficiency

We utilized the dataset (STECF, 2023) in the analysis, which presents monetary variables in Euros (EUR) on a nominal basis. If nominal monetary time-series variables are not adjusted for inflation, nominal values include the influence of time-dependent price increases. Without adjustment, observed increases in variable values may be solely attributed to price changes and may not accurately reflect real value growth. Adjustment involves aligning nominal values with changes in purchasing power, facilitating the expression of their real values. Given that nominal output values encompass variations attributed to inflation, deflating these values based on a designated reference year is imperative. To accomplish this, the nominal variables have been adjusted by deflating them in accordance with the Gross Domestic Product (GDP) of each respective country, utilizing the base year of 2012.

All variables utilized in the analysis pertain to the level of EU member countries. The dataset for this investigation encompasses 22 European Union member countries, each representing a decision-making unit (DMU), namely Belgium, Bulgaria, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, and Sweden. Both input and output variables incorporate the respective sums from 2013 to 2022. This methodology assumes that the EU fishery sector utilizes all inputs to generate outputs within the same year as aggregated totals, akin to utilizing cross-sectional data.

When determining the minimum number of Decision-Making Units (DMUs) in DEA, the condition under consideration is as follows (Miran, 2021):

DMU >= 2 × Number of inputs × Number of outputs ∴ DMU >= 20

Given that our dataset comprises 22 countries (DMUs), it meets the minimum number of DMUs requirement. This indicates that we have obtained sufficient and reliable data in terms of both the number of countries and the time period.

Considering that environmental efficiency values are equal to or greater than 1, non-discretionary factors affecting it were analyzed using truncated regression (Greene, 2018), as the relevant literature recommends employing truncated regression for efficiency analyses (Simar & Wilson, 2007; Banker & Natarajan, 2008). In truncated regression models, certain dependent variable ranges are excluded from the sample. This means that observations of the dependent variable that fall below or above specific threshold values are systematically removed from the sample. In truncated regression, no observations exist for the dependent and independent variables corresponding to specific threshold values.

Software

Environmental efficiencies were calculated via the library of *deaR* in R package using the model_sbmeff function from the deaR package in R (Coll-Serrano, Benítez, & Bolós, 2018)[1]. These calculations can also be performed on the deaR website at https://rbensua.shinyapps.io/deaR/.

2. Results

The study's findings are reported by initially detailing the environmental efficiencies of the European Union countries, followed by an in-depth analysis of the non-discretionary factors that influence these efficiencies.

The dataset comprises data from 22 countries, including key variables related to the fisheries sector in the European Union. The live weight of landings averages 4.38 billion tonnes, with a minimum of 10.88 million tonnes and a maximum of 25.09 billion tonnes, exhibiting a standard deviation of 6.17 billion tonnes. The real fishing revenue has a mean value of €555.08 million, ranging from €5.41 million to €3.51 billion, with a standard deviation of €883.55 million.

The CO_2 emissions from energy consumption in the fishing sector average 261.31 million kg, with a minimum value of 655,055.81 kg and a maximum of 1.74 billion kg, showing a standard deviation of 422.87 million kg. Similarly, energy consumption averages 94.15 million liters, with a minimum of 236,022.98 liters and a maximum of 625.69 million liters, with a standard deviation of 152.36 million liters.

The gross tonnage fishing days exhibit a wide range, averaging 107.69 million, with values spanning from 31,161.29 to 2.19 billion, and a standard deviation of 464.63 million. The total vessel tonnage has a mean of 122,718.70 tonnes, with a minimum of 1,289.44 tonnes and a maximum of 687,977.46 tonnes, with a standard deviation of 159,346.77 tonnes.

The number of engaged crew members averages 6,300.13 persons, with a minimum of 109.57 persons and a maximum of 32,558.67 persons, with a standard deviation of 9,481.25 persons. Lastly, the operating costs in the fisheries sector average €402.00 million, with a minimum of €1.62 million and a maximum of €2.50 billion, exhibiting a standard deviation of €653.85 million.

2.1. *Environmental Efficiencies by EU Countries*

The environmental efficiencies (EE) of European Union countries in the fishery sector, specifically concerning CO_2 emissions from marine gas oil consumption, are provided in Table 1. Environmental efficiency measures how efficiently a country's fishery sector manages its energy consumption to minimize CO_2 emissions while maintaining or increasing fishery output. A value of 1 indicates maximum environmen-

[1] The R codes used are: model_sbmeff (Data,orientation = "io", rts = "crs") and model_sbmeff (Data, orientation = "oo", rts = "crs").

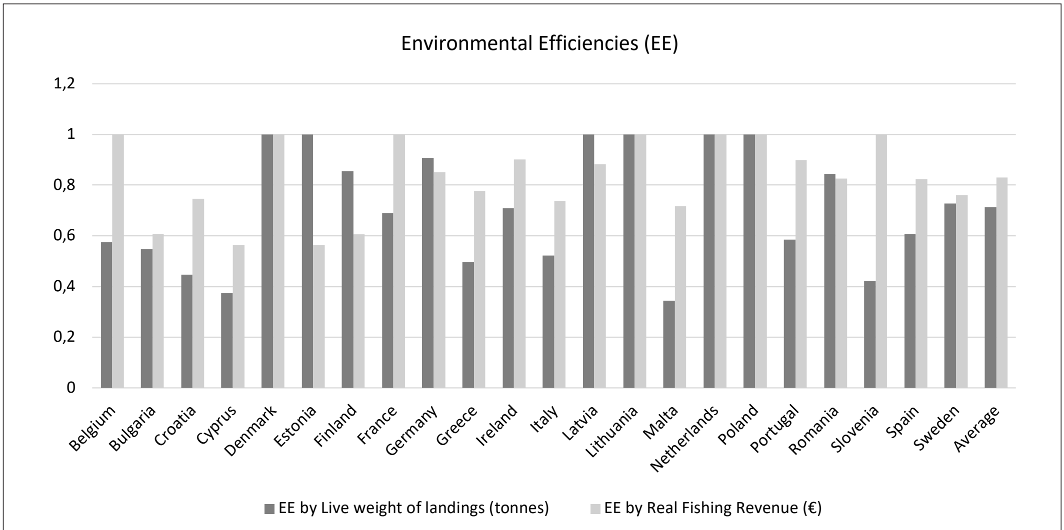
Table 1 - EU countries' fishery sector's environmental efficiencies obtained from Tone Slacks-Based Measure (SBM) with undesirable outputs.

Live weight of landings (tonnes)				*Real Fishing Revenue (€)*			
Country	*EE*	*Country*	*EE*	*Country*	*EE*	*Country*	*EE*
Belgium	0.575	Italy	0.523	Belgium	1.000	Italy	0.739
Bulgaria	0.547	Latvia	1.000	Bulgaria	0.609	Latvia	0.883
Croatia	0.448	Lithuania	1.000	Croatia	0.746	Lithuania	1.000
Cyprus	0.374	Malta	0.344	Cyprus	0.565	Malta	0.718
Denmark	1.000	Netherlands	1.000	Denmark	1.000	Netherlands	1.000
Estonia	1.000	Poland	1.000	Estonia	0.565	Poland	1.000
Finland	0.855	Portugal	0.586	Finland	0.606	Portugal	0.899
France	0.690	Romania	0.844	France	1.000	Romania	0.827
Germany	0.908	Slovenia	0.422	Germany	0.852	Slovenia	1.000
Greece	0.497	Spain	0.608	Greece	0.778	Spain	0.823
Ireland	0.708	Sweden	0.727	Ireland	0.901	Sweden	0.761
Average	0.712			Average	0.831		

tal efficiency, meaning that the country's fishery sector efficiently manages its energy consumption to minimize CO_2 emissions without compromising fishery output. Values closer to 1 indicate high environmental efficiency, reflecting effective energy consumption and CO_2 emission management in the fishery sector, while values below 1 suggest the need for improvements in these areas to sustain fishery output.

In the first model, we considered the *live weight of landings* as the good output and CO_2 emissions resulting from energy consumption as the undesirable output. Regarding environmental efficiency in the fishing sector, Latvia, Lithuania, Netherlands, Poland, and Estonia have achieved a perfect score of 1.000 (Table 2, Figure 1). This accomplishment reflects their ability to maintain high output levels while minimizing

Figure 1 - Environmental efficiencies by the EU countries with respect to live weight of landings (tonnes) and real fishing revenue (€).



CO_2 emissions, underscoring their commitment to sustainable practices. On the other hand, Denmark, Finland, France, Germany, Ireland, Portugal, and Romania demonstrate a moderate level of environmental efficiency, with scores ranging from 0.700 to 1.000. Meanwhile, Belgium, Bulgaria, Croatia, Cyprus, Greece, Italy, Malta, Slovenia, Spain, and Sweden have environmental efficiency scores below 0.700, indicating a need for enhanced efforts to improve sustainability practices and reduce CO_2 emissions per unit of output. Overall, the average environmental efficiency among the European Union countries examined is 0.712, highlighting the need for improvement in adopting more sustainable and environmentally friendly practices within the fishing sector. Results indicate that the European Union fishing sector has the potential to reduce its CO_2 emission volume resulting from energy consumption by 28.8% (Table 2).

In the second model, we examined the good output as the revenue derived from fishing activities and the undesirable output as the CO_2 emissions from energy consumption. Among European Union countries, Belgium, Denmark, France, Lithuania, Netherlands, Poland, and Slovenia stand out with the highest environmental efficiency score of 1.000 (Table 2, Figure 1). These countries have effectively implemented practices in their fishing sectors that minimize CO_2 emissions while maximizing revenue generation. Additionally, Germany, Greece, Ireland, Italy, Latvia, Portugal, and Romania demonstrate significant environmental consciousness, with environmental efficiency scores ranging from 0.700 to 1.000. However, Bulgaria, Croatia, Cyprus, Estonia, Finland, Malta, Spain, and Sweden lag with environmental efficiency scores below 0.700. This indicates a need for improvement in implementing sustainable and environmentally friendly practices to reduce CO_2 emissions while maintaining revenue generation. Overall, the average environmental efficiency for all European Union countries is 0.831, suggesting a relatively good level of environmental consciousness and efficiency in the fishing sector across the EU. Nevertheless, variations among individual countries highlight the necessity for tailored strategies to enhance environmental performance in specific regions. Under current conditions, the European Union fishing sector has the potential to reduce its volume of CO_2 emission volume resulting from energy consumption by 16.9% without reducing its current revenue (Table 1).

By considering both the live weight of landings and fishing revenue, we find that the average environmental efficiency across all European Union countries stands at 0.712 and 0.831 respectively. This indicates that while there is room for improvement in implementing more sustainable and environmentally friendly practices based on the live weight of landings, the fishing sector demonstrates a relatively good level of environmental consciousness and efficiency when revenue is taken into account. This difference suggests that EU countries are more efficient at generating higher revenue per unit of CO_2 emissions than at maximizing the physical quantity of fish caught per unit of emissions, highlighting an opportunity to enhance sustainability in terms of production volume.

Environmental efficiencies obtained from Tone Slack-Based Measure (SBM) with undesirable outputs are based on both live weight of landings and real revenues as good outputs and CO_2 emissions as undesirable outputs. The difference between the two environmental efficiencies is statistically significant ($t = -2.388$, $p = 0.026$), indicating that the environmental efficiency based on real fishery revenues is greater than the one based on the live weight of landings.

Table 2 displays the percentage difference between actual and target inputs and outputs in the fishing sector of EU countries, calculated based on the live weight of landings. Even if Belgium were to reduce its energy consumption by 56.3%, vessel capacity by 13.14%, vessel personnel by 30.68%, and operating expenses by 23.15%, it could still potentially increase the live weight of landings by 91.62% while simultaneously decreasing emissions by 56.30%. Belgium needs to make the most significant reduction in energy consumption, with a reduction of 56.3%, France with 44.8%, and Italy with 42.27%. Malta has the potential to increase its live weight of landings, which is considered a good output, by 3.81 times.

Table 2 - Percentage difference of actual and target inputs-outputs in the fishing sector of EU countries, based on live weight of landings.

Country	*Energy Consumption (liter)*	*Fishing Days (count)*	*Total Vessel Tonnage (tonnes)*	*Engaged Crew (count)*	*Operational Costs (€)*	*Weight of landings (tonnes)*	*CO_2 Emission (kg)*
Belgium	-56.30	0.00	-13.14	-30.68	-23.15	91.62	-56.30
Bulgaria	0.00	-17.73	0.00	-66.76	0.00	165.34	0.00
Croatia	0.00	-29.22	0.00	-25.03	0.00	246.13	0.00
Cyprus	0.00	-81.00	0.00	-69.05	0.00	335.13	0.00
Denmark	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estonia	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Finland	-21.76	-64.25	-14.27	0.00	0.00	12.02	-21.76
France	-44.58	-33.62	0.00	0.00	-53.13	45.24	-44.58
Germany	0.00	-43.21	-40.76	0.00	-2.34	20.28	0.00
Greece	-15.29	-91.69	0.00	-89.16	0.00	187.27	-15.29
Ireland	-30.54	0.00	-24.81	-71.95	-9.06	51.86	-30.54
Italy	-42.27	-85.14	0.00	-82.81	0.00	140.41	-42.27
Latvia	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lithuania	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malta	0.00	-24.63	0.00	-50.45	0.00	381.48	0.00
Netherlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Portugal	-17.30	-19.39	0.00	-37.43	-28.50	123.86	-17.30
Romania	-32.51	0.00	-26.76	-68.69	0.00	4.32	-32.51
Slovenia	0.00	-65.30	0.00	-35.06	0.00	273.42	0.00
Spain	-24.86	-56.71	0.00	-78.86	0.00	104.04	-24.86
Sweden	-40.36	-25.19	0.00	0.00	0.00	34.79	-40.36

According to Table 3, the countries that need to reduce marine gas oil the most to achieve environmental efficiency are Italy with 70.78% and Greece with 57.02%, based on fishing revenue. Since our model associates CO_2 emissions with marine oil consumption, the reduction in CO_2 emissions in these countries is proportionate to the decrease in usage. The countries that can obtain the most significant increase in fishing revenue in response to the reduction in CO_2 emissions are Estonia with 131.26% and Cyprus with 112.72%.

Regarding real fishing revenue, there is a decrease ranging from 11% to 39.8% across all inputs, while fishing revenue has experienced a 6% increase. Moreover, there is a 26.2% reduction in CO_2 emissions.

When considering overall aggregates (Table 4), in terms of the live weight of landings, a decrease ranging from 3.2% to 62.1% is observed across all inputs, with a notable increase of 70% in the live weight of landings. Additionally, there is a 24.6% reduction in CO_2 emissions.

Model countries for minimizing CO2 emissions

EU countries that fail to achieve environmental efficiency in the fishing sector can take the most suitable countries as models and work to reduce their CO_2 emissions (Table 5). Concerning live weight of landings, in the reduction of CO_2 emissions caused by the fishing sector, Denmark could serve as a model for Belgium; Estonia and Latvia for Bulgaria; Estonia and Latvia for Croatia; Estonia and Latvia for Cy-

Table 3 - Percentage difference of actual and target inputs-outputs in the fishing sector of EU countries, based on fishing revenue.

