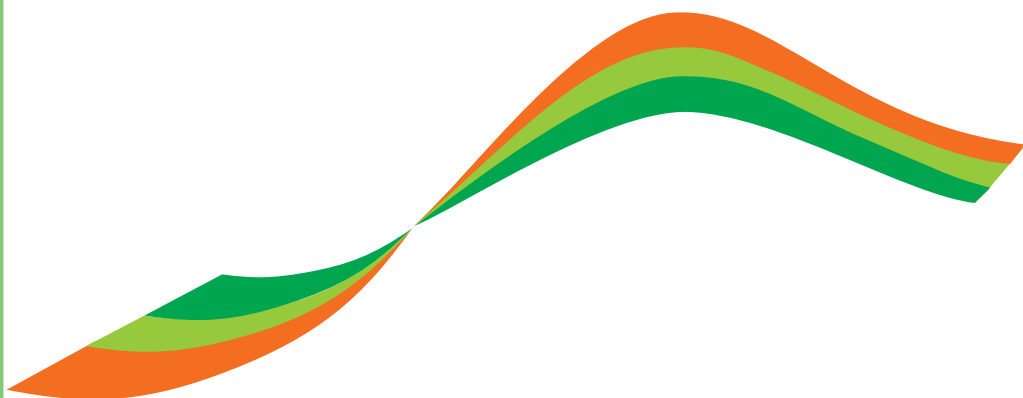




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Food Economy

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Special Issue: Water Resources for Sustainable Agriculture Guest Editorial

Veronica Manganiello^a, Raffaella Pergamo^a

^a CREA Research Centre for Agricultural Policies and Bioeconomy, Italy

We are pleased to present this special issue of *Economia agro-alimentare/ Food Economy*, entitled *Water Resources for Sustainable Agriculture*, which contains four rigorously peer-reviewed articles, all written in English. This issue focuses on one of the most urgent and complex challenges of our time: the sustainable management of water resources in agriculture and food systems.

Why is addressing water resources crucial? Water is the foundation of life, food security, and agricultural productivity. However, growing pressures from climate change, population growth, and increased agricultural demand are profoundly changing the way societies perceive and manage this vital resource. Droughts, irregular rainfall, and competition between agricultural, industrial, and domestic uses are forcing policymakers, scientists, and farmers to reconsider traditional water management models.

In this context, research plays a vital role in providing evidence-based strategies, technologies, and governance models that can ensure the sustainability, resilience, and equity of water use. This special issue aims to contribute to this debate by presenting innovative studies that explore how different sectors of the agri-food system are adapting to water-related challenges.

The first article, *The contribution of national irrigation investment planning to sustainable water resource management in the Po River district*, by Raffaella Pergamo, Luca Adolfo Folino, Marianna Ferrigno, Marica Furini, Manal Hamam, Veronica Manganiello, Antonio Manzoni, Alessandra Pesce, and Benedetto Rocchi, highlights the fact that safeguarding water resources has become essential for the future of agriculture. Through an ex-post evaluation of irrigation investments in Italy's most irrigated area, the Po River Basin District, the authors propose a set of sustainability indicators that integrate technical, environmental, and social dimensions. The study emphasises the importance of coordinated policies to enhance irrigation efficiency and promote the rational use of water.

The second article, ***Grazing Impacts on Biodiversity, Carbon Cycle, Water Efficiency, and Animal Welfare: A Review***, by Giulia Pastorelli, Ilaria Falconi, Maria Assunta D'Oronzio, and Raffaella Pergamo, explores the complex interrelations between grazing systems and environmental sustainability. By applying the PICO (Population, Intervention, Comparison, Outcome) framework to European studies published between 2010 and 2025, the authors demonstrate that moderate, well-managed grazing can improve biodiversity, enhance water-use efficiency and support soil carbon sequestration. The review also emphasises that animal welfare and ecosystem health can be achieved together through integrated management approaches that combine traditional knowledge and precision technologies.

The third contribution, ***Sustainable water management in viticulture under climate stress: irrigation requirements and potential of controlled water deficit***, by Veronica Manganiello, Silvia Chiappini, Sofia Galeotti, Luigi Tarricone, and Raffaella Pergamo, focuses on Mediterranean viticulture, which is one of the sectors most exposed to climatic variability. The study utilises census data and geospatial analysis to estimate water requirements for vineyards and evaluate the potential of Regulated Deficit Irrigation (RDI) to increase water use efficiency without compromising grape quality. The findings underscore the pressing need for adaptive policies and site-specific technologies to sustain wine production in a warming climate.

The final article, ***Irrigation reuse of urban treated wastewater: a qualitative analysis to support crop production in Campania***, by Marica Furini, Veronica Manganiello, Raffaella Pergamo, Olga Addimanda, Valeria Battaglia, Antonio Manzoni, Sofia Galeotti, Manal Hamam, and Marianna Ferrigno, addresses the potential of reusing treated wastewater in agriculture as a sustainable response to water scarcity. The authors propose an innovative methodological approach to identifying the Utilised Agricultural Area (UAA) that can potentially be irrigated with reclaimed water. This approach focuses on high-value Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) crops in the Campania region. The study demonstrates how targeted investments in water reuse infrastructure can enhance resilience, safeguard high-quality production, and support regional agricultural competitiveness.

Taken together, these contributions offer a comprehensive overview of how water challenges are reshaping agricultural systems and public policies. They also reaffirm the need for integrated, cross-disciplinary approaches that consider water as a strategic, social, and environmental asset, not merely a physical resource.

This special issue aims to advance the collective understanding of water's role in building a sustainable and resilient food economy by fostering dialogue among economists, agronomists, environmental scientists, and policymakers.



The contribution of national irrigation investment planning to sustainable water resource management in the Po River district

Raffaella Pergamo^a, Luca Adolfo Folino^a, Marianna Ferrigno^a,
Marica Furini^a, Manal Hamam^{*a}, Veronica Manganiello^a,
Antonio Manzoni^a, Alessandra Pesce^a, Benedetto Rocchi^b

^a CREA, Research Centre for Agricultural Policies and Bioeconomy, Italy

^b University of Florence, Italy

Abstract

Safeguarding water resources has become a strategic need to maintain the viability of agricultural operations, which are significantly reliant on water accessibility. The urgency of this requirement is amplified by the manifest effects of climate change, necessitating the implementation of specific solutions to improve irrigation system efficiency and foster sustainable use of water resources.

This research seeks to conduct an ex-post analysis of irrigation investments in the Po River Basin District, Italy's most important agricultural area and one of the most irrigated in Europe, examining their sustainability by developing indicators that include technical, environmental, and social dimensions. The analysis examines interventions devised and executed by land reclamation and irrigation consortia, primarily targeting irrigation – including multipurpose reservoirs – as well as those directed towards environmental protection and the preservation of land and agricultural productivity amid instability.

Preliminary findings underscore the role of both current and prospective investments in enhancing the overall efficiency of the region. The research offers valuable insights for policymakers, affirming the critical importance of investments in irrigation infrastructure for enhancing the resilience and long-term sustainability of agriculture and the national water system.

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* *Corresponding author:* Manal Hamam - Research Technologist, Council for Agricultural Research and Economics - Research Centre for Agricultural Policies and Bioeconomy (CREA-PB), Rome, Italy. E-mail: manal.hamam@crea.gov.it.