Country	*Energy Consumption (liter)*	*Fishing Days (count)*	*Total Vessel Tonnage (tonnes)*	*Engaged Crew (count)*	*Operational Costs (€)*	*Weight of landings (tonnes)*	*CO_2 Emission (kg)*
Belgium	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulgaria	-50.72	0.00	-62.93	-80.43	-0.00	77.43	-50.72
Croatia	-13.12	0.00	-37.51	-51.34	0.00	55.07	-13.12
Cyprus	-40.98	-25.51	-0.00	-48.25	-39.85	112.72	-40.98
Denmark	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estonia	-22.62	-0.00	-57.94	-40.02	-35.56	131.26	-22.62
Finland	-22.93	-11.08	-14.63	0.00	0.00	107.27	-22.93
France	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Germany	0.00	0.00	-41.03	-2.93	-1.90	34.85	0.00
Greece	-57.02	-46.89	-0.00	-55.23	-49.17	0.00	-57.02
Ireland	-21.86	0.00	-16.41	-68.95	-3.92	0.00	-21.86
Italy	-70.78	0.00	-0.00	-14.00	-49.73	-0.00	-70.78
Latvia	-5.10	0.00	-31.42	-60.88	0.00	21.28	-5.10
Lithuania	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malta	-31.91	0.00	-50.88	-74.29	-0.00	46.62	-31.91
Netherlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Portugal	-22.48	0.00	-27.57	-69.71	-29.78	0.00	-22.48
Romania	-33.40	0.00	-58.14	-84.17	-0.00	8.55	-33.40
Slovenia	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spain	-33.58	0.00	-0.00	-53.74	-12.36	9.43	-33.58
Sweden	-43.92	0.00	-17.37	-33.06	-0.00	18.75	-43.92

prus; Denmark and Latvia for Finland; Denmark and Latvia for France; Denmark and Latvia for Germany; Denmark and Latvia for Greece; Denmark for Ireland; Denmark and Latvia for Italy; Estonia and Latvia for Malta; Latvia for Portugal; Estonia and Latvia for Romania; Estonia and Latvia for Slovenia; Denmark and Latvia for Spain; Denmark and Latvia for Sweden. Denmark appears to be the most favorable model country, as it is recommended as a model for multiple countries, including Belgium, Finland, France, Germany, and Sweden for reducing CO_2 emissions the fishing sector generates.

When considering the fishing revenue, in the context of reducing CO_2 emissions the fishing sector generates, Denmark and Slovenia could serve as models for Bulgaria; Denmark and Slovenia for Croatia; Slovenia for Cyprus; Slovenia for Estonia; Denmark and Slovenia for Finland; Denmark and Slovenia for Germany; France and Slovenia for Greece; Denmark and Netherlands for Ireland; Denmark, France, and Slovenia for Italy; Denmark and Slovenia for Latvia; Denmark and Slovenia for Malta; Denmark and Slovenia for Portugal; Denmark and Slovenia for Romania; Denmark and Slovenia for Spain; Denmark and Slovenia for Sweden (Table 5). Denmark and Slovenia emerged as the most considered model countries in the context of reducing CO_2 emissions the fishing sector generates, as they are recommended as models for multiple countries, including Bulgaria, Croatia, Estonia, Finland, Germany, Greece, Ireland, Italy, Latvia, Malta, Portugal, Romania, Spain, and Sweden.

Table 4 - EU countries' fishery sector's differences in total actual and target inputs/outputs.

Inputs	*Live weight of landings (tonnes)*				*Real Fishing Revenue (€)*			
	Target Total	*Actual Total*	*Difference*	*%*	*Target Total*	*Actual Total*	*Difference*	*%*
Energy Consumption	1,522,916,987	2,071,376,134	-548,459,147	-26.5	1,486,704,505	2,071,376,134	-584,671,629	-28.2%
Fishing Days	2,180,147	5,747,472	-3,567,325	-62.1	5,113,525	5,747,472	-633,947	-11.0%
Total Vessel tonnage	2,614,242	2,699,811	-85,569	-3.2	2,495,753	2,699,811	-204,058	-7.6%
Engaged Crew	58,301	138,603	-80,302	-57.9	83,500	138,603	-55,103	-39.8%
Operational Cost	7,396,426,936	8,629,241,555	-1,232,814,619	-14.3	7,412,869,438	8,629,241,555	-1,216,372,117	-14.1%
Outputs								
Good Output	164,365,520,658	96,357,731,374	68,007,789,284	70.6	12,941,487,441	12,211,712,180	729,775,261	6.0%
Undesirable output (CO_2 Emission)	4,226,688,577	5,748,876,610	-1,415,024,600	-24.6	4,126,184,815	5,748,876,610	-1,508,452,805	-26.2%

Table 5 - Model countries to reduce CO_2 emissions with respect to live weight of landings.

Countries to be Modeled after	*Model countries with respect to live weight of landings*			*Model countries with respect to real fishing revenue*		
Belgium	Denmark			Denmark	Slovenia	
Bulgaria	Estonia	Latvia	Poland	Denmark	Slovenia	
Croatia	Estonia	Latvia	Poland	Slovenia		
Cyprus	Estonia	Latvia	Poland	Slovenia		
Finland	Denmark	Latvia		Denmark	Slovenia	
France	Denmark	Latvia		Denmark	Slovenia	
Germany	Denmark	Latvia		France	Slovenia	
Greece	Denmark	Latvia		Denmark	Netherlands	
Ireland	Denmark			Denmark	France	Slovenia
Italy	Denmark	Latvia		Denmark	Slovenia	
Malta	Estonia	Latvia	Poland	Denmark	Slovenia	
Portugal	Latvia			Denmark	Slovenia	
Romania	Estonia	Latvia		Denmark	Slovenia	
Slovenia	Estonia	Latvia	Poland	Denmark	Slovenia	
Spain	Denmark	Latvia		Denmark	Slovenia	
Sweden	Denmark	Latvia	Poland			

2.2. *Non-Discretionary Factors Affecting Environmental Efficiency*

Identifying non-discretionary factors influencing environmental efficiency is pivotal in formulating strategies to mitigate CO_2 emissions. Therefore, we will investigate these influential non-discretionary factors using a truncated regression model, employing environmental efficiency variables derived from the live weight of landings and fishing revenue as dependent variables (Table 6). Environmental efficiency is transformed by computing its reciprocal and by construing it within the 0-1 range. This reciprocal

Table 6 - Non-discretionary factors in the regression models and units.

Non-discretionary factors	*Unit*
Population	Number of people
Coastal Length	Kilometer
Real GDP	$US of 2012
Number of fishery enterprises with 2-5 vessels	Count
Number of fishery enterprises with less than 5 vessels	Count
Number of fishery enterprises with 1 vessel	Count
Mean vessel age	Years
Atlantic	Dummy (1: having a coast by the Mediterranean Sea; 0: having a coast by the North Sea)
Mediterranean	Dummy (1: having coast by the Atlantic Ocean; 0: having coast by the North Sea)

transformation yields a value of 1 for efficient countries and greater than 1 for inefficient countries. Truncated regression methodology was employed due to the reciprocal transformation of the environmental efficiency variable serving as the dependent variable, confined to the interval [1, ∞], within the left-limit truncation regression model (Simar & Wilson, 2007).

Truncated regression estimation results are presented in Table 7 for two different good outputs, both of which are statistically significant at α=0.05. It is important to note that the coefficients in the estimation results are interpreted with an inverse sign, as the dependent variable is 1/EE.

Based on the truncated regression model estimated for live weight of landings (Table 7), as the number of fishery enterprises with 1 vessel increases in a European Union country, the environmental efficiency of the fishing sector, which considers CO_2 emissions from fuel consumption, increases. This implies that the more the fishery enterprises, represented by those with only one vessel, tend to be more environmentally efficient in terms of CO_2 emissions per unit of output. As the number of fishery enterprises with 2 to 5 vessels increases in a European Union country, the environmental efficiency of the fishing sector, which considers CO_2 emissions from fuel consumption, increases. This suggests that larger fishery enterprises may be less environmentally efficient, possibly due to higher fuel consumption associated with larger fleets. As a country's population increases, the fishing sector's environmental efficiency, which considers CO_2 emissions from fuel consumption, increases. This suggests that countries with larger populations may invest more in sustainable fishing practices or have stricter regulations, leading to higher environmental efficiency in the fishing sector. As per capita income increases, the environmental efficiency of the fishing sector, which considers CO_2 emissions from fuel consumption, increases. This indicates that higher-income countries may have better technology or resources to reduce CO_2 emissions per unit of output in the fishing sector. The environmental efficiency of the fishing sector, considering CO_2 emissions from fuel consumption, is lower in countries with a coastline on the Mediterranean Sea compared to those with a coastline on the North Sea. Similar to the previous statement, this highlights regional differences in environmental efficiency, specifically between countries bordering the Mediterranean Sea and those bordering the North Sea. As the average age of fishing vessels increases, there is, in the younger fishing vessels, a decrease in environmental efficiency considering CO_2 emissions from fuel consumption in the fishing sector, followed by an increase in environmental efficiency as vessels get older. This suggests a non-linear relationship between the age of fishing vessels and environmental efficiency, with efficiency initially decreasing as vessels age, possibly due

Table 7 - Truncated regression estimation results (dependent variable is 1/EE).

Independent variable	*Live Weight of Landings (tonnes)*		*Real Fishing Revenue (€)*	
	Coefficient (Z value)	*Marginal effect*	*Coefficient (Z value)*	*Marginal effect*
Number of fishery enterprises with 1 vessel	-0.000055* (-1.83)	-0.0000552	-0.00016*** (-2.84)	-0.000160
Number of fishery enterprises with 2-5 vessels	-0.001198*** (-3.86)	-0.0011982	-0.00026 (-0.39)	-0.000260
Number of fishery enterprises with less than 5 vessels	0.000967 (1.36)	0.0009671	0.002157 (1.52)	0.002157
Population	-0.002994*** (-4.27)	-0.002994	-0.002572* (-1.79)	-0.002572
Coastal Length	0.000038* (1.76)	0.0000377	0.00007* (1.92)	0.000070
Real GDP	-0.000008*** (-3.12)	-70.60e-06	-0.00001** (-2.01)	-0.000010
Atlantic	-0.062827 (-0.31)	-0.062827	0.773028** (1.99)	0.773028
Mediterranean	0.944889*** (6.5)	0.9448894	0.64569** (2.52)	0.645690
Mean Vessel Age	0.374386*** (9)	0.374386	0.205692** (2.01)	0.205692
Squared Mean Vessel Age	-0.005957*** (-9.01)	-0.0059569	-0.004265** (-2.34)	-0.004265
Constant	-3.4176*** (-5.54)		-0.704067 (-0.52)	
Wald test	$\chi^2(10) = 660.15$***		$\chi^2\ (10) = 19.22$**	

[a] Since it is calculated as 1/IO(CRS), the signs of the coefficients should be interpreted inversely.
,, and *** represent significance at 0.1, 0.05, and 0.01 levels, respectively.*
Truncated regression estimation results for live weight of landings.

to increased fuel consumption or emissions, followed by improvements in efficiency at later stages, potentially through technological upgrades or retrofits (Table 7).

Truncated regression estimation results for Fishing Revenue

According to the truncated regression model estimated for the live weight of landings for fishing revenue (Table 7), as the number of fishery enterprises with 2-5 vessels increases, environmental efficiency also increases. As the number of fishery enterprises with 1 vessel increases, environmental efficiency also increases. This suggests that smaller-scale fishing operations have a lower environmental impact than more extensive operations. This might be because smaller operations are more likely to use sustainable fishing practices or have less intensive fishing methods. As the population increases, environmental efficiency decreases. This could indicate that higher population densities lead to more pollution or resource depletion, thus reducing environmental efficiency. It might also imply that larger populations put more pressure on natural resources. As the coastal length increases, environmental efficiency decreases. This suggests that longer coastlines may face more significant challenges in maintaining environmental quality, possibly due to increased human activity or difficulty in managing pollution. As the real national income increases, environmental efficiency increases. This implies that wealthier countries have the resources to invest in environmental protection measures or technologies, leading to higher environmental efficiency.

As the environmental efficiency of countries with coastlines on the Mediterranean Sea increases compared to countries with coastlines on the North Sea, environmental efficiency is lower. This indicates that countries with coastlines on the Mediterranean Sea tend to have lower environmental efficiency than those on the North Sea. This could be due to differences in governance, economic development, or environmental policies between these regions. As the average age of fishing vessels increases, there is initially a decrease in environmental efficiency in newer vessels, considering CO_2 emissions from fuel consumption in the fishing sector, followed by an increase in environmental efficiency at later ages. This suggests a non-linear relationship between the age of fishing vessels and environmental efficiency, with efficiency initially decreasing as vessels age, possibly due to increased fuel consumption or emissions, followed by improvements in efficiency at older vessels, potentially through technological upgrades or retrofits. As the environmental efficiency of countries with coastlines on the Atlantic Ocean increases compared to countries with coastlines on the North Sea, environmental efficiency is higher. This implies that countries with coastlines on the Atlantic Ocean tend to have higher environmental efficiency than those on the North Sea. This could be due to various factors, such as different environmental policies, levels of industrialization, or natural resource management practices in these regions (Table 7).

3. Discussion

Our study's findings align with various studies in the literature that have examined environmental efficiency in different sectors, including specialized milk farms in the EU, aviation, cement production, and coastal fisheries. Focusing on the European Union's fishing sector and specifically considering CO_2 emissions as a measure of environmental efficiency, our study fills a gap in the existing literature.

Shirazi *et al*. (2020) have previously measured environmental efficiency in airline companies based on greenhouse gas emissions. At the same time, Ozkan *et al*. (2016) examined efficiency in Turkey's cement sector concerning environmental impacts. These studies provide a foundation for understanding how environmental efficiency can be assessed in different industries, laying the groundwork for our study to apply similar methodologies to the EU fishing sector. Zhou *et al*.'s (2007) novel approach to measuring environmental performance using non-radial DEA methodology is relevant to our study as it emphasizes the importance of integrating pollutants into efficiency analysis frameworks. This aligns with our study's focus on CO_2 emissions and highlights the significance of considering environmental impacts in efficiency assessments. Li *et al*.'s (2020) study on fisheries productivity in China's coastal regions using the DEA-Malmquist index underscores the importance of evaluating technological efficiency in fisheries production, which resonates with our study's emphasis on identifying areas for improvement in the EU fishing sector's environmental efficiency. Fare *et al*.'s (2007) examination of undesirable outputs in fisheries management using DEA methodology is relevant to our study as it addresses the challenge of reducing undesirable outputs without compromising desirable outputs, a key consideration in assessing environmental efficiency in the fishing sector. Okeke-Ogbuafor *et al*.'s (2024) discussion on climate-smart fisheries policies in Sierra Leone highlights the importance of balancing CO_2 emissions reduction with food security, which is relevant to our study's broader implications for policy development in the EU fishing sector. Wang *et al.* (2017) found that the average environmental efficiency is approximately 0.714, which is very close to that of the European Union (EU) that we calculated. Durgun's (2019) study on small-scale fishing activities and their environmental efficiency, considering the personal values, attitudes, and job satisfaction of fishers, provides insight into the factors influencing environmental efficiency in the fishing sector, complementing our study's findings on specific EU countries' environmental efficiencies concerning CO_2 emissions. Both our paper and Alsaleh *et al*.'s (2023) study focus on the environmental impacts of the fishing industry in the EU, particularly concerning sustainability and CO_2 emissions. While Alsaleh *et al*. (2023) emphasized the relationship between fisheries production, governance, and marine waste, our paper specifically highlights environmental efficiency variations across EU nations, focusing on CO_2 emissions as an undesired output. Key overlaps include the identification of disparities among EU countries in sustainability practices and the potential for improvement. Our findings that CO_2 emissions can be reduced without revenue loss complement Alsaleh *et al*.'s (2023) argument for adopting sustainable and environmentally friendly technologies. Both studies emphasize the role of tailored policies and innovations to enhance sustainability while maintaining economic performance in the fishing sector, supporting shared goals of environmental and economic balance. Our study and Alsaleh *et al*.'s (2023) second study both examine the environmental challenges of the EU fisheries sector, focusing on emissions and sustainability. However, while our paper primarily addresses CO_2 emissions and environmental efficiency, Alsaleh *et al*.'s (2023) study explores blue carbon degradation and its links to fishing practices, fossil fuel use, and socio-economic factors. Both this study and Miran *et al*. (2025) assess environmental efficiency in EU sectors using Tone's SBM with undesirable outputs, but fisheries show higher efficiency (0.712–0.831) than specialized milk farms (0.599). While Latvia, Lithuania, the Netherlands, Poland, and Estonia lead in fisheries, Malta, Ireland, Italy, and the Netherlands are top performers in specialized milk farming. Estonia and Bulgaria rank among the least efficient in both sectors, indicating persistent sustainability challenges. Unlike specialized milk farming, where larger farms improve efficiency, fisheries benefit from smaller-scale operations (1-5 vessels) due to lower fuel consumption per unit. These findings highlight the need for sector-specific sustainability policies, including fleet modernization and fuel efficiency measures in fisheries.

Our findings contribute to the existing literature by providing a comprehensive assessment of environmental efficiency in the EU fishing sector, specifically considering CO_2 emissions, and offer insights that can inform policy development and sustainability efforts in the industry.

4. Policy implications

The findings of this study carry several policy implications for the European Union (EU) fisheries sector in terms of environmental efficiencies, particularly for CO_2 emissions. Firstly, targeted interventions are needed to support the EU member states with lower environmental efficiencies, especially those scoring below the average. Tailored interventions can help these countries adopt more sustainable and environmentally friendly practices. Secondly, economic incentives should be considered to encourage member states with higher environmental efficiencies to share best practices and promote the adoption of sustainable methods.

Additionally, research and innovation funding should be allocated to develop technologies and practices that enhance environmental efficiency, such as fuel-efficient vessels and renewable energy use. International collaboration is crucial to address climate change and reduce CO_2 emissions in the fisheries sector, requiring engagement in global initiatives and knowledge-sharing among member states. Furthermore, policies should integrate environmental considerations into broader fisheries strategies, with robust monitoring and reporting mechanisms established to assess environmental efficiencies regularly.

Using renewable energy sources such as solar, wind, or hydrogen to power fishing vessels can significantly reduce or eliminate diesel fuel usage. Incorporating hybrid or fully electric fishing vessels into operations can significantly reduce or eliminate the need for diesel fuel. Utilizing more efficient and fuel-efficient diesel engines can help reduce fuel consumption and emissions for the same amount of work. Transitioning from traditional, fuel-intensive fishing methods (e.g., trawling) to less fuel-intensive methods (e.g., longline fishing) can help reduce diesel fuel usage. Better planning and rotation can minimize travel during the fishing season, reducing diesel fuel consumption. Educating and raising awareness among fishermen about less fuel-intensive practices is crucial for reducing diesel fuel usage.

To enhance sustainability in the fisheries sector, targeted policy interventions are essential for countries with lower environmental efficiency, such as Belgium, Bulgaria, Croatia, Cyprus, Greece, Italy, Malta, Slovenia, Spain, and Sweden. These nations should prioritize the adoption of fuel-efficient fishing technologies and vessel retrofitting programs to reduce CO_2 emissions per unit of output. The European Union could support these efforts by providing subsidies or tax incentives for investments in energy-efficient engines and alternative propulsion technologies. Additionally, policymakers in low-efficiency countries should establish fuel consumption limits for fisheries, promoting the use of alternative fuels such as biofuels or hybrid engines to minimize emissions. The implementation of onboard energy monitoring systems would further enable better tracking and enforcement of sustainable energy consumption practices.

Countries with lower environmental efficiency should look to Latvia, Lithuania, the Netherlands, Poland, and Estonia as models, as these nations have successfully minimized CO_2 emissions while maintaining high productivity. Establishing an EU-wide knowledge-sharing platform could facilitate the transfer of best practices, including quota management, fleet optimization, and the use of selective fishing gear, to improve efficiency in lower-performing nations.

Furthermore, financial incentives should be introduced to encourage the adoption of low-emission fishing techniques and participation in sustainability certification programs, such as MSC (Marine Stewardship Council) certified fisheries. Governments could also implement carbon pricing mechanisms, where vessels exceeding emission thresholds are subject to levies, thereby incentivizing more sustainable fishing practices.

While moderately efficient countries, such as Denmark, Finland, France, Germany, Ireland, Portugal, and Romania, may focus on technological advancements to enhance efficiency, countries with lower environmental efficiency may first prioritize regulatory reforms and fleet restructuring to align with sustainability objectives.

Our findings indicate that Mediterranean countries generally exhibit lower environmental efficiency compared to North Sea and Atlantic fisheries. To address these disparities, stronger regional cooperation within the EU sustainability framework is necessary to harmonize regulations and introduce tailored marine spatial planning strategies that balance economic and environmental priorities. By implementing these targeted policy measures, countries with lower environmental efficiency can significantly reduce their CO_2 emissions while ensuring the long-term sustainability of the fisheries sector.

Finally, incentives for innovation targeting CO_2 emission reduction can drive a shift towards cleaner and more sustainable approaches in the EU fisheries sector.

5. Conclusion

This study examines how European Union (EU) countries perform environmentally in the fishing industry, focusing on CO_2 emissions from using marine fuel. We used a method that analyzes both good outputs (like the live weight landings or revenue) and undesired output (like CO_2 emissions).

The study highlights significant variations in environmental efficiencies across EU member states, drawing from extensive data compiled by the Scientific, Technical, and Economic Committee for Fisheries (STECF) of the European Commission. While certain countries demonstrate exemplary environmental efficiency, achieving perfect scores in minimizing CO_2 emissions per unit of output, others exhibit lower efficiency scores, indicating areas for improvement in sustainability practices.

We found significant differences among EU countries in how efficiently they manage environmental issues in fishing. Some countries are excellent at keeping CO_2 emissions low while maintaining high levels of live weight landings. Others are less efficient, indicating they have room to improve their sustainability practices.

Importantly, our research shows that the EU fishing sector could greatly reduce CO_2 emissions without losing revenue. For example, based on the live weight landings, the sector could cut CO_2 emissions by 28.8%, and by 16.9% based on fishing revenue. This highlights the potential to make fishing more sustainable while still being profitable.

When we looked at the live weight landings as the good output and CO_2 emissions as the undesired one, countries like Latvia, Lithuania, the Netherlands, Poland, and Estonia scored the highest in environmental efficiency. This means they catch a lot of fish while keeping emissions low. Countries like Denmark, Finland, and France had moderate scores, while others like Belgium, Greece, and Spain had lower scores, indicating a need to reduce emissions per unit of fish caught. On average, EU countries scored 0.712 out of 1, showing there's room for improvement in eco-friendly fishing practices.

When considering revenue from fishing as the good output, countries like Belgium, Denmark, and France achieved the highest efficiency scores. They effectively reduce CO_2 emissions while maximizing earnings. Some countries lagged behind and need to adopt better sustainable practices to lower emissions without hurting revenue. The overall average efficiency score was 0.831, which is relatively good, but differences among countries suggest the need for tailored strategies to improve environmental performance.

We also found that environmental efficiency based on revenue is higher than that based on the live weight landings. This suggests that focusing on revenue may lead to better environmental outputs. Additionally, countries like Belgium and Italy could significantly reduce energy use and emissions while increasing the amount of fish caught. For instance, Belgium could reduce energy consumption by 56.3%, boost fish catches by 91.62%, and lower emissions by 56.3%. These findings show there's potential for specific actions to enhance sustainability and efficiency in the EU fishing sector.

In conclusion, this study provides valuable insights into the environmental sustainability of the EU fishing industry. It offers data-driven recommendations for policymakers and stakeholders. By prioritizing sustainability and innovation, EU countries can work together to make the fishing industry more environmentally friendly and economically viable, aligning with global climate and sustainability goals.

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Confronting a date monoculture in Tunisia: Can underused date varieties decrease farm economic vulnerability?

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Abstract

Crop diversity is promoted for its environmental benefits. However, few analyses have been conducted on whether crop diversity can reduce farm economic vulnerability to multiple production stresses. Deglet Noor is the most frequently grown variety of date in Kebili Region, Tunisia. Other date varieties, termed "common date varieties", were formerly considered to be less profitable and hence marginalised. Date production in this region is facing constraints linked to climate change, decreasing water availability and rising labour costs. The study compares the economic benefits of producing Deglet Noor dates and common date varieties at farm level, when faced with different production stresses. A survey was made of 123 farmers producing dates in Kebili Region. In the absence of stress, Deglet Noor is the most profitable variety, but its profitability is particularly vulnerable to different stresses. By contrast, the profitability of common date varieties is much less sensitive to these stresses. Stress-free environments become increasingly rare in Tunisian oases. Hence, re-directing interest towards common date varieties could help build less vulnerable oasis farming systems.

Keywords: *Climate change, Crop diversification, Dates, Economic vulnerability, Profitability, Underutilised crops, Tunisia.*

1. Introduction

Crop diversity has frequently been shown to enhance the environmental sustainability of agricultural systems (Beillouin *et al*., 2019; Tamburini *et al*., 2020). In practice, however, many agrosystems worldwide are organised around a single or a few crops (Martin *et al*., 2019). In ag-

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ricultural systems in which most farms produce for the market, for crop diversity to be adopted or be maintained, a key enabling factor is that plot or farm level diversity produces a higher average income. However, monoculture may be more profitable or may be considered by farmers to be more profitable than diversified systems, particularly in the short term (Lin, 2011). Incentives to monoculture may include sustained market demand, especially thanks to the creation of specialised value chains and supporting public policies, plus the possibility of driving down costs including through mechanisation, simplified farm management, or limited labour needs (Salaheen, 2019; Bravo-Peña and Yoder, 2024). In addition, even when crop diversity does reduce farm economic vulnerability, farmers may not have sufficient information and consequently continue to favour monocropping (León Araya, 2023).

The many studies on the benefits of crop diversity analyse its impacts on the environment and on agricultural production but are less focused on farm profitability (Beillouin *et al*., 2019). The few studies that considered farm profitability showed that there is no standard correlation between crop diversity and farm profit: the relation is context-specific (Bravo-Peña and Yoder, 2024). Thus, a problem is what kind of economic data could be made available to the actors of specific agrosystems to inform the discussion of whether farmers would be better off if they diversified their crop production.

Moreover, over the past decade, there has been a growing interest about the role of neglected and underutilized species as a component of agricultural system diversification (Padulosi *et al*., 2021). Broadly, these species can be defined as species that: 1) have long-standing cultivation in a specific environment and are well-adapted to it; 2) have limited production and value chain or have been marginalised; and/or 3) have received minimal attention from agricultural innovation systems (Mabhaudhi *et al*., 2019). These species are increasingly praised for the key role they can play in transitions towards more sustainable agricultural systems in a context of climate change and natural resource degradation (Hossain *et al*., 2021). Studies on neglected and underutilised species have often focused on their environmental or nutritional benefits (Ali and Bhattacharjee, 2023; Chivenge *et al*., 2015), whereas few studies have considered whether these species can become a profitable alternative to major crops. Their authors generally found that there was a need to improve marketing and processing options to improve their profitability so that they become of genuine economic interest to farmers (Bandula *et al*., 2023; Morimoto *et al*., 2021).

Crop diversity is a major issue in southern regions of Tunisia. More than 250 local date varieties can be found in oases located in these regions (Rhouma, 2005). In the 1970s, the government developed an agro-industrial value chain to export dates (Gendre *et al*., 2007). The chain focused on the variety Deglet Noor because of its high yield potential, easy storage, and market demand. In the 2022/2023 season, Deglet Noor accounted for 85.7% of dates exported from Tunisia (Onagri, 2023). Kebili Region has become the main region for the production and export of dates in Tunisia, and Deglet Noor is now at the core of the entire agricultural system of the region (Benmoussa *et al*., 2022). However, production of Deglet Noor is currently affected by an increasing number of risks. First, in 2021, an outbreak of mites affected date production and caused serious damage to Deglet Noor palm trees in particular. Second, Deglet Noor palm trees require a lot of irrigation and water is becoming increasingly scarce in traditional oases (Mekki *et al*., 2022). Third, production of Deglet Noor is costly, especially due to labour needs, and the cost of labour has been increasing rapidly in recent years. Compared with Deglet Noor, common date varieties have lower production costs and the palm trees of theses varieties are known to adapt to water scarcity better than Deglet Noor.

In this context, some farmers and staff of the regional office of the Ministry of Agriculture in Kebili Region have shown increasing interest in investigating whether producing more common date varieties could help reduce the vulnerability – particularly the economic vulnerability – of farms facing increasing risks that affect date production. However, little local economic data is available to inform a discussion on this issue. The present article compares the economic benefits of producing Deglet Noor dates and those of common date varieties at farm level, in the face of various production stresses.

Moreover, common date varieties can be considered as neglected and underutilised species. North Africa possesses a rich but underexploited genetic heritage of date palm varieties (Ismaïl and Hassine, 2021; Ouamnina *et al*., 2024). Discussions about the role of neglected and underutilised species in fostering more resilient agricultural systems have been ongoing for several decades in sub-Saharan Africa, Latin America, Europe, and Asia (Padulosi *et al*., 2021). However, apart from a few studies (e.g., Dop *et al*., 2019; Koussani *et al*., 2022), this discussion has been relatively limited in North Africa. In many regions of North Africa, the production of capital-intensive crops has contributed to economic development but has led to increasingly fragile agricultural systems, because of climate change and the often-unsustainable use of natural resources (Kadiri *et al*., 2022). Thus, the promotion of common dates could become a promising example of making use of the rich agrobiodiversity in North Africa so as to improve the long-term sustainability of agricultural systems.

2. Impacts of crop diversification on farm economic vulnerability to production stresses

The few studies on linkages between agrobiodiversity and economic vulnerability of farms generally found that crop diversification reduces income variability, although this is not always the case (Lennox, 2015). Moreover, some authors report that the impact of crop diversification on average farm income is positive and others that it is negative (Asare *et al*., 2014; Schroth and Ruf, 2014). Many factors influence the linkage between crop diversity and farm income, including the specificities of each agrosystem or farming practices (Bravo-Peña and Yoder, 2024; Niether *et al*., 2020). Linkage depends on the respective weights of "economies of scale", i.e. increasing the production of one product increases farm productivity, versus "economies of scope", i.e. when the integrated production of multiple outputs increases productivity (De Roest *et al*., 2018).

Studies of the economic impacts of diversification on farm income variability have mostly considered stress caused by climate, markets, and diseases. Several studies focused on a single stress: Clément *et al*. (2023) simulated the impact of fluctuations in the price of farm products on farm income in one region in Vietnam. Bozzola and Smale (2020) measured the impact of diversification on the variability of farm income in Kenya in a context of climate variability. Auffhammer and Carleton (2018) used a regional approach in India to study the impact of crop diversification on farm income variability in the face of drought. Other studies of crop diversification considered different stresses simultaneously, for example, climate and markets (Lennox, 2015) but they did so without measuring the specific economic impact of each type of stress. Kozicka *et al*. (2020) considered risks concerning climate and plant diseases to simulate the income of a representative farm under various crop diversification scenarios in Uganda. The model used in their study accounted for multiple factors and evaluation criteria, but the complexity of the model makes it difficult to present the data obtained to agricultural system actors.

Some analyses of the impacts of crop diversification on farm vulnerability have focused on underutilised crops. These crops are generally considered to decrease production risks. Indeed, such crops often only require limited quantities of pesticides and fertilizers (Chivenge *et al*., 2015), they are generally adapted to local soil, water availability and quality, and to local climate conditions, and their production may be less damaging to the environment (Baldermann *et al*., 2016; Mattas *et al*., 2024; Tadele, 2018). Some of these crops may have limited markets but still play a major role in home consumption (Boulay *et al*., 2021). Such studies often argue that underutilised crops offer cross-cutting solutions to multiple constraints (Mabhaudhi et al., 2019). However, there is limited knowledge on the impact of producing underutilised species on farm economic vulnerability.

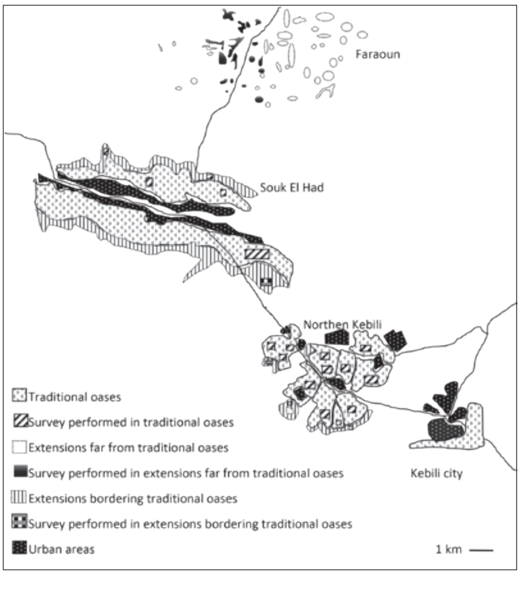
In terms of methods, most studies that analysed the economic benefits of crop diversity measured farmers' income in situations of low versus high crop diversity without considering how risks can affect these benefits (e.g. Hayran *et al*., 2018; Kurdyś-Kujawska *et al*., 2021; Zabala *et al*., 2023; Mzyece *et al*., 2023). Other studies considered farmers' perception of risks as an explanatory factor of diversity, without calculating the real impact of diversification on farmers' incomes (Bernzen *et al*., 2023). Only a few authors measured the impact of crop diversity on farm benefits when farms face with specific stresses (e.g. Clément *et al*., 2023), and such studies generally only assessed the impact of one type of production stress. However, to be able to discuss the economic advantages of crop diversification with local actors, all major production stresses need to be included. To our knowledge, to date, no study has measured farmers' incomes by comparing a situation of monoculture and crop diversity when the farm faced different types of stress.