Introduction

To ensure the continuity of agricultural activities the conservation of water resources is now a strategic priority for every country (Hamam *et al.*, 2024). This need is further reinforced by the adverse effects of climate change, which makes it increasingly necessary to adopt measures aimed at improving the efficiency of irrigation systems (Et-taibi *et al.*, 2024). In this context, the strategic Green Deal project, through which the European Union aims to achieve climate neutrality by 2050, takes on particular importance (Boix-Fayos *et al.*, 2023).

In the ambitious plan for ecological reform, the protection of water resources plays a crucial role (Bieroza *et al.*, 2021). This is highlighted not only by the strategies of the Green Deal (Manzoni *et al.*, 2025), but also by the objectives of the Common Agricultural Policy 2023-2027 and, above all, the Water Framework Directive (WFD) (Bieroza *et al.*, 2021).

The latter has regulated European water bodies for over twenty years according to strict environmental sustainability standards through the implementation of River Basin Management Plans in the various Member States (Copetti and Erba, 2024). In this context, the new Water Resilience Strategy (Kumar *et al.*, 2020), recently released by the European Commission¹ to address the most urgent challenges in safeguarding the EU's water resources, is also particularly important (Srivastav *et al.*, 2021; Ricciardo Calderaro *et al.*, 2024).

As in other Member States, sustainable and efficient water management is also a priority in Italy (Colella *et al.*, 2021). Indeed, the Mediterranean area is a geographical context where the effects of drought and water stress (EEA, 2021) are having an increasingly significant impact on the economy, particularly on the agricultural sector (Vizinho *et al.*, 2021).

For this reason, the Ministry of Agriculture, Food Sovereignty, and Forestry is implementing a long-term investment strategy to modernize infrastructure and increase water efficiency (Vieira *et al.*, 2020; Jiang, 2023).

This study aims to analyze irrigation investments carried out in the Po River Basin District, assessing their sustainability from technical,

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2. The district fully encompasses the regions of Piedmont, Aosta Valley, Lombardy, and Emilia-Romagna, while it partially includes Liguria, Veneto, Tuscany, Marche, and the Autonomous Province of Trento. However, Tuscany and Liguria have no irrigated areas within the district, and in Marche, irrigated land accounts for less than 10% of the region's total area.

environmental, and social perspectives through the development of specific indicators related to the planned and implemented interventions in the area. In particular, the analysis focuses on projects promoted by land reclamation and irrigation consortia, primarily aimed at irrigation purposes, including the construction of multipurpose reservoirs, and at safeguarding agricultural land from hydrogeological risks.

The analysis focused on the Po River Basin District², the largest in Italy, covering an area of approximately 83,000 km² (Gharsallah *et al.*, 2024).

This territory was identified as the main recipient of funding, receiving about 34% of the total resources – equivalent to approximately €750 million, according to the CREA Yearbook 2023. Data on the funded investments and key indicators are stored in DANIA, the National Database of Investments for Irrigation and the Environment (Ferrigno *et al.*, 2022).

The investments considered in this research originate from three main, complementary public funding sources: a) the National Rural Development Program (NRDP) 2014-2020; b) the 2021 Agricultural Operational Plan (AOP), financed by the Development and Cohesion Fund (DCF); and c) the 2021 National Recovery and Resilience Plan (NRRP). The planning documents associated with these programs have been analyzed to identify their key objectives, which have been linked to the main targets of the Water Framework Directive (WFD), as outlined in the 2021-2027 River Basin Management Plan for the Po District (RBMP Po 2021-2027).

The research question addressed is as follows: “*In light of the water savings expected from the planned investments, to what extent and in what ways will they contribute to improving the sustainability of water resource management?*”.

The article is structured as follows. The following section analyzes the planning documents associated with the interventions considered, to highlight the stated objectives regarding sustainability in water resource management and increased efficiency in their use for irrigation purposes. Based on this analysis, three indicators of the efficiency gains expected from the investments have been defined and are described in a section dedicated to the data and methodology used. This is followed by a section presenting the results of the analysis of data obtained from the DANIA database. Eventually, some considerations on the policy implications for water resource management are presented in the concluding section.

1. Promoting irrigation efficiency in the Po River Basin District

1.1. Public funding sources

a) National Rural Development Program (NRDP) 2014–2020

As part of the 2014-2020 CAP programming period, a National Rural Development Program (NRDP) was launched with the aim of supporting strategic interventions at the national level, including the modernization of irrigation networks. The program placed a particular emphasis on the sustainable and efficient use of water resources in agriculture, an increasingly important issue in the face of growing pressure on natural resources. Among the various measures included in the NRDP, Measure 4, dedicated to “Investments in physical assets” (ex-Article 17 of EU Regulation 1305/2013), plays a key role. Submeasure 4.3, which was allocated a total budget of €360 million, focuses on investments in infrastructure for the development and modernization of agriculture and forestry. This includes interventions related to access to agricultural and forest land, land consolidation, the improvement of energy and water infrastructure, and resource conservation. According to official documentation, the objective is to finance projects aimed at creating or upgrading irrigation infrastructure that can promote more efficient use of water. This includes initiatives to increase storage capacity, improve water management, and implement water-use monitoring systems. The measure, is intended for irrigation authorities, associated agricultural enterprises, and land improvement consortia, and provides for various investments in existing networks, aimed at:

- Upgrading existing irrigation distribution networks (23 projects);
- Improvement of water supply systems and/or installation of meters (13 projects);
- Functional completion of existing irrigation schemes and new irrigation infrastructure (7 projects);
- Investments in irrigation systems for land reclamation and irrigation, which may involve hydraulic works and regulation in the areas where the consortia operate (4 projects);
- Remote control systems (4 projects);
- Reuse of wastewater for irrigation (1 project);
- Restoration of basin efficiency and related supply and distribution works (1 project);
- Building of new reservoirs (1 project).

According to the NRDP, investments aimed at improving the efficiency of irrigated areas have covered a total surface of approximately 546,000 ha, corresponding to 18% of the total area equipped for irrigation. These

interventions were designed to achieve an estimated water saving of around 235 million m³.

b) Agricultural Operational Plan (AOP)

As a complement to the NRDP 2014-2020, the Agricultural Operational Plan (AOP) developed a strategy under Thematic Objectives 5-6² aimed at contrasting desertification, protecting ecosystems, and supporting the adaptation of agriculture to climate change, particularly in areas most at risk of flooding. Another key objective of the plan was to improve both the quality and quantity of water resources, with a focus on surface and groundwater bodies. To achieve these goals, Sub-Plan 2 was introduced, titled “Interventions in the field of irrigation infrastructure, hydraulic land reclamation, flood protection, storage basins, and related technical assistance and advisory programs”. This sub-plan, backed by a budget of €295 million, aimed to consolidate and strengthen the national strategy for investments in irrigation infrastructure (p. 10). The document emphasizes the need for a strategic, national-level approach to ensure the effective and efficient use of the country’s water resources. This includes ensuring that interventions are appropriately scaled and aligned with environmental sustainability, economic viability, and operational effectiveness. Such a strategy is increasingly urgent in a context marked by more frequent water crises and droughts resulting from ongoing climate change (pp. 10-11). The AOP also highlights several critical shortcomings in national water resource management. To address these issues, the planned actions aim to improve the quality of water bodies, both directly and indirectly, through a more rational and balanced use of available water (p. 14). Finally, the document details the eligible interventions (pp. 15), which include, for example:

- restoring the efficiency of water supply basins;
- building new of inter-company reservoirs managed by consortia and related adduction and distribution works;
- completion of existing irrigation schemes and new irrigation infrastructure;
- improvement of the supply systems and distribution networks of existing irrigation systems;
- upgrading of existing irrigation system distribution networks;
- investments in irrigation systems for land reclamation and irrigation;
- investments for energy production from mini-hydroelectric plants used for water lifting;
- investments in remote control systems;
- investments for the use of purified wastewater for irrigation;
- integrated strategic planning of national importance.

c) *National Recovery and Resilience Plan (NRRP)*

The National Recovery and Resilience Plan (NRRP) has also set clear objectives to improve the efficiency of water use. In particular, under Mission 2, titled “Green Revolution and Ecological Transition” €15.05 billion has been allocated to M2C4, dedicated to “Protection of the Territory and Water Resources” which includes several specific targets (p. 147):

- Strengthening the capacity to predict the effects of climate change through advanced and integrated monitoring and analysis systems;
- Preventing and combating the consequences of climate change on hydrogeological instability and the vulnerability of the territory;
- Safeguarding air quality and biodiversity in the territory through the protection of green areas, soil, and marine areas;
- Ensuring security of supply and sustainable and efficient management of water resources throughout the entire cycle.