3. Method

3.1. *Study site*

Dates have been produced for centuries in traditional oases in Kebili Region. From the 1990s on, farmers started planting new palm groves, locally referred to as "extensions". At first, the extensions were located in the vicinity of traditional oases. Later on, farmers started drilling individual boreholes much farther away from these oases, to create additional extensions. This led to a major increase in land planted with date palm trees. In 2022, traditional oases in Kebili Region accounted for 10,500 ha and extensions for 32,700 ha (Mekki *et al*., 2022). In traditional oases, most irrigation water is obtained from collective boreholes that are managed by water user associations. Plots in these traditional oases often have insufficient access to water, both in terms of quantity and in terms of frequency, as the time between water turns ranges from 25 to 60 days. As a result, some farmers in traditional oases have drilled individual boreholes to supplement the water supplied by the water user associations. Drilling boreholes in traditional oases and in extensions is illegal, as the administration considers that the aquifer is overexploited, but farmers continue to drill.

Figure 1 - Study area in Kebili Region, Tunisia.



Two study areas were selected for the present study (Figure 1). The first comprises the traditional oases plus the surrounding extensions in northern Kebili district. This area was selected because it has the largest number of common date palm varieties in Kebili Region. The second one is Faraoun extension area in Souk El Had district. This area is representative of the new palm groves that have been developed far from traditional oases thanks to easy access to groundwater.

There are three categories of date varieties: semi-dry dates, dry dates and soft dates. Soft varieties are harvested continuously, while semi-dry and dry varieties are harvested all at once. Dry and semi-dry varieties can be stored and are consequently easy to export. Deglet Noor is a semi-dry variety. Soft varieties are characterised by high-water content, which exposes them to fermentation and makes them difficult to store. They have to be sold within two to four weeks after harvest. Most soft varieties are grown for self-consumption and any excess is distributed to family members and neighbours.

3.2. *Methodological framework*

Farm economic vulnerability is sometimes assessed "ex ante", i.e. an assessment of the extent to which farms could be affected by possible

Table 1 - Framework for the comparison of common date varieties with the reference Deglet Noor variety in different situations and stresses.

Type of stress	*Situation involving limited stress*	*Situation involving high stress*
Water scarcity	Plot in a palm grove extension or in a traditional oasis but with access to an individual borehole (no problem of access to enough water)	Plot located in a traditional oasis with no access to an individual borehole (major problems linked to access to water)
Mite infestation	Year 2022 (minor problem)	Year 2021 (major problem)
Cost of labour	Year 2022 (minor problem)	Future scenario for the year 2030 (major problem)

risks. In this approach, vulnerability is generally measured using a set of indicators that consider exposure, sensitivity and adaptive capacity of the farm to several risks (Baca *et al*., 2014; Shaibu *et al*., 2020). In the present paper, we consider economic vulnerability "ex post", i.e. the degree to which a farm is harmed due to a perturbation or stress (Turner *et al*., 2003). Additionally, methods differ in the indicators used to measure vulnerability (Sneessens *et al*., 2019) and whether the point of view is static or dynamic (Dardonville *et al*., 2021). Hereafter, we focus on the extent farm annual income was affected by a specific stress that happened. We consider various settings in which farm exposure, sensitivity and adaptive capacity differ to compare farm vulnerability to stresses that really exist.

We built a methodological framework to compare the economic benefits of producing Deglet Noor versus common date varieties when faced with three kinds of stress: water availability, mite infestation, and labour costs (Table 1). The reference situation with no stress is production in extension areas where access to irrigation water is easy and the year was 2022, when labour costs were a minor issue and farming practices successfully limited mite infestation. We compared yields and farm incomes, measured as net benefit per date palm tree, which is what the farmers in Kebili Region usually do. Production costs were calculated and included the capital costs of drilling boreholes and installing solar panels, which is almost the only source of energy in the in extensions (Mekki *et al*., 2022) and the cost of the irrigation equipment (see Appendix A for details). The capital costs of drilling a borehole in traditional oases were also considered.

We compared a situation in which a stress is present and a situation in which the same stress is absent or only has a minor impact on production. Thus, in the present paper, our definition of economic vulnerability only applies to the "short-term" and does not account for the "long-term" capacities of farms to evolve, to reduce sensitivity to stresses and apply adaptive actions.

The first stress – water availability – was taken into account by comparing the situation in three different types of plots. The first situation refers to plots located in the extensions, where access to water is easy. The second situation covers plots in traditional oases that have an individual borehole, so access to water is consequently also easy. However, in traditional oases, the plots owned by farmers are usually fragmented as a result of inheritance, the date palms are sometimes more 60 years old so yields are decreasing, and pests circulate between the farm plots easily. Consequently, the production conditions are much better in extensions than in plots in traditional oases even in cases where the latter have access to sufficient water. The third situation refers to plots located in traditional oases but have no individual boreholes, meaning water availability is a major constraint. We compared net income per Deglet Noor palm and per common date palm in the three situations.

The second stress was caused by the dust mite Oligonychus afrasiaticus, which is one of the four main date palm pests in Tunisia. These mites can cause severe damage to the fruit (Ben Chaaban *et al*., 2011). Infestation by these mites increases during heat waves (Palevsky *et al*., 2003), which are becoming more frequent under climate change. Deglet Noor was found to be more sensitive to dust mites than several common date varieties (Ben Chaaban *et al.*, 2011). Dust mites have been present for years in Kebili Region but in the past, their impact was limited and farmers rarely treated their date palms against mites. In 2021, infestation by mites was very high due to high temperatures and a drought and seriously affected yields and farm incomes. In 2022, a new treatment method had become available and information concerning it was given to farmers, which resulted in a much more limited infestation than in the previous year. We thus compared the income per Deglet Noor palm and that of common date varieties in 2021 and 2022, while also accounting for the different situations in terms of water availability, as it had an impact on tree sensitivity to stress.

In southern regions of Tunisia, agricultural labour is becoming increasingly scarce and expensive, as young people are less interested in farming and migrate in search of better jobs (Carpentier, 2018). Over the past decade, labour costs have increased above and beyond inflation and the cost of labour for date production increased at an annual rate of 14.5% between 2015 and 2022 (calculated in constant currency i.e. adjusting for inflation). Other production costs and the selling price of dates increased broadly at the same pace as inflation over the same period. We built a business-as-usual scenario by 2030 in which we considered that all costs and prices would follow national inflation and that labour costs would continue to increase at the same rate above and beyond inflation. We calculated the impact of increased labour cost on the profitability of date production in this scenario. We compared the income per Deglet Noor palm with the income per common date palm in 2023 and under such a scenario by 2030 (considering the situation in traditional oases and in extensions).

3.3. *Data collection and analysis*

A survey of 123 farmers was carried out in May 2023. Farmers were asked how many date palms they had, about their production costs (detailing cost categories as detailed in Appendix A), yields, and the selling prices for all date palm varieties they grew in 2021 and 2022. They were also asked about the date varieties and number of palm trees they had planted over the period 2007-2022 and the date varieties and the number of trees they planned to plant in the period 2023-2032.

Together, the 123 farmers managed a total of 182 plots, of which 122 plots are located in traditional oases and 60 plots in extensions. Nineteen percent of farmers who owned plots in traditional oases had their own borehole they used to irrigate the plot in addition to the water they obtained from collective boreholes. The average planting density in plots located in traditional oases was 150 palms per hectare and farmers had an average of 0.63 ha, usually divided into several plots. The planting density in plots in the extensions was on average 120 palm trees per hectare, while the farmers farmed on average 4.5 ha.

The farmers interviewed reported that the Deglet Noor variety dominated both in traditional oases (70% of palm trees) and in extensions (90%). Taken together, the farmers we interviewed grew 41 varieties of common dates in traditional oases and 26 varieties in extension areas. Female trees of common date varieties represented 28% of all trees in traditional oases and 9.5% in extensions. The remainder were male palm trees whose pollen can fertilize female palm trees of any variety.

Apart from Deglet Noor, the most prevalent common semi-dry variety was Alig, which accounted for 47% of common date palm trees in traditional oases, and 56% of common date palm trees in the extensions. Alig is often planted to make date paste which is used in pastry making; it has an established international market and fetches a good price. Kenta was the most prevalent dry variety in traditional oases and in extensions and represented 17% of common date palms in the oases and 19% in the extensions. In recent years, actors of the date value chain in Kebili Region have been paying increasing attention to the Kenta variety because it has an international market often in countries where consumers want cheap dates. Moreover, it is increasingly used to manufacture date powder, since dry dates are easily ground and dried. Gosbi was the most prevalent soft variety, representing 2.2% of common date palm trees in traditional oases and 2% in the extensions. Our comparative economic analysis with the reference variety Deglet Noor only included the three common varieties most present in each category, i.e., semi-dry (Alig), dry (Kenta) and soft (Gosbi), in the traditional oases and extensions of the study area.

4. Results

4.1. *Production costs*

Table 2 lists the production costs for Deglet Noor, Alig, Kenta and Gosbi varieties in the plots located in traditional oases without access to an individual borehole and in extensions. In the traditional oases, the cost of irrigation water corresponds to the amount paid to the water user association. When farmers also have an individual borehole in traditional oases, irrigation costs increase by 6.6 Tunisian Dinars (TND) per tree (on top of what they pay to the water user association), thus total production costs were 96.9 TND for Deglet Noor variety and 58.9 TND for Alig, Kenta and Gosbi varieties (in May 2022, 1 US$ = 3.1 TND). The Deglet Noor variety is labour-intensive, the labourers have to climb the trees several times in the season to perform tasks including pollination, chiselling and destemming, bagging, removing palm fronds and harvesting. Other varieties only require two tasks: pollination and harvesting. Chiselling and destemming are not done for common date varieties because these dates are not marketed according to size. Bagging is not used for common dates because they are more resistant to rainfall and are harvested before the beginning of the rainy period. Dry palm fronds are not removed from common date palm trees because these trees are considered to be more resistant than Deglet Noor trees to insects that may develop in these parts of the trees. Common date palm trees also require less fertiliser than Deglet Noor. The overall cost of producing Deglet Noor, in both extension and traditional oases, is thus much higher than the cost of producing Alig, Kenta and Gosbi.

4.2. *Reference situation and impacts of water scarcity*

Table 3 lists the yields of the four main varieties found in both traditional oases and extensions, in the three above-mentioned plot situations in 2022. In traditional oases, the com-

Table 2 - Production cost of Deglet Noor, Alig, Kenta, and Gosbi in 2022.

	Plot in a traditional oasis (without access to an individual borehole)		*Plot in a palm grove extension*	
	Deglet Noor	*Alig-Kenta-Gosbi*	*Deglet Noor*	*Alig-Kenta-Gosbi*
Average cost per palm tree in 2022 (Tunisian Dinars - TND)				
Irrigation water	7.3	7.3	8.3	8.3
Labour related to irrigation	1.8	1.8	4.2	4.2
Labour for other date production tasks	49.0	20	49.0	20.0
Plot cleaning (removing dry palm fronds, etc.)	0.6	0.6	0.8	0.8
Fertilisation	7.1	3.8	7.7	4.4
Tillage	6.3	6.3	6.3	6.3
Positioning plastic bags to protect the dates	4.1	0	5.8	0
Sulphur treatment to prevent against mite attacks	11.0	11.0	12.5	12.5
Transportation cost to buyer	1.6	0	2.0	0
Total production costs	88.8	50.8	96.6	56.5
Share of labour in total production cost (%)	55	39	51	35

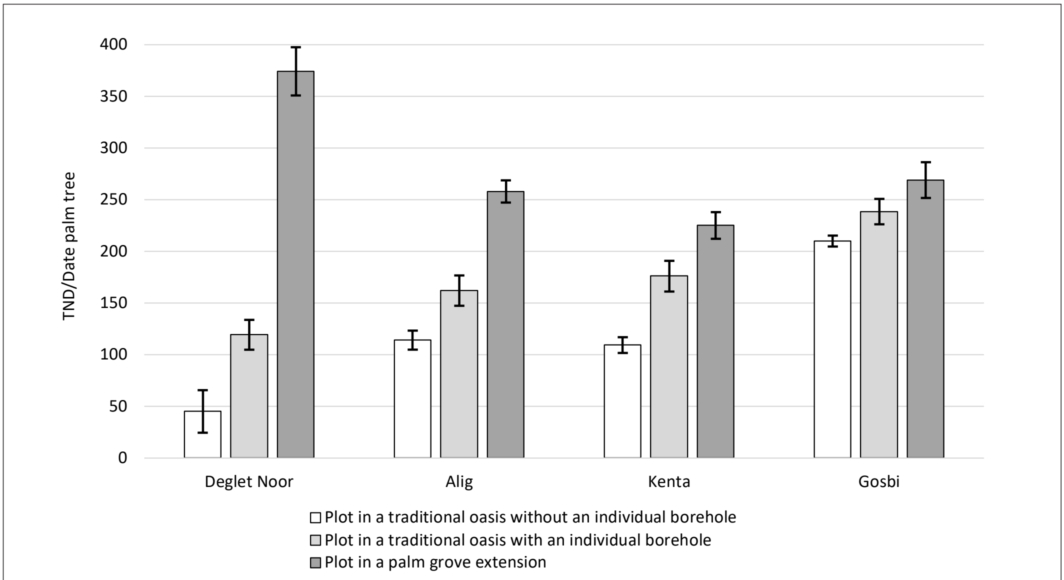
Table 3 - Yields and selling prices of the four date varieties in traditional oases and extensions.

Variety	*Deglet Noor*	*Alig*	*Kenta*	*Gosbi*
Yields				
Plot in a traditional oasis without an individual borehole (kg/tree)	85	112	180	65
Plot in a traditional oasis with an individual borehole (kg/tree)	130	120	200	75
Plot in a palm grove extension (kg/tree)	185	155	221	85
Decrease in yield between a plot with an individual borehole and one without a borehole in a traditional oasis (%)	34	6.6	10	13
Average selling price (TND per kg)				
In traditional oases	1.6	1.7	1	4
In extensions	2.5	2.1	1.3	4

parison between plots with and without access to an individual borehole shows that water stress reduces Deglet Noor yield by one third. Common date varieties are more resistant to water scarcity. Table 3 also shows selling prices. Deglet Noor dates are classified according to their quality, each class has a specific selling price (Table B1 in appendix). The price given for Deglet Noor in Table 3 represents the average price that accounts for the different quality classes. This classification is not used for other varieties, for which there is only one overall price.

Figure 2 shows the income per palm tree in the three plot situations in 2022 (in this figure and in following one's bars represent standard errors). Income per Deglet Noor palm tree was low in a situation of water stress resulting from a marked drop in yield along with high production costs. In plots located in traditional oases and equipped with a borehole, the income was also low. This was not due to water scarcity, but rather because in 2022, problems connected with mite infestations of Deglet Noor palm trees were still affecting these oases. Common date varieties were more profitable than Deglet Noor in traditional oases. However, the price of Alig and Kenta varieties has only increased significantly in the past 10 years and farmers seldom plant new trees in traditional oases. This explains why Deglet Noor was still the most planted variety in

Figure 2 - Income per date palm tree in 2022.



traditional oases. Moreover Figure 2 only gives the income if the entire yield is sold. Gosbi is a soft variety, it is consequently highly perishable and can only be sold in the two weeks following harvest, which limits its sales potential. As a result, a considerable proportion of the yield (approximately 80%) is destined for home consumption or given to relatives.

4.3. *Impacts of mite infestation*

The major mite infestation of date palms in 2021 affected many of the palm trees belonging to the farmers we interviewed (Figure 3). That year, high temperatures and long periods between irrigation water turns in traditional oases created a favourable environment for the development of mites. In traditional oases, Deglet Noor trees appeared to be more affected by the mite than common date varieties. According to a representative of the Kebili date technical centre, mites develop preferably on tender leaflets, which is the case of Deglet Noor palm trees. By contrast, most common date palm trees have hard leaflets. Moreover, there are more mites on trees that are harvested late in the season. Deglet Noor is harvested between November and December, i.e. later than Gosbi (mid-August), Kenta (early October), and Alig (late October). In the extensions, water is present and irrigation is regular. This creates a humid microclimate that is unfavourable for the development of mites.

In 2022, a sanitary protocol for mite prevention had been communicated to farmers: 86% of the farmers in the extensions we interviewed and 57% of farmers in traditional oases applied it. Thus, palm trees were much less infested both in traditional oases and in extensions, compared with in 2021. Still, there were differences: farmers more generally cleaned the palm groves and sprayed sulphur power as a preventive treatment in the extensions. In traditional oases, fewer farmers applied the treatment and the palms belonging to a farmer who had applied the treatment could still be infected later on because neighbours had not carried out the treatment. Thus, in 2022, mite infestation remained higher than in traditional oases than in extensions.

Due to inflation, production costs and selling prices for Deglet Noor were higher in 2022 than in 2021 (respectively 15% and 23% higher). This was due to mite infestation, especially because there were far fewer dates of good quality available on the market. However, the sharp increase in price between 2021 and 2022 did not affect the fact that, between 2015 and 2022, produc-

Figure 3 - Percentage of palm trees infested by mites in 2021 and 2022.

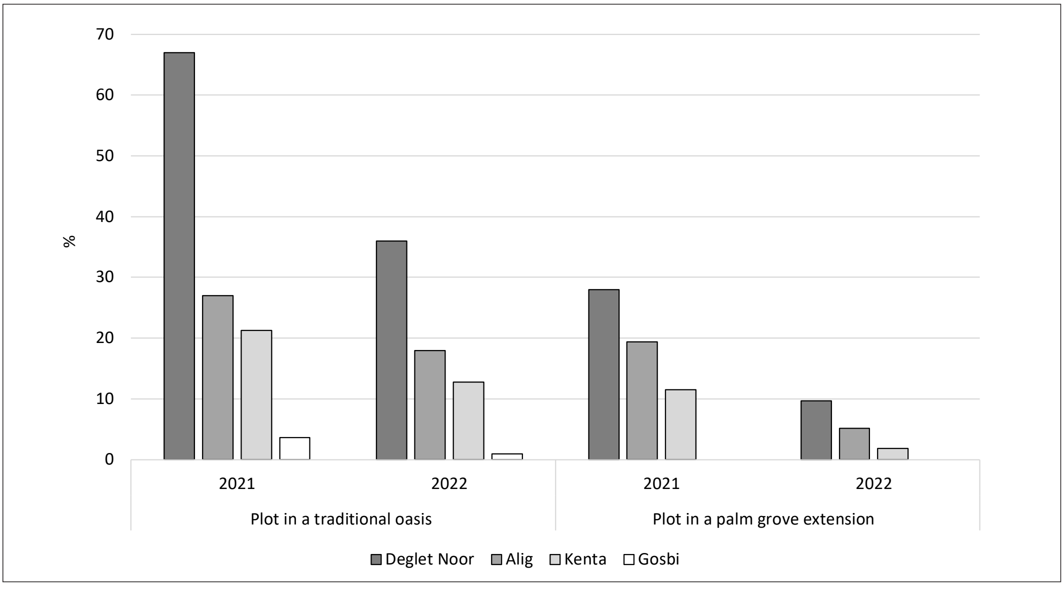
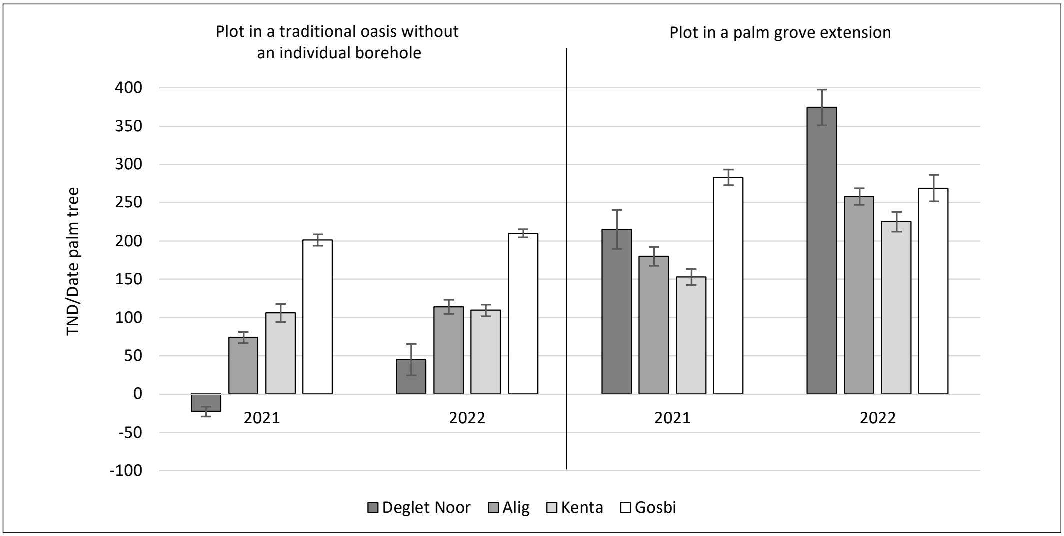


Figure 4 - Comparison of palm tree income between 2021 (high mite infestation) and 2022 (limited mite infestation).



tion costs and the selling price followed national inflation rates. By contrast, the selling prices for common varieties remained stable between 2021 and 2022. In 2021, due to the drop in yield, the income from the Deglet Noor variety (calculated on average for a whole plot) was negative in a plot located in a traditional oasis with no access to a borehole (Figure 4). By contrast, the income from common date production in plots located in traditional oasis without access to an individual borehole was not much affected by the mite infestation. In the extensions, the Deglet Noor variety remained profitable in both years, because the infestation rate remained low.

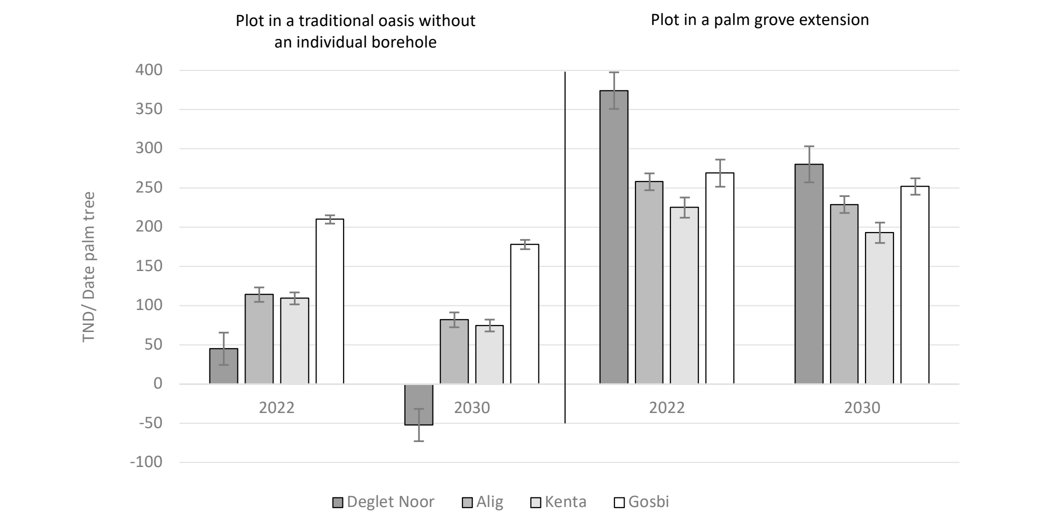
4.4. *Future impacts of increasing labour costs*

Figure 5 shows date palm tree income in traditional oases (without access to a borehole) and in extensions, according to a future scenario for 2030 whereby: 1) production costs (excluding labour) and selling prices increase at the same pace as national inflation; 2) labour costs continue to increase at the same rate over and above the inflation rate as they did between 2015 and 2022. In Figure 5, prices in 2030 are presented using constant dinars as of 2022. In such a scenario, by 2030, labour costs for Deglet Noor will represent 84% of total production costs in an extension and 86% in a traditional oasis. In the extensions, Deglet Noor will remain the most profitable variety even though the increase in production costs reduces the difference in profitability between Deglet Noor and other varieties. In such a scenario, in traditional oases, income from Deglet Noor will become negative due to rising labour costs. The decrease in the profitability of common date varieties is much lower and these dates will remain profitable in traditional oases under this scenario. In fact, growing common date varieties can help solve the growing problem of labour scarcity not only because less work is required for production, but also because harvesting of common date varieties is spread out over a much longer period than that of Deglet Noor.

4.5. *Plantation of palm seedlings*

Farmers mostly plant palm seedlings in extensions, as space is available there to extend cultivated areas. In plots located in traditional oases, planting new trees would require removing existing palm trees, which in practice, very seldom happens. In the extensions, most of the farmers we interviewed planned to continue planting Deglet Noor (75% of planned trees) and Kenta, Alig and Kentichi will represent most of common date varieties (together more than 23% of

Figure 5 - Palm tree income in a future scenario by 2030 involving increasing labour costs.



planned trees, Table 4). Kentichi is a dry variety used for making date powder, a product whose national and international markets have expanded in recent years. The number of farmers who planned to plant the Alig variety during the period 2023-2032 was three times higher than the number of farmers who planted Alig during the period 2007-2022. The same evolution is expected for Kenta.

Farmers continued to favour Deglet Noor because the market for the variety remained stable, especially the export market but the farmers we interviewed confirmed that they had become aware of the interest of cultivating common date varieties in order to continue making a profit despite increasing risks. Alig, Kenta and Kentichi were the preferred common date varieties because they had also an acknowledged export market. Moreover, unlike some other common date palm varieties, their seedlings are easy to find. More specifically, the 20 farmers who planned to plant Kenta, Alig or Gosbi (instead of Deglet Noor) mentioned that (i) demand on the national and export market was high for Alig and Kenta (15 farmers); (ii) these 3 varieties were resistant to water stress and diseases and required limited labour (12 farmers); (iii) they value biodiversity per se, which is considered to be a local patrimony (7 farmers); and (iv) 5 farmers planned to grow Gosbi for self-consumption.

5. Discussion

In situations where production is fully under control, i.e. access to sufficient water, controlled labour costs, prevention of diseases and pest infestations, etc.), Deglet Noor is clearly more profitable than common date varieties. However,

Table 4 - Past and scheduled plantation of main palm varieties.

	Deglet Noor	*Alig*	*Kentichi*	*Kenta*	*Gosbi*
Share of interviewed famers having plots in extensions that planted each date variety during 2007-2022 (%)	57	7	5	7	2
Share of interviewed farmers having plots in extensions than plan to plant each date variety during 2023-2032 (%)	43	20	8	20	5

the profitability of Deglet Noor is much more at risk than the profitability of common date varieties in the event of drought, high labour costs and pest infestations. Common date palms are physiologically more robust to different types of stress and since their cost of production is lower, the income obtained from their production is less affected by changes in these costs.

In the future, date production factors in Kebili Region will probably be increasingly difficult to control. Water in traditional oases will probably become increasingly scarce, due to the growing difficulties of running water user associations (Mekki *et al*., 2022). Extensions already face a continuing drop in groundwater levels due to intense pumping for irrigation (Mekki *et al*., 2022). Moreover, the increasing number of abandoned plots in traditional oases (already observed in 2023), will likely significantly increase the occurrence of pests and diseases. Due to climate change, conditions will increasingly favour infestation by dust mites. Consequently, in extensions, and to an even greater extent in traditional oases, factors enabling Deglet Noor profitability may be increasingly less certain in the future. Moreover, in extensions in which farmers still plant trees, choosing the variety of date and hence the degree of crop diversification will increasingly involve a trade-off between profitability and risk management (e.g. Kurdyś-Kujawska *et al*., 2021).

Increasing numbers of studies point out that, while "modern" agricultural systems perform well when production conditions make it possible to get the best out of new crops (or varieties), when such conditions are not met, "traditional" varieties fare better e.g. thanks to their ability to cope with harsh climate conditions (Assefa *et al*., 2021). Underutilised species are increasingly acknowledged to have a promising role to play to build sustainable farming systems under climate change (Hossain *et al*., 2021). The present study has shown that the profitability of common date varieties is already valid compared with Deglet Noor, like in other examples of underutilised species (Galappaththi and Schlingmann, 2023). Common dates involve lower economic risks than "modern" input-intensive crops, due to their lower investment costs. Thus, they do fit the three criteria proposed by Gruere *et al*. (2006) for defining underutilised species: "they are locally abundant but globally rare, that scientific information and knowledge about them is scant, and that their current use is limited relative to their economic potential".

6. Conclusion

Deglet Noor monoculture has been the backbone of agricultural – and more generally of the economic – development of Kebili Region since the 1970s. This model is increasingly jeopardised by the increased occurrence of production stresses. In addition to the well-known ecological advantages of diversification, the present study shows that producing common date varieties can reduce the economic vulnerability of farms to several production stresses.

At a time of climate change and degradation of natural resources, Tunisian agricultural policies should focus less on economic growth of the date sector and instead identify pathways to build more resilient agricultural systems in oases. The promotion of common date varieties can be a major pillar of a strategy towards resilient agricultural systems. First, the type of analysis presented in this paper could be disseminated to help change in the opinion of many actors (farmers, other actors of date value chains, staff of public administrations) who still consider Deglet Noor to be the only variety to be promoted and marketed. Second, specific support could be provided to help farmers plant common date varieties in traditional oases – where these varieties will become more and more adapt to local production stresses than Deglet Noor. Third, support to the marketing of common dates is needed, both on the national and on the international market.

Many crop diversification studies analyse the factors that explain farmers' decisions to opt for crop diversification. Such studies are very useful when the case for diversification is clear and the main question is what can be done to support farmers in diversifying. In Kebili Region, like in many other regions worldwide, the debate is still underway about how and to what extent it makes sense to opt for more crop diversity, especially from the farmer's perspective, and in some places the debate has hardly even started. One of the obstacles to this debate, which should include among others farmers and public actors in charge of agricultural policies, is lack of data. The present study shows it is indeed possible to build an "economic case" for crop diversification. By comparing the farm level profitability of various diversification options when farmers face a series of stresses, the method detailed in the present paper can produce data that can be easily used to inform discussion concerning the appropriate level of crop diversity in an increasingly uncertain environment.

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Appendix A

Hereafter we detail the costs considered for undertaking economic analysis.

a) Irrigation water

In traditional oases, this corresponds first to the cost paid to the water user association. This is calculated as the tariff per hour multiplied by the number of irrigation hours during one year. In case farmers have a borehole (in extension and in traditional oasis), this cost includes the capital cost of drilling a borehole and buying irrigation equipment and solar panels (duration of equipment considered as being 20 years). Energy costs are generally nil because of the wide spread use of solar energy and maintenance costs are negligible.

b) Labour related to irrigation

Cost of date palm irrigation labour per irrigation multiplied by the number of times trees are irrigated per year.

c) Labour for other date production tasks

Producing Deglet Noor variety requires that labourers climb palm trees several times per season: once for removal of the palm, twice for pollination, once for chiselling and manipulation of the date regime, once for bagging, and once for harvesting. Each ascent involves a special labour price per tree. By contrast, common date trees require only two ascents for pollination and harvest.

d) Plot cleaning

One hectare requires three days of cleaning for one employee.

e) Fertilisation

This task is two-pronged. First, every year, farmers deposit ammonium nitrate around each tree. Second, once every three years, farmers plough around the trees, put diammonium phosphate, and add manure around date palm trees.

f) Tillage

Every year, farmers hire a service-provider that comes with a tractor and till the whole plot.

g) Positioning plastic bags to protect the dates

Plastic bags are used to protect date bunches from rainfall and mosquitoes. A palm tree in a traditional oasis contains an average of 12 bunches as palm trees are older, whereas in the extension it contains an average of 17 bunches, one mosquito net bag per bunch. They are renewed on average once every three year.

h) Sulphur treatment to prevent against mite attacks

Farmers spray sulphur two times, from 2021 onwards. The calculation did not take into account additional treatment in case of mite attack.

i) Transportation cost to buyer

Yield of Deglet Noor date is generally high in each farm so farmers need to hire a truck to transport harvested dates to middle men. By contrast, due to small quantities, farmers transport common dates using their own vehicles.