About one-third of the funds allocated (4.38 billion) financed four types of investments:

- *Investment 4.1:* Investments in primary water infrastructure for water security;
- *Investment 4.2:* Reduction of losses in water distribution networks, including digitization and monitoring of networks;
- *Investment 4.3:* Investments in the resilience of the irrigation agrosystem for better water resource management;
- *Investment 4.4:* Investments in sewerage and wastewater treatment.

In light of the above, it can be noted that the sustainability objectives aimed at promoting a more efficient use of water resources, supported by the AOP, PNSR, and PNRR funds, are fully aligned with those established by the Water Framework Directive (Martinengo *et al.*, 2021), as well as with the ecological transition objectives outlined by the European Green Deal and the CAP 2023-2027. As highlighted in the Programme of Measures, which is the cornerstone of the Po River Basin Management Plan, these objectives, set out in Article 1 of the Water Framework Directive, are being actively pursued:

- To prevent further deterioration, protect and improve the status of aquatic ecosystems and terrestrial ecosystems and wetlands directly dependent on aquatic ecosystems in terms of water requirements;
- Facilitating sustainable water use based on the long-term protection of available water resources;
- To aim for enhanced protection and improvement of the aquatic environment, including through specific measures for the gradual reduction of discharges, emissions and losses of priority substances and the cessation or gradual elimination of discharges, emissions and losses of priority hazardous substances;

- Ensure the gradual reduction of groundwater pollution and prevent its increase;
- Contribute to mitigating the effects of floods and droughts.

1.2. Key Types of Measures (KTM) of the Po River Basin Management Plan

To achieve these objectives, the Po River Basin Management Plan includes the implementation of several Key Type Measures (KTM) (Figure 1), which are sets of coordinated actions designed to address common pressures affecting the status of water bodies within the district (Ruberto *et al.*, 2023). Among these, KTM.8 is particularly significant, as it focuses on “Measures to increase water efficiency for irrigation, industry, energy, and domestic use”. This measure is broken down into a range of specific actions, all aimed at optimizing water use for irrigation purposes within the Po River Basin, as outlined in the Programme of Measures:

- *KTM08-P3-b039*: Mapping of irrigation efficiency and identification of targets for savings and/or efficiency improvements at different territorial scales (water body, irrigation scheme/consortium, sub-basin, district);
- *KTM08-P3-b041*: Implementation of plans to reduce withdrawals to achieve targets at different territorial levels to ensure the water saving objective defined by the District Water Balance Plan - Irrigation sector;
- *KTM08-P3-c121*: Structural actions to improve the irrigation system for the purpose of saving and using water resources efficiently;
- *KTM08-P3-b039*: Mapping of irrigation efficiency and identification of targets for savings and/or efficiency improvements at different territorial levels (water body, irrigation scheme/consortium, sub-basin, district);
- *KTM08-P3-b040*: Identification of efficiency levels, targets, and actions for water savings at the sub-basin and water body level – sectors other than irrigation;
- *KTM08-P3-b041*: Implementation of plans to reduce withdrawals to achieve targets at different territorial levels to ensure the water saving objective defined by the district-scale Water Balance Plan - Irrigation sector;
- *KTM08-P3-c121*: Structural actions to improve the irrigation system for the purpose of saving and using water resources efficiently.
- Furthermore, it is possible to note once again how the RBMP and the funds outlined above complement each other. In this regard, the Program of Measures identifies elements of synergy with the investments of the NRRP (p. 22, Table 4.1):

Figure 1 - Key Types of Measures (KTMs)

Codice Misura	Titolo Misura	DescrizioneIntervento	PNRR
KTM02-P2-b012	Realizzazione e utilizzo di tecnologie innovative per il trattamento degli effluenti zootecnici per promuovere interventi di economia circolare	Realizzazione di biodigestori per il trattamento degli effluenti zootecnici	M2C1 M2C2 (incentivo biometano)
KTM02-P2-b012	Realizzazione e utilizzo di tecnologie innovative per il trattamento degli effluenti zootecnici per promuovere interventi di economia circolare	Accordo di programma una gestione sostenibile degli effluenti zootecnici al fine di ottenere un miglioramento dello stato qualitativo dei corpi idrici riducendo il possibile impatto derivato dall'attività zootecnica.	M2C1 M2C2 (incentivo biometano)
KTM04-P1-a017	Realizzazione di interventi di bonifica dei siti contaminati e di messa in sicurezza	Bonifica dei siti orfani	M2C4 - Investimento 3.4
KTM06-P4-a022	Predisposizione dei Piani di gestione del demanio fluviale e lacustre e delle pertinenze idrauliche finalizzati alla ricostruzione di ambienti fluviali e lacustri diversificati e al recupero della biodiversità		M2C4
KTM06-P4-b027	Realizzazione di interventi integrati di mitigazione del rischio idrogeologico, di tutela e riqualificazione degli ecosistemi e della biodiversità (integrazione dir. Acque, Alluvioni, Habitat, Uccelli, ecc.)	Interventi di difesa idraulica sugli alvei che prevedano risezionamenti e miglioramenti sulle condizioni morfologiche dell'alveo e delle zone golenali e spondali, favorendo riduzione degli irrigidimenti, pluricursalità, riconnessione altimetrica	M2C4
KTM06-P4-b027	Realizzazione di interventi integrati di mitigazione del rischio idrogeologico, di tutela e riqualificazione degli ecosistemi e della biodiversità (integrazione dir. Acque, Alluvioni, Habitat, Uccelli, ecc.)	Interventi per la "Rinaturazione dell'area del Po"	M2C4 - Investimento 3.3
KTM08-P3-c121	Azioni strutturali per il miglioramento del sistema irriguo ai fini del risparmio e dell'uso efficiente della risorsa idrica	Investimenti nella resilienza dell'agrosistema irriguo per una migliore gestione delle risorse idriche	M2C4
KTM08-P3-c122	Azioni strutturali per assicurare il riequilibrio della disponibilità idrica a scala di area vasta	Investimenti in infrastrutture idriche primarie per la sicurezza dell'approvvigionamento idrico	M2C4
KTM14-P4-b088	Monitoraggio della situazione territoriale delle scale di risalita per la fauna ittica (analisi del funzionamento delle esistenti e censimento delle necessità di riconnessione e di deframmentazione)		M2C4
KTM26-P5-a108	Informazione, educazione e formazione sui contenuti e sull'attuazione del Piano	Formazione rivolta ai tecnici PA e degli Enti Locali su tipologia ed efficienza degli interventi integrati	M2C4

Source: River Basin Management Plan of the River Po District.