Appendix B

Table B1 - Classification of the Deglet Noor variety.

Categories of dates fruits of Deglet Noor	*First choice*	*Second choice*	*Third choice*	*Dates in bulk (fallen from the fruit bunch)*	*Livestock feed*
Selling price of the Deglet Noor variety (TND/kg)	3.7	2.5	1.5	1	0.2
Percentage of quantity sold for each choice in 2022)					
Plot in a traditional oasis without an individual borehole (%)	17	25	15	7	36
Plot in a traditional oasis with an individual borehole (%)	25	25	15	7	28
Plot in a palm grove extension (%)	50	10	25	5	10

Assessing sustainability in small dairy cattle farms: Pathways for improvement in northeastern Tunisia

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Abstract

In Tunisia, rising costs, low productivity, and climate change have reduced cattle numbers in the last decade. This study evaluates the sustainability of small dairy cattle farms in northeastern Tunisia and explores pathways for improvement. A sustainability assessment was conducted on 109 dairy farms in Bizerte, using IDEA method to evaluate agroecological, socioterritorial, and economic dimensions. At the regional level, sustainability was highest in agroecology, moderate in economics, and lowest in socioterritorial aspects. Cluster analysis identified four groups. The first supports employment and resource use but struggles with organic farming and waste management. The second practices agroforestry with moderate biodiversity but faces economic challenges. The third excels in biodiversity and manure management. The fourth benefits from diversification and self-sufficiency, enhancing performance. For long-term sustainability, the dairy sector must adopt resilient systems with mixed forage crops, improve funding and subsidies, and invest in infrastructure, training, and cooperatives to boost productivity, reduce environmental impact, and integrate farmers into the value chain.

Keywords: *Sustainability, Dairy cattle farms, IDEA, Cluster analysis, Tunisia.*

1. Introduction

Dairy cattle farming plays a crucial role in the Tunisian economy, providing significant contributions both economically and socially (Dhraief *et al.*, 2019). This strategic sector represents an important part of the country's agro-food industry, contributing about 7% of its total value (Chebbi, 2019). Additionally, it accounts for approximately 25% of animal production and 11% of overall agricultural production. In 2015, it provided employment for over 112,100 farmers,

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which is more than 40% of all agricultural jobs in the country. The increase in demand for animal-based products in Tunisia over recent decades highlights the strategic importance for food security, the economy, and nutrition. This sector also requires particular attention regarding associated environmental and socioeconomic challenges (Soltani *et al.*, 2011).

The dairy value chain in Tunisia is sensitive and could be negatively affected by the opening of the Tunisian market to European milk and dairy products, which are considered more competitive. Within this value chain, small- and medium-sized farmers face numerous problems and threats that weigh on its present and could jeopardize its future in an already challenging global context associated with climate change and soil degradation (FAO, 2021). Therefore, the quest for competitiveness in local dairy farming in Tunisia is crucial to reducing the significant gap between domestic milk supply and demand (Steinfeld *et al*., 2006). It is important to consider the environmental and health concerns related to this expansion, such as soil biodiversity loss (Caplat *et al*., 2012) and greenhouse gas emissions, highlighting the urgency of adopting sustainable and environmentally friendly agricultural practices.

The low productivity observed in small- and medium-sized dairy farms can be explained by multiple constraints, including low nutritional values and poor technical management of dairy cows, especially in smaller farms (Sraïri *et al.*, 2007; M'Hamdi *et al.*, 2017; Attia *et al.*, 2022). In the field, strategies and practices for developing the local dairy sector primarily focus on improving farmers' incomes rather than seeking social balance, and even less on reducing environmental threats.

Dairy farms in Tunisia face increasingly warmer temperatures, exceeding cows' thermo-neutral zone for over five months each year, leading to reduced production efficiency and substantial economic losses (Bouraoui *et al*., 2002). Frequent droughts, often occurring for two consecutive years after no more than three years of normal rainfall, have diminished the quality and availability of fodder – a critical constraint for livestock farming (Kayouli, 2006). This has hindered the genetic potential of high-yielding breeds, raising concerns about their ability to adapt to these harsh conditions (Hammami *et al.*, 2008). Projected climate change scenarios are expected to exacerbate these challenges, further impacting natural resources, animal productivity, health, and the sustainability of livestock-based production systems (Ben Salem, 2011).

Reflecting on the performance and sustainability of small and medium dairy farms is important. The sustainability of these agricultural operations is crucial for ensuring food security, reducing poverty, and preserving natural resources, particularly in developing countries (Schindler *et al.*, 2015) Indeed, assessing agricultural sustainability is an essential step in building the knowledge necessary to improve management and evolve toward more sustainable practices and systems. Thus, this assessment contributes to the design of innovative solutions to enhance the sustainability of farms (Bockstaller *et al*., 2015). A decision-making support objective should accompany this assessment through public policy guidelines that encourage environmentally friendly agricultural practices.

Several methods, such as RISE (Häni *et al*., 2003), MOTIFS (Meul *et al*., 2008), SAFA (FAO, 2014), FoPIA (Bechir and Ounalli, 2020), DPSIR (Bechir *et al*., 2020), and SIAT (Corvo *et al*., 2021), have been developed to study agricultural farm sustainability, but mainly in developed countries and to a much lesser extent in developing countries (Fadul-Pacheco *et al.*, 2013). Among these methods, IDEA (Indicateurs de Durabilité des Exploitations Agricoles or Farm Sustainability Indicators) describes the overall performance of farms, taking into account the three dimensions of sustainability: agroecological, socioterritorial, and economic. This method enables an in-depth analysis of each aspect of sustainability, including all dimensions of the farm and is compatible with different contexts (Zahm *et al*., 2008). The IDEA method has been used in various studies assessing the sustainability of agricultural systems (Attia *et al.*, 2022; Baccar *et al.*, 2018; Gharbi *et al*., 2022; M'Hamdi *et al.*, 2017; Bekhouch-Guendouz, 2011).

This study aims to assess the sustainability of the small dairy cattle farms in northeastern Tunisia and explores pathways for improvement. A sustainability evaluation was undertaken with 109 smallholder dairy farms in the Bizerte region using the IDEA method in the agroecological, socioterritorial, and economic scales.

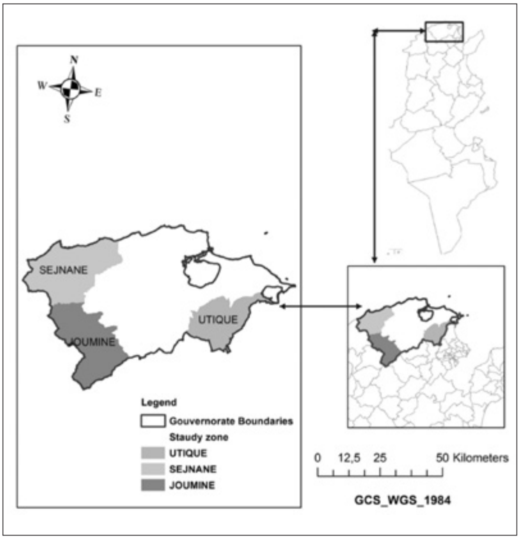
2. Methodological framework

2.1. *Study area*

The study area focused on the two regions of Sejnane-Joumine and Utique in Bizerte governorate (Figure 1). This region is located in the extreme northeast of the country and benefits from a privileged geographic position with a broad opening to the Mediterranean. Bizerte covers an area of 3,750 km² and in April 2014 had a population of 568,219. This area is characterized by a humid and semi-humid climate, receiving an average rainfall of over 600 mm, which promotes forage production.

The study region represents a dairy basin characterized by small- and medium-sized dairy cattle producers. The Utique region is an old dairy basin and the leading milk producer in the governorate. It ranks third in the number of producing female cattle. The Sejnane-Joumine region features an integrated cattle farming system. It ranks first in terms of the number of productive females (6,762) and third in milk production (18,205 liters per day).

Figure 1 - Study area (Authors' elaboration, 2024).



2.2. *Study design*

The study area was chosen due to the diversity of crops and the importance of dairy cattle farming activity. The survey was conducted among 109 selected dairy cattle farmers. The sample size was determined using the equation of Cochran WG (1977) with a confidence interval of less than 95% and a precision of 10%. The formula used is $n = N/(1 + (e^2)$, where n is the sample size, N is the population size, and e is the level of precision. Farmers were selected based on specific criteria to ensure representativeness of the sample.

2.3. *Data collection*

The data used were collected through field surveys of 109 farmers from Sejnane-Joumine (59 individuals) and Utique (50 individuals), who have small and medium sized farms, with an average herd size of six cows and an average area of 4.85 ha.

Various types of data were collected during the two-year period (2021-2023). The data included statistical information and specific data related to the IDEA method. This method consists of 122 questions. The specific guide for this method includes general information about the farm, livestock, management practices, biodiversity aspects, land use, management and farming practices, life quality, and economic aspects.

In addition to a literature review on farm sustainability assessment, and field surveys, six mini-workshops have been co-organized successively since 2021, including National Institute of Agronomic Research of Tunisia (INRAT), North-West Sylvo-Pastoral Development Office (ODESYPANO) Sejnane, Livestock and Pasture Office (OEP) Mateur, and territorial extension unit (CTV) Sejnane-Joumine and Utique (Table 1). These working meetings involved the main stakeholder groups concerned with dairy production.

Table 1 - Description of multi-stakeholder workshop organized in the study area.

Date	*Location*	*Partici-pants*	*Topics*
24 March 2024	Agricultural Investment Promotion Agency (APIA) Bizerte	3	Collection of statistical data on the dairy value chain in Bizerte (for sampling). Discussion of the variables determining the sustainability of dairy cattle farming in Bizerte. Presentation of the IDEA method. Data collection for the IDEA exercise.
12 September 2021	INRAT Tunis	28	National workshop: "Diagnosis of the dairy value chain in Bizerte." Discussion of the variables determining the viability of dairy cattle farming in Bizerte.
25 March 2022	ODESYPANO Sejnane	11	Sampling and fieldwork preparation. Presentation of IDEA survey elements.
16 April 2022	OEP Mateur	3	Data collection for the IDEA method. Discussion of the variables determining the viability of dairy cattle farming in Bizerte.
5 May 2022	CTV Sejnane	4	Sampling and fieldwork preparation. Presentation of IDEA survey elements. Discussion of IDEA sustainability indicators.
23 May 2023	ODESYPANO Beja	16	Regional workshop: "Sustainability indicators and methods for assessing the sustainability of cattle farming in the regions of Sejnane-Joumine and Utique." Discussion and validation of IDEA method results.

Source: Authors' elaboration, 2024.

2.4. *Data analysis*

The data analysis was based on the IDEA method, a tool based on 42 indicators developed by Vilain (2003), who identified three scales: agro-environmental with 18 indicators, socio-territorial with 18 indicators, and economic with six indicators. In this study, the method was adapted while retaining all components and initial thresholds. Each indicator provides information about the level of sustainability. The score from the lowest scale among the three mentioned scales reflects the level of sustainability of the farm (Zahm *et al.*, 2008). This analysis is combined with principal component analysis and ascending hierarchical classification—statistical analyses to classify the farms into groups according to the sustainability scores.

3. Results

3.1. *Descriptive analysis of the sustainability of dairy cattle farming systems*

Overall sustainability is rated at 151/300 points for Sejnane-Joumine and 134/300 points for Utique. The agroecological scale scores the highest with 56.37 points, followed by the economic scale at 55.7 points (Figure 2). The socioterritorial scale has the lowest score at 32.13 points, which is the main limiting factor for the sustainability of these farms. This limitation stems from weaknesses observed in the product and territorial quality, as well as the ethics and human development components. Enhancing the sustainability of these dairy farming systems requires addressing all three scales.

The component of *spatial organization* has a relatively high average of 14.17 points, driven by high parcelization (5.14/6 points) and effective management of organic materials, with farmers using manure on over 20% of the utilized agricultural area (UAA) to enhance soil fertility and reduce fertilization costs (2.75/5 points). The *farming practices* component also scores significantly with an average of 20.1/34 points, where the liquid organic waste indicator, assessing effluent management, achieved a perfect score since none of the visited farms used liquid organic waste (manure). The *in-*

Figure 2 - Representation of the sustainability scales of farms.

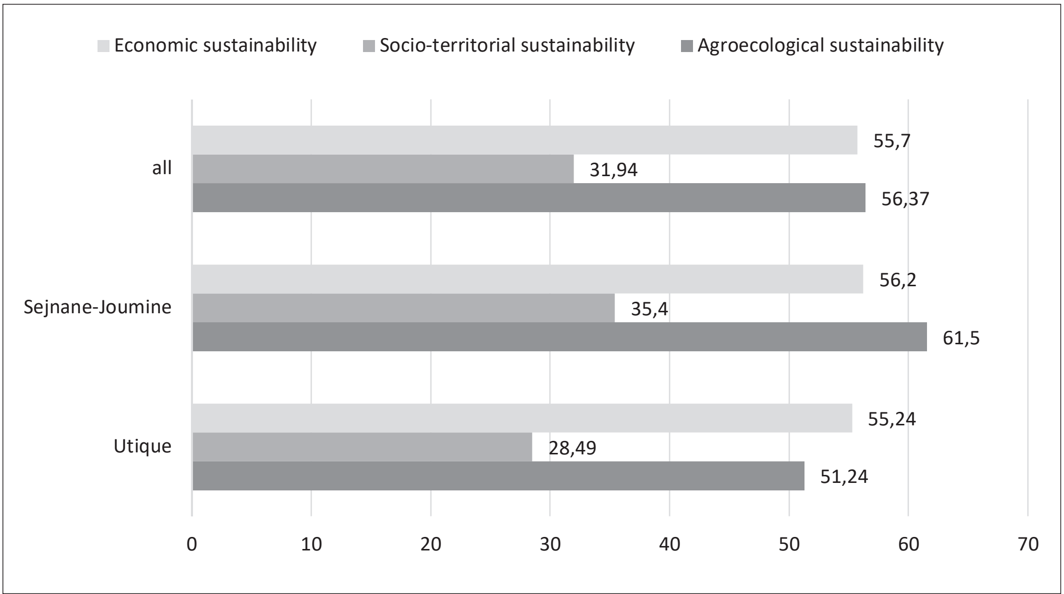
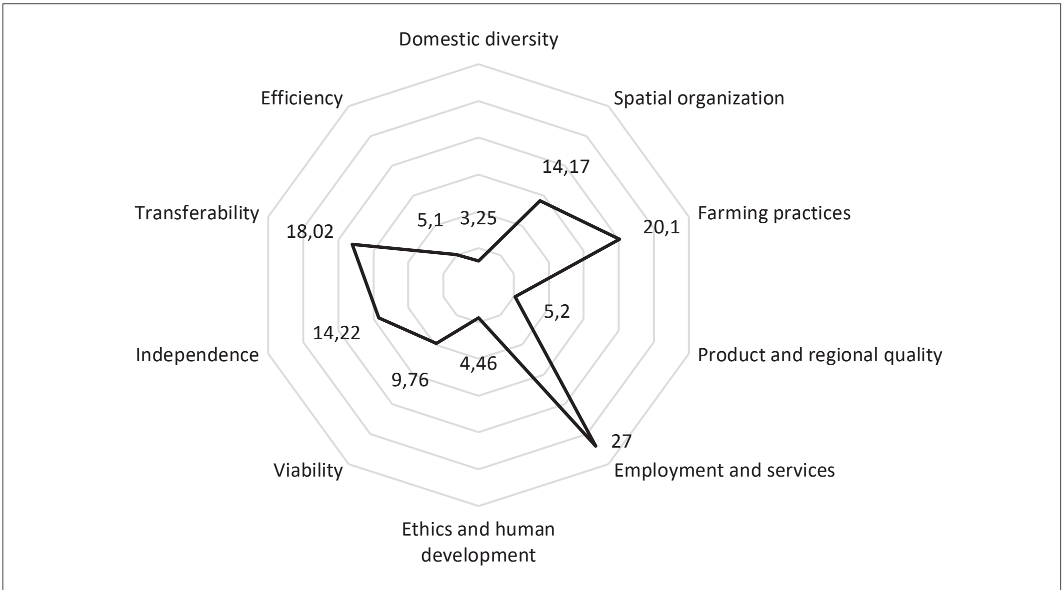


Figure 3 - Graphic representation of the sustainability components.



dependence component, with a score of 22.95 points, reflects financial autonomy, as farmers did not receive credit due to their land tenure status, which did not meet the requirements of funders. Lastly, the *transferability* component, which measures the ease of farm succession, scored highest in economic transmissibility due to the low capital levels of the farms relative to the full-time family agricultural workforce (Figure 3).