The Water Balance Plan of the Po RBMP also aims to protect water resources for future generations through criteria of solidarity and compliance with environmental standards, addressing the climate change currently underway. As can be seen in Annex 1.2 of Document “Update of the district characteristics”, among the general objectives of the Water Balance Plan, Objective 3 “Water crisis and drought management” promotes “proactive management of water scarcity in drought conditions, in order to minimize its impact on the socio-economic and environmental system, also taking into account possible future climate change scenarios”. This general objective is divided into three Specific Objectives (p. 7):

- Promote the implementation of a shared system for real-time monitoring of the water balance, drought forecasting, and early warning, based on best practices, appropriate technologies, and reasonable costs;

- Identify the actions necessary for proactive drought management at the district level, including defining critical parameters for classifying the current climate condition (indicators, climate variables, and thresholds);
- Define criteria and guidelines for the development/alignment of regional and/or district plans aimed at water conservation.

2. Materials and methods

The assessment of irrigation investment policies, their planning, and the selection of infrastructure has a significant and lasting impact on numerous stakeholders; for this reason, it was necessary to consider multiple objectives using a multi-criteria analysis (Zargham *et al.*, 2011). In general, identifying and evaluating viable project options is a fundamental step in finding the most satisfactory solution in terms of economic development opportunities, environmental impact and social impact.

Multi-Criteria Analysis (MCA) techniques are an effective approach to this end, as they are methodological tools that allow project alternatives to be compared based on multiple evaluation criteria.

In the simplest case, the choice between different alternatives can be guided by a single decision criterion. In economic evaluations, for instance, investments are ranked according to the balance between their cost and benefits (Mishan, 1988), as measured by the net present value (the discounted difference between benefits and costs) or the internal rate of return. However, in spatial planning and environmental assessments, it is rarely possible to rely on a single objective.

In the context of irrigation investments, for instance, the decision to build a new system or modernise an existing network cannot be based solely on economic factors. Other criteria must also be considered, such as:

- environmental sustainability (water savings, impact on ecosystems, water quality);
- social compatibility (benefits for agricultural communities, equity in the distribution of resources);
- climate resilience (the system's ability to adapt to changes in water availability);
- technical and economic efficiency of the intervention.

Multi-criteria analysis enables the integration of various aspects, combining quantitative criteria, such as costs, benefits, and irrigation volumes, with qualitative criteria, such as landscape impacts, environmental constraints and social acceptability. These are expressed in their respective units of measurement as well as through dimensionless indices based on expert assessment.

The main advantage of MCA over other economic techniques, such as cost-benefit analysis, is its methodological flexibility. It is possible to include heterogeneous criteria and weight them, accordingly, evaluating each element with the most appropriate assessment method.

Furthermore, environmental impact assessments – including those relating to large-scale irrigation projects – consider more than just the perspectives of technicians and researchers. It is now recognised that the decision-making process must also involve local communities and stakeholders, such as farmers, land reclamation consortia, administrations and citizens.

From this perspective, the analysis is multi-criteria and multi-decision, aiming to represent the different preferences, expectations and needs of those involved. This participatory approach helps make decisions more widely accepted, sustainable and long-lasting, which is essential for the success of any irrigation investment geared towards sustainability and efficient water resource management. In the latter case, the use of MCA lies in the need to treat water as a scarce resource and combine multiple criteria in management decisions rather than just one.

Multicriteria analysis has been designed and is widely applied as a decision tool in allocating limited resources among alternative interventions. In theory, every complex investment program should follow a coherent process where alternative options of investment are compared with reference to a set of goals to be pursued (economic, environmental, social), based on a set of quantitative indicators (Zargham and Szidarovszky, 2011). The expected result is a list of investments ordered to maximise the results valued against a multiple set of criteria. The decision procedure should include also a formal quantification of weights expressing how possible trade-offs among different goals have to be managed, according to the preferences of decision makers. A wide set of quantitative techniques (such as for example the *analytic hierarchy process*, cfr. Saaty & Vargas, 2012) can support the participatory processes where the relative importance of different goals is negotiated and weights decided.

In our analysis we adopt an ex-post, evaluation perspective of investment decision done. Projects have been already financed and partially implemented, according to a set of planning documents whose goals have been discussed in the previous section. We assume that the investment decisions have been done according to a multiple set of criteria to pursue different policy goals (Table 1).

We assume that each objective has been represented in the decision process by a quantitative indicator. Our aim is to provide evidence on the relative importance (weight) given to each of these indicators in the decision process. The contrast with stated goals, as expressed by planning documents, and the actual relative importance given to different goals will provide a first

evidence on coherence of the planning process, useful to orient investment decision in the future.

Table 1 - Ex-post decision analysis for an overview of irrigation investments promoted by the Ministry of Agriculture

Purpose	Objectives	Criteria
Increase water efficiency in agriculture	Social	Safeguard agricultural businesses
	Environmental	Enable water savings and protect ecosystems
	Economic	Ensuring the country's food sovereignty and safeguarding food security in production

We have therefore extracted data from the DANIA database on 28 irrigation authorities in five regions, with 73 projects at various stages of funding:

- Planned for financing;
- Financed;
- Under construction;
- In operation.

The projects analyzed were divided according to the source of funding, beneficiary, and type of project:

- Law 145/2018;
- Law 160/2019;
- AOP 2019;
- Law 178/2020;
- AOP 2022;
- NRDP;
- NRRP.

The projects were selected from the DANIA database based on the completeness of the data relevant to the survey, about:

- Expected water savings;
- Area made more efficient by the intervention;
- Amount financed.

Based on the selected data, the following indicators were then calculated, reflecting the water efficiency objectives for irrigation outlined by the various funding programs from three different perspectives (criteria):

- *Amount financed per hectare made efficient (economic indicator – ECO1):* This indicator concerns the economic intensity of the investment per hectare of area made efficient; it can be considered an indicator of the “dimensional” efficiency of the planned interventions;
- *Cubic meters of water saved per euro invested (economic indicator – ECO2):* This indicator considers the efficiency of investment expenditure in terms of “cost-effectiveness”, considering the capacity of each euro of investment to contribute to water savings; it can be considered an indicator of the “technical” efficiency of the planned investment in achieving water saving targets;
- *Cubic meters of water saved per hectare made more efficient (Environmental indicator - AMB1):* This is an indicator of the “environmental” efficiency of the intervention measured as the gain in efficiency in the use of water for irrigation per hectare of land subject to the planned investments.

For each intervention, the three indicators mentioned above were calculated, along with a normalized index that allows the distance between the different interventions to be analyzed, measured based on the indicators with a value ranging from 0 (worst case) to 1 (best case) according to the formula:

$$X_{i,j} = \frac{x_{i,j} - x_{j\ worst}}{x_{j\ best} - x_{j\ worst}}$$

Where $x_{i,j}$ is the value of the indicator j in the intervention i , while $x_{j\ best}$ and $x_{j\ worst}$ are the values of the indicator j in the most efficient and least efficient cases, respectively.

The average values of the indices and ranks obtained from the investments were grouped by source of funding and region and were weighted according to the cost of the investment in the case of dimensional efficiency (ECO1 index), the m³ of water saved in the case of technical efficiency (ECO2), and the areas of intervention in the case of environmental efficiency (AMB1), according to the formula:

$$W_{j,r} = \frac{\sum_{i=1}^{n_r} X_{i,j} w_{i,j}}{\sum_{i=1}^{n_r} w_{i,j}}$$

Where:

- $W_{j,r}$ is the weighted average of the efficiency index j in the case of the source of funding/region r ;

- $X_{i,j}$ is the efficiency index of the intervention i ;
- $w_{i,j}$ is the weight assigned to the intervention i in the case of the index j (Euros invested, m³ of water saved and ha of surface area transformed for dimensional, technical and environmental efficiency, respectively);
- n_r is the number of interventions included in the funding source/region r .

3. Results and discussions

Total investments relating to the 73 interventions considered in the Po River Basin District in the period 2018-2024 exceeded €666 million. About the equipped area, the investments involve approximately 419,000 hectares, while for water saving approximately 320 million m³ have been calculated when the investments are fully operational. Combining the importance of assessing the sustainability of irrigation infrastructure investments and balancing the economic and social benefits of irrigation with the protection of the environment and natural resources, an analysis was carried out of how much the water efficiency of the area affected by these interventions would increase.

The following tables show the essential data for the 15 most efficient interventions, ranked according to the value of the indicators (ECO1, ECO2, and AMB1).

Amount financed per hectare of efficiency gained (ECO1)

Table 2 shows the investments based on the ECO1 indicator. This indicator is given by the ratio between the unit cost of the investment (€) and the area covered by the intervention (ha) and allows the economic intensity of the investment per hectare of surface area to be assessed.

In this case, the indicator is sorted in ascending order, indicating a preference for interventions involving lower expenditure per unit of area. Looking at the normalized index, the difference between the values of the best investments is minimal, demonstrating substantial homogeneity. It is important to note, however, that only 7.6% of the funds available for all sources of financing were allocated to the investments shown in the table. About size efficiency, the allocation of resources favored less efficient interventions: only 39.3% of resources were allocated to the 50% best interventions.

Table 2 - Interventions ranked according to the value attributed to the economic indicator (ECO1)

ID	Sources of funding	Region	Amount (€)	Area (ha)	Water saving (mc)	ECO1 Dimensional efficiency (€/ha)	Index
73	AOP 2022	Veneto	494.790	14.404	35.570.880	34,35	1,000
72	AOP 2022	Emilia-Romagna	499.590	13.434	303.293	37,19	1,000
71	AOP 2022	Emilia-Romagna	500.000	12.072	35.870	41,42	1,000
70	AOP 2022	Lombardia	484.421	11.566	3.945.981	41,88	1,000
69	AOP 2022	Veneto	483.970	8.480	890.400	57,07	1,000
68	AOP 2022	Emilia-Romagna	420.000	4.222	2.273.037	99,48	0,999
67	L. 145/2018	Lombardia	1.428.708	11.566	600.000	123,53	0,999
66	NRDP	Lombardia	5.547.177	37.000	39.810.000	149,92	0,999
65	L. 178/2020	Emilia-Romagna	2.709.821	13.622	2.202.548	198,93	0,998
64	AOP 2022	Emilia-Romagna	483.565	1.107	1.181.730	436,82	0,995
63	NRRP	Emilia-Romagna	2.700.000	5.470	2.640.000	493,60	0,995
62	L. 178/2020	Emilia-Romagna	8.706.145	17.413	1.889.473	499,98	0,995
61	L. 178/2020	Piemonte	9.609.688	13.994	625.845	686,70	0,992
60	NRDP	Lombardia	4.710.674	6.500	7.150.000	724,72	0,992
59	NRDP	Emilia-Romagna	11.788.043	14.700	2.283.070	801,91	0,991

Cubic meters of water saved per euro invested (ECO2)

Table 3 shows investments ranked according to the ECO2 indicator. This indicator is given by the ratio between m³ of water saving and euros invested, a cost-effectiveness ratio that represents the technical efficiency of the interventions.

Table 3 - Interventions sorted according to the value assigned to the economic indicator (ECO2)

ID	Sources of funding	Region	Amount (€)	Area (ha)	Water saving (mc)	ECO2 Techno-economic efficiency (mc/€)	Index
73	AOP 2022	Veneto	494.790	14.404	35.570.880	71,9	1,000
70	AOP 2022	Lombardia	484.421	11.566	3.945.981	8,1	0,113
66	NRDP	Lombardia	5.547.177	37.000	39.810.000	7,2	0,100
68	AOP 2022	Emilia-Romagna	420.000	4.222	2.273.037	5,4	0,075
25	L. 178/2020	Piemonte	8.243.677	2.127	25.228.800	3,1	0,043
64	AOP 2022	Emilia-Romagna	483.565	1.107	1.181.730	2,4	0,034
69	AOP 2022	Veneto	483.970	8.480	890.400	1,8	0,026
52	AOP 2019	Lombardia	4.000.000	3.500	6.415.081	1,6	0,022
60	NRDP	Lombardia	4.710.674	6.500	7.150.000	1,5	0,021
53	NRRP	Veneto	7.200.943	6.357	10.582.488	1,5	0,020
13	NRDP	Veneto	5.500.000	550	8.000.000	1,5	0,020
16	NRDP	Lombardia	6.507.960	849	7.907.518	1,2	0,017
43	NRDP	Piemonte	5.925.684	3.258	6.259.153	1,1	0,015
39	NRRP	Veneto	7.500.000	3.646	7.543.197	1,0	0,014
63	NRRP	Emilia-Romagna	2.700.000	5.470	2.640.000	1,0	0,014

In this case, the indicator is sorted in descending order, as interventions that achieve greater water savings for the same expenditure are preferred. Looking at the normalized index, there is a significant gap in terms of technical efficiency within the group of most efficient interventions. In particular, the “best” investment in terms of cost-effectiveness is in a different order of magnitude in terms of water savings achieved. This outcome can be attributed to the investment’s objective of modernizing the remote monitoring system of the entire irrigation district. As a result, it entails lower costs while delivering higher water savings than interventions centered on the rehabilitation and upgrading of irrigation infrastructure. In the case of technical efficiency, the overall allocation also favored less efficient interventions: the best 50% of all interventions considered were financed with 37.7% of resources.

Cubic meters of water saved per hectare improved (AMBI)

Table 4 shows the best investments based on the AMBI indicator. This indicator is given by the ratio between m³ of water saved and areas (ha) made more efficient and allows the technical and environmental efficiency gains in water use for irrigation generated by the investments to be assessed.

Table 4 - Interventions ranked according to the value assigned to the economic indicator (ECO2)

ID	Sources of funding	Region	Amount (€)	Area (ha)	Water saving (mc)	AMBI Environmental efficiency (mc/ha)	Index
13	NRDP	Veneto	5.500.000	550	8.000.000	14.545	1,000
25	L. 178/2020	Piemonte	8.243.677	2.127	25.228.800	11.861	0,815
7	NRDP	Veneto	6.200.000	505	5.131.123	10.161	0,698
14	NRDP	Lombardia	5.225.032	527	4.908.436	9.314	0,640
16	NRDP	Lombardia	6.507.960	849	7.907.518	9.314	0,640
9	NRDP	Veneto	8.300.000	760	5.515.776	7.258	0,499
10	NRDP	Lombardia	5.421.550	514	2.837.773	5.521	0,379
5	NRDP	Piemonte	20.000.000	1.150	5.266.000	4.579	0,315
4	AOP 2019	Piemonte	7.325.000	220	970.000	4.409	0,303
8	L. 145/2018	Piemonte	3.330.000	290	1.200.000	4.138	0,284
2	L. 160/2019	Lombardia	7.600.000	166	680.000	4.096	0,281
17	NRRP	Emilia-Romagna	14.250.000	2.090	8.503.905	4.069	0,280
1	L. 145/2018	Valle D'Aosta	15.000.000	177	612.800	3.462	0,238
26	NRDP	Veneto	9.816.637	2.703	9.072.000	3.356	0,231
15	NRDP	Lombardia	4.279.802	475	1.500.000	3.158	0,217

Source: Author's elaboration.