Table 2 - Indicator scores for the production diversity component (PDC).

	Diversity of annual and temporary crops	*Diversity of perennial crops*	*Animal diversity*	*Enhancing genetic heritage*	*PDC*
All	5.95	3.1	9.8	3.25	22.1
Sejnane-Joumine	6.2	4.6	10.6	3.4	24.8
Utique	6	1.6	9	3.1	19.4
Theoretical maximum	14	14	14	6	33

3.1.2. *Sustainability assessment of the agroecological scale*

The *diversity of annual and temporary crops* component averages 22.1/33 points, with Sejnane-Joumine scoring 24.8/33 and Utique 19.4/33 (Table 2). The *domestic plant biodiversity* indicator, which measures the variety of plants on farms, averages 5.95/14 points. The *diversity of perennial crops,* based on the presence of grasslands, arboriculture, agroforestry, and agro-silvopastoralism, averages 3.1/14 points across both areas. *Animal diversity*, determined by the number of productive animal species and breeds, scores 9.8/14 in Sejnane-Joumine and 10.6/14 in Utique, with the high score reflecting the combination of sheep and cattle farming in 78% of the farms. The indicator for *genetic heritage enhancement*, which supports local breeds and endangered species, shows low scores. Over the past 20 years, the local breed has been replaced by imported breeds (Holstein breed) that are more productive but less resilient to the climatic challenges in Tunisia.

The *spatial organization* component, with an overall average value of 14.17/33 points, includes several key indicators reflecting farming practices (Table 3). The *crop rotation* indicator scores low, at just 17% of the theoretical maximum, due to the limited plot size, which averages 5.37/6 points, restricting farmers' ability to grow enough forage and cereal crops to meet their livestock's food needs. The *organic matter management* indicator scores 2.75/5, as most farmers apply manure to over 20% of their Utilized Agricultural Area (UAA) to enhance soil fertility and reduce costs. The *space for enhancement* indicator is low (1.6/5), highlighting poorly managed forage areas affected by overgrazing and monoculture. Similarly, *forage area management* scores just 1/3 due to unplanned grazing and inadequate post-mowing care.

The *agricultural practices* component, which focuses on soil protection, treatment techniques, and the management of energy and non-renewable resources like irrigation water, is capped at 34 points and has an average score of 20.1 points. The *fertilization* indicator, which measures the ratio between imports (fertilizers, concentrated feed, and roughage) and exports (milk, animals, and plants), reveals nitrogen pollution from nitrate leaching, resulting in an

Table 3 - Scores of indicators for the component related to spatial organization (SOC).

	Crop rotation	*Plot size*	*Organic matter management*	*Ecological regulation*	*Space enhancement*	*Management of forage areas*	*SOC*
All	1.4	5.37	2.75	2.05	1.6	1	14.17
Sejnane-Joumine	1.4	5.6	2.8	2.6	2.1	1.2	15.7
Utique	1.4	5.14	2.7	1.5	1.1	0.8	12.64
Theoretical maximum	8	6	5	12	5	3	33

Table 4 - Indicator scores for the agricultural practices component (APC).

	Fertiliza-tion	*Liquid organic effluents*	*Pesticides*	*Veterinary treatments*	*Water resource management*	*Protection of soil resources*	*Energy dependence*	*APC*
All	1.75	3	6.25	1.35	3.2	0,55	4	20.1
Sejnane-Joumine	0.8	3	7.1	1.4	3.2	0,8	4.7	21
Utique	2.7	3	5.4	1.3	3.2	3,2	3.3	19.2
Theoretical maximum	8	3	13	3	4	5	10	34

unbalanced and polluted environment, with an average score of 1.75/8, ranging from 0.8/8 in Sejnane-Joumine to 2.7/8 in Utique (table 4). The *use of pesticides* indicator, which addresses threats to human health and ecosystems, scores modestly with Sejnane-Joumine at 6.25/13 and Utique at 7.1/13. The *veterinary treatments* indicator scores 1.35/3, revealing inadequate veterinary care in building-based farming systems. *Soil protection* is minimal, with a low score of 0.55/5, as most farmers neglect conservation practices. *Energy dependence* remains high, scoring 3.3/10 in Utique and 4.7/10 in Sejnane-Joumine, reflecting heavy reliance on fertilizers, fuel, and electricity.

3.1.3. *Sustainability assessment of the socioterritorial scale*

The quality of products and territories component, capped at 33 points, includes five indicators: *product quality, local and human development, non-organic waste management, space accessibility, and quality of life.* The *quality process* indicator, which covers all products from the studied territories such as milk, meat, honey, cow's cheese, and curdled milk, received a score of zero due to the lack of official labeling, organic certification, and traceability despite high consumer demand, reflecting a weak quality assurance approach. Additionally, the *social involvement indicator*, which reflects the dynamism and social vitality of the territories, scored poorly, with an average of 0.25/6, as Sejnane-Joumine recorded 0.1/6 and Utique 4/6, highlighting a significant disparity in the richness and diversity of the associative environment (Table 5).

The *employment and services* component, capped at 33 points, includes various indicators reflecting local economic practices. The short supply chains indicator scores relatively low, with Sejnane-Joumine at 0.28/7 and Utique at 0.12/7, as milk is sold directly to collection centers, and young bulls and lambs are sent to livestock markets, with only a small amount of honey sold directly to consumers (table 6). The *valorization of local resources*, reflecting dependence on suppliers, scores the highest within this component, with Sejnane-Joumine scoring 6.6 and Utique 6.2, averaging 6.4 points. The *services and pluriactivity* indicator, related to commercial services, agritourism, and social inclusion practices, shows

Table 5 - Indicator scores of the quality of products and territories component (QPTC).

	Quality process	*Enhancing built heritage*	*Non-organic waste management*	*Space accessibility*	*Social involvement*	*QPTC*
All	0	0.9	1.8	2.4	0.1	5.2
Sejnane-Joumine	0	2.9	1.9	2	0.4	7.2
Utique	0	1.9	1.85	2.2	0.25	6.2
Theoretical maximum	10	8	5	5	6	33

Table 6 - Indicators scores of the employment and services component (ESC).

	Short supply chains	*Valorization of local resources*	*Services and pluriactivity*	*Contribution to employment*	*Collective work*	*Probable sustainability*	*ESC*
All	0.12	6.2	0.6	5.1	0.1	1.5	27
Sejnane-Joumine	0.28	6.6	0.9	4.9	0.2	2	14.05
Utique	0.2	6.4	0.75	5	0.15	0.15	14.6
Theoretical maximum	7	10	5	6	5	5	33

Table 7 - Indicator scores of the ethics and human development component (EHDC).

	Contribution to global food balance	*Animal welfare*	*Training*	*Work intensity*	*Quality of life*	*Isolation*	*Hygiene and safety*	*EHDC*
All	3	1	0.4	0.06	2.8	1.9	0.6	4.46
Sejnane-Joumine	4	1.4	0.9	0.4	3.3	2.7	0.9	6.7
Utique	3.5	1.2	0.65	0.23	3.05	2.3	0.75	5.58
Theoretical maximum	10	3	6	7	6	3	4	34

poor results, with Sejnane-Joumine scoring 0.9 and Utique 0.6, averaging 0.75 points. Finally, the *contribution to employment* indicator scores 4.9/6 in Sejnane-Joumine and 5.1/6 in Utique, reflecting the employment of a few permanent workers for livestock farming and seasonal workers for crop production, leading to an overall average of 5.1/6.

The *ethics and human development* component, capped at 34 points, includes indicators such as *contribution to global food balance, animal welfare, training, work intensity, quality of life, isolation, and hygiene and safety* (Table 7). The contribution to global food balance indicator scores an average of 3.5/10, with Sejnane-Joumine at 4/10 and Utique at 3/10, reflecting relatively low farm profitability due to excessive reliance on purchased livestock feed. The animal welfare indicator scores poorly, with an average of 1.2/3 points. *Training,* which had a low average score of 0.65/6 points, is not prioritized by most farmers, as 90% do not participate in relevant training programs. The *quality-of-life* indicator, based on farmers' self-assessment, shows acceptable values with scores of 2.8/6 in Sejnane-Joumine and 3.3/6 in Utique, reflecting moderate feelings of isolation. *Hygiene and safety* scored an average of 0.75/4 points due to inadequate facilities for storing pesticides, as evidenced by the unsafe storage conditions in buildings used by occasional workers, resulting in scores of 0.9/4 for Sejnane-Joumine and 0.6/4 for Utique.

3.1.4. *Sustainability assessment of the economic scale*

Viability is assessed through two components: *economic viability* (C1) and the *rate of specialization* (C2). The overall average score for both regions is 8.35/30 points, with Sejnane-Joumine scoring 9/30 and Utique 7.7/30 (Table 8). These results stem from low specialization rates, mainly due to the dominance of breeding systems focused solely on milk production. This lack of diversification contributes to an average economic viability score of 5.65/20 points, with Sejnane-Joumine scoring 5.3/20 and Utique 6.0/20. The low score reflects farm unprofitability, exacerbated by rising input costs such as concentrated feed, roughage, plant seeds, and veterinary expenses. Similarly, the economic specialization indicator scores modestly, with

Table 8 - Indicator scores of the economic components (EC).

	Indicators of viability component		*Indicators of independence component*		*Transmissibility*	*EC*
	Economic viability	*Rate of economic specialization*	*Financial autonomy*	*Sensitivity to aid*		
All	5.65	2.7	12.95	10	18.02	5.1
Sejnane-Joumine	6	3	12	10	18	5.2
Utique	5.3	2.4	13.1	10	18.04	5
Theoretical maximum	20	10	15	10	20	25

Sejnane-Joumine scoring 3.0/10 and Utique 2.4/10, averaging 2.7/10.

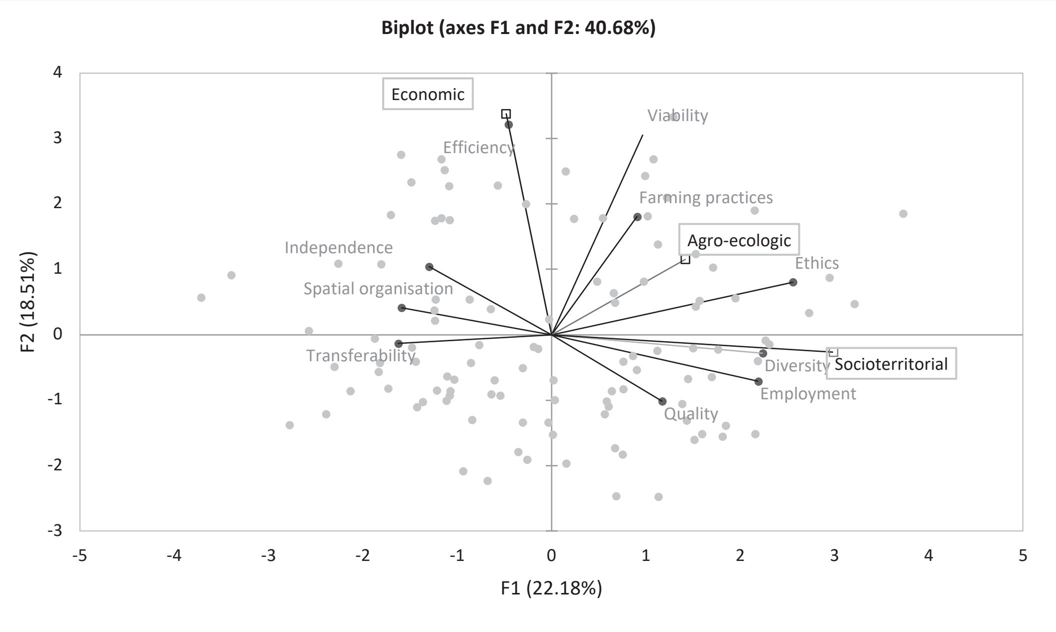
The *independence* component, which includes *financial autonomy* (C3) and *sensitivity to aid* (C4), scores an average of 22.95 points, with Sejnane-Joumine scoring 22.0 and Utique 23.1, indicating financial independence despite limited government support. *Financial autonomy* scores 12.95/15, with Sejnane-Joumine at 12/15 and Utique at 13.1/15. Small farmers, lacking access to formal credit, rely on peddlers and input suppliers for small loans. Sensitivity to aid scores 10/10, highlighting a strong dependence on support that remains unmet by the state. The *economic transmissibility* indicator scores highest at 18, driven by low farm capital and reliance on family labor. In contrast, *production efficiency* scores just 5.1/25, reflecting poor feeding management, high dependence on concentrated feed, and limited use of expert guidance for inputs.

3.2. *Typology of small farmers based on sustainability scales and components*

The principal component analysis (PCA) reveals a dominant first component (F1) that accounts for 22.176% of the total variability, with the first four axes (F1–F4) explaining nearly 65% of the variability. The first two axes (F1 and F2) contribute 40.682% to the cumulative variability and are used in the hierarchical ascending classification (HAS) to identify breeder groups (Figure 4). The agroecological and socioterritorial scales are strongly represented on axis F1, contributing 41% and 86%, respectively, while the economic scale is mainly represented on axis F2 with a 14% contribution. A positive correlation exists between the agroecological and socioterritorial scales (r = 0.257), whereas the agroecological and economic scales show a low correlation (r = 0.085), and the economic and socioterritorial scales are independent. The agroecological scale is positively correlated with all components except quality and independence, while the socioterritorial scale is negatively correlated with spatial organization, independence, transmissibility, and efficiency. The economic scale is highly correlated with viability and efficiency (r = 0.797 and 0.857, respectively) but negatively correlated with components of the socioterritorial scale, such as quality, jobs, ethics, and diversity.

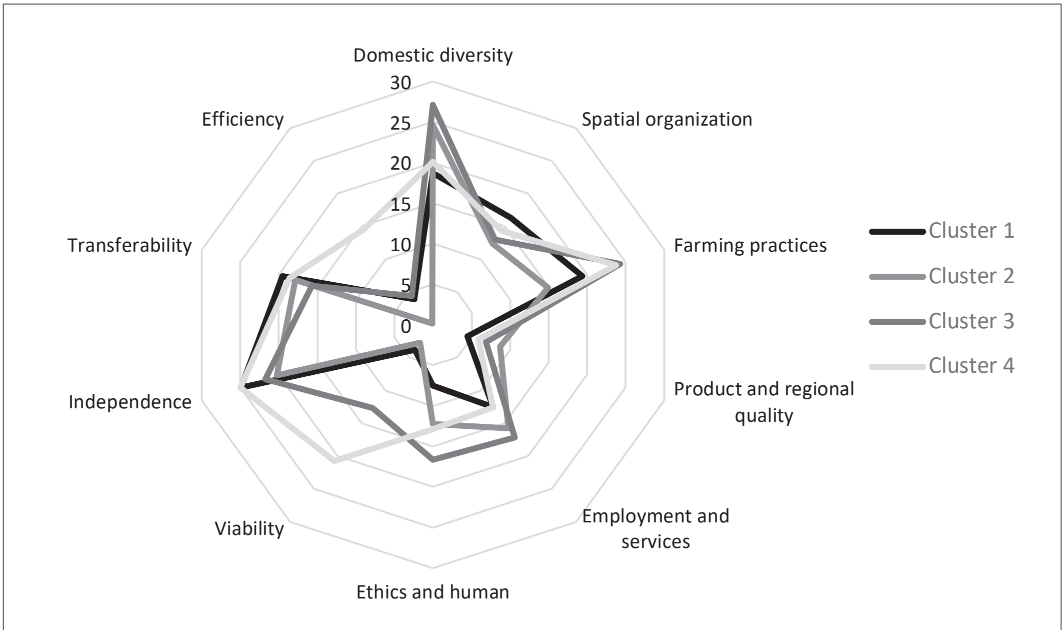
Based on the IDEA method indicators, the hierarchical ascending classification (HAS) results reveal four distinct breeder groups (Figure 5). The first group, representing 35% of the surveyed sample (mostly from Utique), is characterized by significant employment contribution (94%) and the use of local resources (61%). However, this group faces challenges related to the absence of labels, organic farming, and low involvement in professional organizations and human development. The second group (23.85% of the sample, mostly from Sejnane-Joumine) exhibits average racial and plant biodiversity, agroforestry practices, and fodder and fertilizer independence but struggles with poor livestock nutrition management, affecting economic performance. The third group (20% of farmers, primarily from Sejnane-Joumine) shows high livestock and

Figure 4 - Graphical representation of the principal component analysis of farm sustainability components and scales.



plant biodiversity, good manure management, and flood meadow presence but faces soil erosion and poor energy management, hindering economic growth. The fourth group (22.93% of the sample) consists of farms with diverse activities, including dairy cattle rearing and crop production, and demonstrates strong farm input use, leading to good performance.