In this case too, the indicator is ranked in descending order, as greater water savings, for the same surface area, are desirable. Looking at the normalized index, the dispersion of values in the 15 best investments is quite significant and greater than in the previous indicators, indicating that the different nature of the interventions and the different conditions in which they are carried out can lead to quite diverse results in terms of efficiency in water

use for irrigation. In the case of the environmental efficiency indicator, the overall allocation of funds is better than the previous criteria: the best 50% of all investments were financed with about half of the resources (48.3%).

Tables 5 and 6 compare the sources of funding and the regions based on the average ranking obtained by the respective investments in relation to the various indicators.

Table 5 - Evaluation of funding sources based on the average ranking of the indicators considered

Source of funding	Amount		Dimensional efficiency (€/ha)		Techno-economic efficiency (€/m ³)		Environmental efficiency (m ³ /ha)	
	M€	%	Average index	Average rank	Average index	Average rank	Average index	Average rank
AOP 2019	43,1	6,5	0,876	42	0,012	28	0,037	49
AOP 2022	3,4	0,5	0,999	4	0,820	2	0,046	53
L. 145/2018	33,8	5,1	0,526	55	0,004	40	0,020	59
L. 160/2019	26,0	3,9	0,828	40	0,006	28	0,042	47
L. 178/2020	105,2	15,8	0,941	35	0,026	20	0,038	57
NRRP	257,5	38,6	0,956	41	0,008	29	0,048	43
NRDP	197,3	29,6	0,928	46	0,039	18	0,082	38
Total	666,3	100,0	0,914	42	0,135	20	0,052	47

Source: Author's elaboration.

Regarding the first indicator, the best average ranking is associated with AOP 2022 funding, which otherwise has one of the worst values for the environmental efficiency indicator. On the other hand, there is an opposite trend for interventions financed by Law 145/2018, which are the most efficient in terms of water saving (ECO2) but have a worse rating for the size efficiency indicator (ECO1) at the highest value.

More generally, it should be noted that resources were allocated with a preference for measures that were more efficient in terms of savings per unit of area (ECO1) than in terms of technical (ECO2) and environmental (AMB1) efficiency. This result probably reflects the existence of a trade-off between the different efficiency criteria.

If the different sources of funding represent different “models” of resource allocation, and assigning equal importance to the three evaluation criteria,

the AOP 2022 program dominates the other funds. It is in fact the fund that, on average, places its interventions at the shortest distance from an ideal irrigation investment hypothetically capable of obtaining the best score across all indicators. This distance can be measured as the difference between the overall score that the “ideal” investment would obtain and the sum of the average normalized scores obtained by each funding line. In the case of the investments considered, the distance varies from 2.450 in the case of investments financed under Law 145/2018 to 1.134 in the case of the AOP 2022 program. Obviously, this result strictly depends on the assumption that equal importance is assigned to the three evaluation criteria and could change if the indicators were “weighted” differently.

Table 6 - Evaluation of regions based on the average ranking of the indicators considered

Region	Amount		Dimensional efficiency (€/ha)		Techno-economic efficiency (€/m ³)		Environmental efficiency (m ³ /ha)	
	M€	%	Average index	Average rank	Average index	Average rank	Average index	Average rank
Emilia-Romagna	297,7	44,7	0,950	40	0,008	36	0,023	56
Lombardia	126,8	19,0	0,926	42	0,051	15	0,064	38
Piemonte	154,4	23,2	0,930	42	0,020	23	0,066	47
Valle D'Aosta	22,3	3,3	0,153	72	0,001	70	0,129	36
Veneto	65,0	9,8	0,944	41	0,397	10	0,114	34
Total	666,3	100,0	0,914	42	0,135	20	0,052	47

Source: Author's elaboration.

Moving on to a comparison between regional areas, Emilia-Romagna, which is the region in which the largest share of funds was invested (44.7%), is the most efficient in terms of the first indicator, even though its projects are ranked higher on average than the average for technical efficiency. The Veneto region achieves the best average score for indicators ECO2 and AMB1 in relation to the first and third indicators, ECO1 and AMB1, presenting the resource allocation “model” closest to the “ideal” one³. Finally, Valle d'Aosta is the region where environmental efficiency has been given the highest priority, favoring interventions that achieve greater water savings per unit of surface area.

Conclusions

The Po River basin is one of the most important agricultural areas in Italy and Europe. It is characterised by high demand for irrigation, a variety of irrigation systems (surface, pressure and sub-irrigation) and an increasing vulnerability to the effects of climate change, such as drought, reduced flow rates and rising temperatures. In this context, irrigation measures must address production needs and the principles of water conservation, the protection of river and agricultural ecosystems, and climate change adaptation. Irrigation actions have dual value: they increase the agricultural system's resilience and promote the rational use of water resources, which is essential for ensuring the sector's future sustainability.

The decision to focus the analysis on the Po District is based on the understanding that modernising the area's irrigation infrastructure is crucial to its productivity. In recent years, the area has experienced severe droughts that have had a significant impact on agriculture. Therefore, investments must make the system more resilient by increasing storage capacity and adopting digital solutions for efficient water management. These investments represent an effort to modernise the extensive and historic network of irrigation canals, which are often obsolete and inefficient. This modernisation is integrated into an approach to managing water resources that includes planning the water balance, monitoring flows and withdrawals, and proactively managing droughts and water surpluses.

The ex-post multi-criteria analysis results provided in this paper is useful for assessing infrastructure investment sustainability. According to planning documents we evaluated the funded investments using criteria going beyond traditional economic parameters, revealing impacts that would otherwise be overlooked or underestimated. Recognising the critical importance of spending on irrigation investments to the future sustainability of agriculture and the national water system is essential, especially in the context of growing challenges related to climate change and resource efficiency. The adopted multi-criteria analysis provides a first evaluation of the investment performance, as the results depend on the sample and normalisation procedures used rather than external benchmarks. This limitation has been explicitly acknowledged, clarifying that the results should be interpreted as comparative judgements of coherence in investment decisions rather than definitive evidence of their sustainability.

Adopting a multi-indicator assessment supplemented by a standardisation system addresses several issues: it accounts for the territorial variability of irrigation systems in the Po basin (including gravity, pressure, micro-irrigation, and sub-irrigation systems); it supports governance and integrated planning; it measures environmental and climate impacts; and it demonstrates

the value of public interventions using objective data, thereby fostering trust and accountability among local communities and stakeholders.

The initial results suggest that the investments made or planned are improving the area's efficiency in several ways. Particular attention is paid to investments that reflect "dimensional efficiency", i.e. the extension of the efficient irrigated area, even if this comes at the expense of other parameters, such as water savings per euro invested or impact per unit of area. The study allows the ex-post verification of whether choices are consistent with the set objectives, and whether the highlighted compromises are due to technical reasons or conscious planning choices.

The Po District's experience represents a model that can be replicated in other Italian irrigation areas. The method based on standardised indicators enables a more in-depth, comparative and integrated assessment of investments. This helps to optimise public resources, improve the targeting of strategic priorities, strengthen the resilience of agricultural systems, and promote sustainable water use. In a context of increasing water scarcity and stricter environmental regulations, this approach is essential for ensuring modern, efficient and sustainable irrigation in the long term.

Conflicts of interest

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Raffaella Pergamo

Senior Researcher, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: raffaella.pergamo@crea.gov.it

Based at MASAF's technical office within the National Rural Network, she contributes to rural development policies related to the implementation of the Common Agricultural Policy (CAP) in Italy. Her research focuses on the economic analysis of supply chains, the sustainability of agricultural production, precision and digital agriculture, the circular economy and the conservation of biodiversity. She is the author and co-author of numerous publications and has presented at various national and international conferences.

Luca Adolfo Folino

Research Technologist, Council for Agricultural Research and Economics - Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: lucaadolfo.folino@crea.gov.it

Luca Adolfo is a Research Technologist (since 2019) at the Research Centre for Agricultural Policies and Bioeconomy (CREA-PB). He completed his undergraduate studies in Economics and Business at the Faculty of Economics of the University of Bari (Italy). He is in charge of the development and management of the National Database of Investments for Irrigation and Environment (DANIA) and supports regions and irrigation entities in problem solving. He has worked as a technical-administrative collaborator at the Institutional Affairs and International Relations Office of CREA and as a Field and Sales Support at Pramerica Life Spa, a former insurance company of the US group Prudential Financial.

Marianna Ferrigno

Senior Research Technologist, Council for Agricultural Research and Economics - Research Centre for Agricultural Policies and Bioeconomy (CREA-PB)

E-mail: marianna.ferrigno@crea.gov.it

The author holds a degree in Environmental Engineering and a Master's degree in Sustainable development and Corporate social Responsibility. She is a Senior Technologist at CREA - Research Centre for Agricultural Policies and Bioeconomy (CREA-PB), involved in research and technical assistance to Ministry of Agriculture on water use in agriculture, and on planning of water related agricultural policies and public investments for irrigation, in coordination with environmental policies for water. She is Responsible of DANIA database (Italian National database of investment for irrigation and environment). She is the author of several publications and panelist at national and international conferences about water policies and supporting databases.

Marica Furini

Research Technologist, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: marica.furini@crea.gov.it

I hold a master's degree in Conservation and management of the natural, environmental and cultural asset, cum laude, at University of Ferrara. I currently work at CREA-PB, Rome, as a technologist (from July 2022), focusing on water resources management, in particular about the reuse of reclaimed wastewater for the agricultural irrigation.

<https://orcid.org/0009-0002-4171-8599>

Manal Hamam

Research Technologist, Council for Agricultural Research and Economics - Research Centre for Agricultural Policies and Bioeconomy (CREA-PB), Rome, Italy

E-mail: manal.hamam@crea.gov.it

Since 2024 Research Technologist at CREA-PB - Research Centre for Agricultural Policies and Bioeconomy. She holds a Master's degree in "Food science and Technology", an Advanced Master's degree in "Agricultural Economics and Policy", and a Ph.D. in "Agricultural, Food, and Environmental Science". Her research area focuses on water management in agriculture and the sustainability of agri-food systems. She is author of several publications and speaker at national and international conferences.

Veronica Manganiello

Research technologist, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: veronica.manganiello@crea.gov.it

The author holds a Master's degree in Biotechnology and a PhD in Economy, Management, and Quantitative Methods, with a research focus on Circular Economy. She is responsible for the SIGRIAN database (National Information System for Water Resources Management in Agriculture) and collaborates on various projects related to agricultural water resource management, with particular attention to environmental and agricultural policies. She also coordinates several institutional agreements and initiatives at both national level and within river basin authorities, aimed at improving the governance and sustainable use of water resources in agriculture. She is co-author of several scientific and technical publications on water use in agriculture.

<https://orcid.org/0000-0003-0348-6600>

Antonio Manzoni

Researcher, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy); Sant'Anna School of Advanced Studies, Pisa

E-mail: antonio.manzoni@crea.gov.it

I hold a Master's Degree in Law, and a Ph.D. in Agricultural and Environmental Law. I currently work at CREA-PB, Rome, as a researcher (from March 2024), focusing on water resources management, the EU Common Agricultural Policy, and sustainable food systems.

Alessandra Pesce

Director of the research centre Policies and Bioeconomy, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: alessandra.pesce@crea.gov.it

Director of the research centre Policies and Bioeconomy, her main fields of research are the definition, monitoring, and evaluation of agri-food development policies, with a particular focus on territorial dynamics, supply chain dynamics, and strengthening sustainability. She is called as expert at international forums and working group. She served as Undersecretary of State at the Ministry of Agricultural, Food, Forestry, and Tourism Policies, with responsibilities on research, innovation, technology transfer, and training in the agri-food sector, as well as issues related to specific production sectors and initiatives in rural areas.

Benedetto Rocchi

Associate professor at the Department of Economics and Business Sciences, University, University of Florence, Italy

E-mail: benedetto.rocchi@unifi.it

Associate professor at the University of Florence, where he teaches Agricultural Economics. His main fields of research are the analysis of agricultural policy and the economics of rural development and food supply chain. He studied income distribution in agriculture and in the rural areas, the distributive impacts of agricultural policy, the impact non-renewable resource abundance on regional development, the impact of economic activities on resource use, the economics of alternative food supply chains and the social consequences of collective choices in bioethics. In 2025 he joined the board of the Italian Association of Agricultural and Applied Economics.

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Grazing Impacts on Biodiversity, Carbon Cycle, Water Efficiency, and Animal Welfare: Review

Giulia Pastorelli^{*a}, Iaria Falconi^a, Maria Assunta D'Oronzio^a,
Raffaella Pergamo^a

^a CREA Research Centre for Agricultural Policies and Bioeconomy, Italy

Abstract

This review examines the role of pasture-based livestock systems in promoting agri-environmental sustainability across four key dimensions: biodiversity, water-use efficiency, carbon cycle, and animal welfare. Despite growing political and scientific interest in extensive grazing, the existing literature remains fragmented and limits a comprehensive understanding of grazing's multidimensional impacts. To address this gap, we conducted a review of studies published between 2010 and 2025, following the Cochrane Handbook and applying the PICO (Population, Intervention, Comparison, Outcome) framework. The analysis focused exclusively on studies conducted in Europe to explore the state of the art on the topic and analyze future policy implications. The results indicate that moderate and well-managed grazing improves biodiversity, increases water-use efficiency, and promotes soil carbon sequestration, especially through rotation practices and tree integration. Access to pasture improves animal welfare, although outcomes vary depending on infrastructure and environmental conditions. The review emphasizes the need for integrated approaches that combine traditional knowledge, environmental design, and precision tools to maximize the sustainability of grazing systems.

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* *Corresponding author:* Giulia Pastorelli - CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy). E-mail: giulia.pastorelli@crea.gov.it.

Introduction

Agriculture plays a crucial role in safeguarding ecosystem services, food security, and landscape preservation. However, demographic expansion, resource competition, geopolitical tensions, and climate change are placing increasing pressure on agricultural systems. In this context, halting biodiversity loss is a priority for the European Union, as outlined in the Farm to Fork and Biodiversity 2030 Strategies (Fraser *et al.*, 2022). The transdisciplinary One Health approach can strengthen resilience and prevention against environmental risks, antimicrobial resistance (AMR), and climate change (Rodriguez, 2024). Within agri-livestock systems, the debate around production intensification is growing. Extensive farming systems, through the diversification of grazing surfaces and species, promote biodiversity and soil fertility (Delaby *et al.*, 2020).