Figure 5 - Clusters profiles according to their sustainability components.



4. Discussion

4.1. *The agro-ecological dimension*

Agricultural strategies across regions face significant challenges in land management and climate adaptation, with some areas prioritizing diversification and resilience, while others struggle with poor crop integration and resource overexploitation. In Tunisia, inefficient land use, exemplified by limited forage diversification and high reliance on industrial inputs, raises concerns about the sustainability of agriculture, negatively impacting productivity and environmental resilience. The Bizerte region, for example, suffers from prolonged droughts and irregular rainfall, which affect water availability for irrigation and livestock, further reducing farm performance (Mwadzingeni *et al*., 2022; Ahmed *et al*., 2023). Soil protection remains a critical issue, with a low adoption of anti-erosion techniques, which contributes to the region's vulnerability. In contrast, European approaches like crop rotation with legumes have proven to enhance farm resilience by 30%, and integrating mixed forage crops, especially legumes, could help restore soil fertility, increase productivity, and mitigate environmental impacts (Steinfeld *et al*., 2006).

The limited diversification of forage crops and high dependence on concentrated feed undermine the food autonomy of farms in Tunisia, a challenge also observed in Europe's intensive agricultural systems, which are vulnerable to price fluctuations and environmental pressures. Agroecological strategies, such as multi-species pastures and crop rotation in Scandinavian countries, reduce dependence on external inputs and enhance soil fertility (Rasmussen *et al*., 2015). In Tunisia, the underutilization of local breeds and limited forage areas mirror the challenges faced in regions like Russia's Central Black Earth, in contrast to the Organic Valley model in the United States, where the use of indigenous breeds has improved farm resilience and profitability. Moreover, veterinary treatments remain limited (1.35/3), and artificial insemination usage is rising, albeit still lower than the scores reported by M'Hamdi *et al.* (2017) (1.7) and Attia *et al.* (2022) (2.3). The increased use of pesticides, a significant issue in Europe, also presents challenges in Tunisia and Algeria due to high costs (Yakhlef *et al*., 2005). While manure is widely used in both countries, livestock effluents are often discharged without specific pollution regulations, raising environmental concerns (Attia *et al*., 2022; Ghozlane *et al.,* 2006). Additionally, while agroecological farming can create employment opportunities, its adoption is hindered by the increased labor requirements (Aubron *et al*., 2016).

The socio-territorial dimension

The study of Tunisian dairy systems reveals significant socio-territorial vulnerabilities, emphasizing the fragility of these systems in contrast to the environmental sustainability focus of the FAO and Dairy Sustainability Framework. The lack of collective organization and underdeveloped short supply chains are major obstacles to farm resilience, with integration into professional organizations and local valorization of products being notably weak in the Bizerte region (Attia *et al*., 2022). These issues are echoed in international contexts such as Georgia (Al Sidawi *et al*., 2021) and Bangladesh (FAO, 2016), where similar challenges limit farm resilience. The absence of certifications and collective organizations restricts market access and income growth, a contrast to the benefits seen in Europe, where 62% of certified farms thrive (Bórawski *et al*., 2020).

Working and hygiene conditions on Tunisian dairy farms are inadequate, falling short of international standards, and the physically demanding nature of the work is discouraging younger generations from entering the field, exacerbating workforce aging (Nandi *et al*., 2022; Lursinsap *et al*., 2023). Cultural and religious factors further complicate farm succession and require deeper investigation (Gasmi *et al*., 2019). Social issues such as low wages and inadequate housing also contribute to poor conditions, with hygiene and safety standards scoring particularly low. Training participation remains limited, preventing the adoption of modern livestock practices and hindering sector growth (Okello *et al*., 2021). However, successful training programs in countries like Colombia and Brazil demonstrate the potential for improving agricultural practices, offering a pathway for similar improvements in Tunisia (Gonzalez *et al*., 2024; Madalena, 2012).

While Tunisian dairy farms show some strengths in forage autonomy and local resource valorization, challenges remain with reliance on external seed supplies and inefficient crop management. The contribution of agriculture to local development is also underperforming, as seen in the low score for "Service and Pluriactivity" (0.75). In contrast, initiatives like educational farms in Poland and agritourism in Italy offer models for diversifying agriculture and promoting rural development (Kacprzak *et al*., 2019). The study also highlights the potential for improving animal welfare, which remains a concern, and farm profitability, which is hindered by inefficient feed use and poor ration management. International frameworks, such as the Feeding Performance Indicator (Lapierre *et al*., 2013), offer a basis for enhancing resource efficiency and improving farm profitability.

The economic dimension

The economic performance of dairy farms in Tunisia is characterized by low profitability, primarily due to high input costs, inefficient resource management, and limited income diversification. These challenges are exacerbated by a heavy reliance on external inputs and market fluctuations, a situation similar to that observed in Bangladesh and certain rural areas of India (Urak *et al*., 2022). Hemme and Otte (2010) argue that dairy farm profitability in developing countries is often hindered by disproportionate production costs relative to milk prices, as seen in Bangladesh where concentrated feed accounts for 60% of production costs. Strategies to improve profitability include income diversification, such as integrating high-value crops to reduce feed costs by 30% (Krupko *et al*., 2023). Additionally, microfinance models inspired by Tanzania and diversification strategies seen in Dutch, Indonesian, and Vietnamese farms offer pathways to improve both economic performance and sustainability by combining dairy production with renewable energy or capital investment (Sembada, 2018). The adoption of semi-extensive farming models, such as those in Argentina, could further enhance economic resilience and reduce feed costs in Tunisia (Naranjo *et al*., 2013).

The analysis also highlights the financial autonomy of Tunisian dairy farms, with an average score of 22.95 for financial independence, surpassing the 13.6 points reported by M'Hamdi *et al.* (2017). This suggests that, despite limited state support, Tunisian farms have achieved a relatively higher degree of financial autonomy. Chatellier (2010) emphasizes that the European Union's Common Agricultural Policy (CAP) provides aid mechanisms to reduce farm vulnerability to market fluctuations, underscoring the importance of managing reliance on subsidies to maintain sustainable economic independence.

5. Conclusion and policy implications

Although the Bizerte region has strong natural, human, and ecological potential, cattle farming remains economically inefficient, socially inequitable, and ecologically fragile, particularly for small and medium-sized farms. To ensure the sustainability of dairy farming systems, this study highlights the need for a transition toward more sustainable livestock systems, drawing inspiration from international experiences that have proven effective. Improving sustainability will inevitably require a concerted effort across social, economic, and agro-ecological dimensions to ensure the long-term viability of the dairy sector and its contribution to rural development.

The supervision of dairy farming has improved production through agricultural development programs and state intervention, particularly in market expansion. However, these advancements have not been sufficient to significantly increase local production. It is therefore crucial to include small and medium-scale farmers in the dairy value chain to foster the sector's sustainable growth.

From this perspective, promoting mixed forage crops that combine legumes and grasses presents a sustainable solution to enrich the soil with nitrogen, improve its organic matter content, reduce greenhouse gas emissions, and optimize production costs. This approach would enhance dairy productivity while minimizing environmental impact.

An effective restructuring of the sector requires several priority actions. It is essential to increase funding for technical modernization to enhance the competitiveness of farms. A better distribution of public subsidies is also crucial to include small-scale farmers and facilitate their integration into the market. Additionally, optimizing processing channels and diversifying commercial outlets are key to enhancing the value of local production. Finally, price adjustments should be considered to ensure adequate profitability for producers.

Investments in rural infrastructure, agricultural technologies, and farmer training are essential to support these efforts. The government must also implement policies to enhance pastoral farms, improve animal health, and reduce greenhouse gas emissions. The development of cooperatives could significantly increase the value of local milk, create stable jobs, and curb rural exodus by engaging more young people in agriculture. In this context, support measures should be introduced, including awareness of financing opportunities, widespread use of artificial insemination, continuous access to water, and the promotion of agricultural innovation.

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Notes

Food Environment and digital technologies, tools for the sustainable transformation of food systems in the Mediterranean

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The transformation towards sustainable food systems[1], an increasingly debated topic at international level, presents multiple challenges related to the different types of agri-food systems[2] existing on our planet that denounce the complexity in the design of policies and interventions at different levels. To achieve greater sustainability and healthiness of the different types of agri-food systems, it is also very important to consider them in their entirety, accepting the close interrelationship, so far little considered, between consumption and production and, at the same time, to analyse the different elements of agri-food systems on which to act.

Among these, the one that is receiving more and more attention in the field of food policies is represented by the *Food Environment* which, in the definition of the High Level Panel Expert of the United Nations Committee on Food Security, refers to the "...physical, economic, political and sociocultural context in which consumers interact with the food system to make their decisions regarding the acquisition, preparation and consumption of food" (HLPE, 2017).

[1] Sustainable agrifood system is a food system that guarantees food and nutritional security for all so that the economic, social and environmental foundations for generating food and nutritional security for future generations are not compromised. Source: HLPE (2014).

[2] In the 2017 HLPE Report, three broad types of food systems are identified, to simplify: (i) traditional food systems; (ii) mixed food systems; and (iii) modern food systems.

In recent decades, emphasis has been placed on the responsibility of consumers' choices based on the idea that raising their awareness and greater food education could influence their eating behaviors by placing many responsibilities on citizens by expecting them to make the right food choices in environmental, social or ethical terms, based on simple information campaigns aimed at adopting sustainable lifestyles.

In daily life, however, food choices are not based on available information but are linked to physical, economic, political, social and cultural factors, most of which are suffered by consumers. The combination of these factors represents the food environment, i.e., the interface between the Food Supply Chain and the consumer, within which people make their food-related choices.

The implications towards the transformation of agri-food systems based on the creation of sustainable food environments today represents a strategic approach for the transformation of agri-food systems. *It is based on the belief that our food choices and their consequent impact are guided, not by the consumer, but by the contexts in which they are taken.*

Therefore, for the sustainable transformation of the food environment it is necessary to act on those elements of a social, economic, commercial, technological nature, as well as of a strategic-political nature, which can put consumers in a position to practice sustainable[3] and healthy diets (such as, for example, the Mediterranean Diet).

The food environment is not only fundamental for shaping people's food choices, but it takes on strategic importance because, by mediating between the needs of consumers and those of producers, it translates food demand patterns into production methods by communicating, for example, which production method to adopt (e.g., organic farming) which type of product is required (AOP, Traditional Products, Terroir, IGP, DOC, etc.) and what the right selling price might be.

In turn, food production shapes the food environment as it determines the availability of food and its characteristics related to the impact on natural resources and climate change, social and cultural aspects, human health and animal welfare.

Unfortunately, today the situation does not correspond to that described as food environments do not favor sustainable food choices and the transformation of this negative trend requires decisive interventions to make food environments favorable to the adoption of healthy and sustainable diets.

In this perspective, it is essential to encourage the desirability of sustainable agri-food products, creating new and better needs for the consumer.

Creating sustainable food environments means ensuring that foods and beverages that contribute to healthy and sustainable diets are the most available, physically and affordably accessible, attractive, widely publicized and popular.

In such environments, not only must the healthiest and most sustainable choices be as natural as possible, but the availability and promotion of foods and beverages on which unhealthy and unsustainable diets are based are at the lowest levels.

[3] Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy while optimizing natural and human resources. Source: Bioversity international and FAO, 2010.

In addition, a consumer ethics is needed that links individual choices to the well-being of the community. This ethics cannot be imposed from above, but must leverage the cultural resources existing in each territory. Cultural dietary models such as the Mediterranean Diet can facilitate the transformation towards sustainable consumption, associating the need for change with cultural identity (Brunori, 2022).

Numerous policies and programs aimed at making the food environment sustainable have been implemented worldwide, although most of those investigated in the literature have focused on high-income countries and less on low- and middle-income countries.

Most of these measures, which should always be accompanied by social, economic and infrastructural policies to ensure that individuals can enjoy sustainable food environments and the possibility for producers to participate in them, have focused on the availability of and physical and economic access to food, on the promotion, advertising and information of food, and on the quality and safety of food.

Technological innovations are also increasingly part of people's daily lives and, in focusing on food environments, which represent all those food-related elements that surround us in our daily reality, we cannot overlook the role that they and digitization, have had on them. As a result, the concept of the *Digital Food Environment began to spread,* understood as that online ecosystem in which information, services and products related to food are made accessible through digital platforms. It includes websites, mobile applications, social media, e-commerce platforms, and virtual communities that influence users' food choices, accessibility, and eating behaviors. We can also consider it as an augmented experience of the food environment through digital technologies ranging from online campaigns on food education, to interactions on social networks and social media, up to apps and platforms related to food delivery services.

Such digital platforms, by offering e-commerce opportunities, facilitate the online sale of food products and allow users to shop from local farmers, grocery stores, and specialized health food retailers. They offer cooking tutorials, nutrition education and meal planning courses, helping users develop skills and knowledge for sustainable and healthy eating. In addition, social media, social networks, and specialized online forums foster food-focused communities where experiences, recipes, and tips can be shared, creating a sense of belonging and mutual support. The digital food environment therefore fosters the building of communities around food-related interests, allowing people to exchange ideas and support each other in adopting more sustainable and healthy lifestyles. With advances in technology, many digital food platforms provide personalized recommendations based on users' dietary, cultural, religious preferences, and sustainability and health goals. In doing so, the digital food environment encourages people to make informed and sustainable food choices.

Finally, digital food environments can improve access to sustainable diets, particularly in underserved areas, by connecting consumers with local farms, grocery stores, and meal delivery services.

However, these technologies inevitably add further complexity to an already complicated food environment that aims to shape the consumer's food choices. In fact, having taken on a strong centrality in the daily lives of individuals, and consequently also in their food environments, they also have a downside represented by the important impacts with respect to the consumption of unhealthy food products that marketing through social media and influencers can have on vulnerable consumers such as minors or such as the promotion of unhealthy diets by phantom pseudo-nutritionists.

In this perspective, therefore, there are significant challenges that must be adequately considered by the legislator as with the continuous evolution of technologies, the digital food environment will play an increasingly significant role in transforming food systems and promoting sustainability, health and well-being in communities around the world.

Technology, therefore, represents a powerful driver of change that acts both on the external dimensions of the Food Environment, such as the availability of food, the level of prices, the properties of products, marketing and regulation, and on the personal dimensions, as it is linked to the convenience, desirability and accessibility of food.

The context described highlights the complexity and diversity of the problems and challenges to be faced for the transformation towards sustainable agri-food systems by intervening on the Food Environment and makes it clear that a better understanding of the interactions between agri-food supply chains, food environments and consumer behavior is essential to understand why and how food models today have negative effects on natural resources, on the economy of the territories, on traditions and culture, on the nutrition and health of the Mediterranean populations.

Understanding these dynamics is necessary to develop science- and research-based intervention strategies and approaches to improve the sustainability and the food and nutrition security for all.

NEW MEDIT

Scope

New Medit is an international open access journal published quarterly on behalf of CIHEAM.
The Journal seeks to act as a bridge between the relevant regional studies to enhance regional cooperation and sustainable development, by providing a platform for theoretical and empirical debate in the fields of social and economic sciences, regional development and environmental studies in the Mediterranean Region.
The main subjects of interest include the economic and social transformations in Mediterranean Countries in particular agro-food economics, rural development, environmental economics and sustainability issues around all Mediterranean region.
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The journal operates with a double-blind peer review policy.
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