Despite growing interest in these systems, literature lacks comprehensive data on the environmental impact of livestock farming, as most studies have primarily focused on carbon footprint (Tittonell, 2021; Opio *et al.*, 2013), neglecting other aspects such as biodiversity, land stewardship, energy efficiency, and sociocultural values.

Elorriaga *et al.* (2013) highlight that the concentration of manure in intensive farming systems and the frequent use of antimicrobials result in significant environmental impacts, including water resource pollution with potential negative consequences for human health. Similarly, Jechalke *et al.* (2014) emphasize that manure spreading practices associated with such production systems may pose high contamination risks and promote the development of antimicrobial resistance.

In the present review, we adopt the PICO framework (Population, Intervention, Comparison, Outcome) to define the scope of analysis and guide the construction of search strings. Following Cochrane guidelines (Cumpston *et al.*, 2024), the study is based on the effects of pasture-based grazing systems in relation to four critical dimensions of agro-environmental sustainability: biodiversity, water use efficiency, carbon cycle, and animal welfare.

1. Background

In recent years, consumers have shown growing interest in purchasing products derived from sustainable agricultural systems, which are perceived as more respectful of environmental integrity and animal welfare. This trend reflects a broader societal concern over the ecological footprint of food production and a demand for transparency in how ecosystems are managed and preserved. Ecosystems provide essential services, such as food

provision, water regulation, and climate mitigation, that underpin human wellbeing and economic development. Yet, these contributions are rarely reflected in traditional economic indicators, creating a disconnect between environmental value and policy action (Vargas *et al.*, 2024). Across many regions, especially those undergoing accelerated agricultural intensification, the lack of long-term planning and water resource monitoring has led to significant sustainability challenges, particularly in terms of water use (Barsotti *et al.*, 2022). At the same time, the abandonment of traditional land use practices, common throughout Europe in recent decades, has had profound impacts on agricultural landscapes, resulting biodiversity loss (Ponzetta *et al.*, 2010). Indeed, it is estimated that 75% of grassland habitats in the European Union are in poor or bad condition, with land abandonment and overgrowth representing key threats (Hessle *et al.*, 2023). The integration of food production with biodiversity conservation has thus emerged as a critical challenge for sustainable development (Gallé *et al.*, 2020). This is particularly urgent in the context of the ongoing need for ecological intensification of farming systems, improving agricultural productivity while minimizing environmental degradation and maintaining ecosystem functions (Beye *et al.*, 2019). Future grazing systems are expected to play a central role in this transition by supplying nutrient- dense food within lower-input systems that reduce reliance on fossil fuels and agrochemicals, and enhance environmental, biodiversity, and animal welfare outcomes (Delaby *et al.*, 2020). Lower-input pasture-based systems offer several advantages: they utilize feed sources inedible to humans (e.g., grasslands) rather than human-edible grains (e.g., soya), and they reduce feeding costs and the environmental footprint of production. Additionally, these systems often align with consumer preferences for higher animal welfare and environmentally sustainable meat products. In this context, the preservation and promotion of autochthonous livestock breeds are of strategic importance. These breeds not only embody genetic diversity crucial for adaptation to local environments, but also support rural development, cultural identity, and food and nutrition security, especially in marginal and pasture-based systems (Agradi *et al.*, 2023). According to Devincenzi *et al.* (2021), grazing behaviour management plays a crucial role in improving animal welfare, product quality, and ecosystem services.

2. Materials and methods

This review was conducted following the methodological principles outlined in the Cochrane Handbook for Systematic Reviews of Interventions, and the review design was structured using the PICO model (Population, Intervention, Comparison, Outcome) (Table 1) (Sala *et al.*, n.d.) to formulate

the research question and organize the thematic domains. The aim was to identify and synthesize scientific literature on the environmental and animal welfare effects of pasture-based grazing systems.

Table 1 - PICO model

P	Population/Problem	Livestock production systems
I	Intervention	Effects of grazing on biodiversity, water use efficiency, carbon sequestration, and animal welfare
C	Comparison	Comparison between livestock systems and farming methods at the European and global level
O	Outcome	Scientific evidence on the most frequently addressed and associated sustainability themes

Source: Authors' elaboration.

To ensure methodological rigor and transparency, inclusion and exclusion criteria were defined a priori, and reinforced by specific guidelines for systematic reviews in the agri-food sector, which emphasize the importance of clearly defining the study question and selecting relevant study designs (Sargeant *et al.*, 2005).

Studies were selected based on their relevance to at least one of the following dimensions: biodiversity, water use efficiency, carbon cycling, and animal welfare in grazing-based livestock systems.

Table 2 - Inclusion and exclusion Criteria

Domain	Inclusion Criteria	Exclusion Criteria
Topic	Studies evaluating grazing effects on biodiversity, water use, carbon cycle, or animal welfare	Studies not addressing at least one of the four sustainability dimensions
Study type	Articles, Narrative reviews	commentaries, opinion pieces
Publication period	From 2010 to 2025	Published before 2010
Geographic scope	Studies conducted in Europe	Studies not conducted in Europe
Open Acces	Full-text available	Abstract only or inaccessible full text

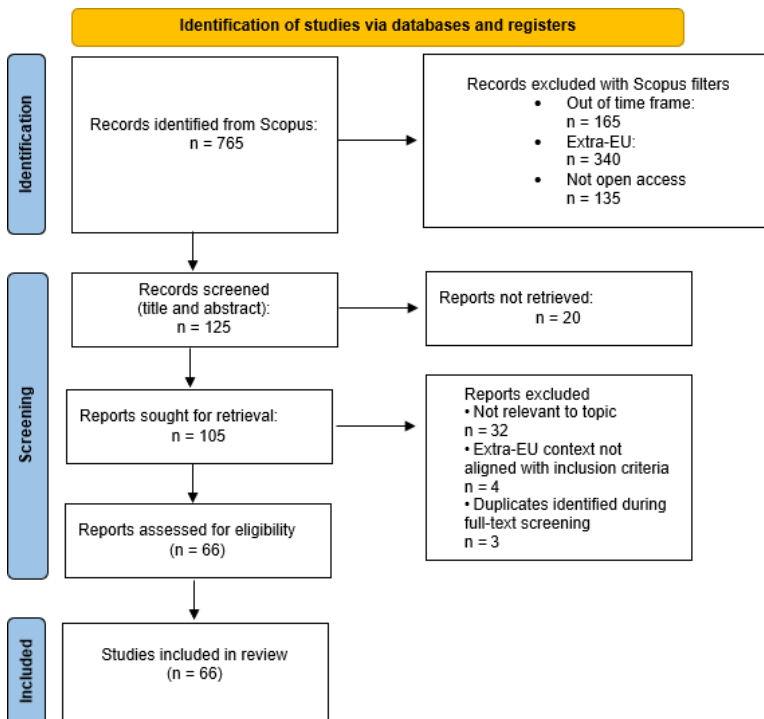
Source: Authors' elaboration.

The initial identification of records was carried out manually via Scopus. Search strings were constructed using combinations of key terms related to the four thematic categories:

- *Pasture grazing and biodiversity.*
- *Pasture grazing and water use.*
- *Pasture grazing and carbon farming.*
- *Pasture grazing and animal welfare.*

The flow diagram representing the systematic selection process for all included studies follows the PRISMA (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols) method (Page *et al.*, 2021). Preliminary exclusion criteria were applied directly on Scopus through filters, including publication date (from 2010 to 2025), availability of full text (open access), and geographic context (with a focus on European studies).

Figure 1 - PRISMA-based Schema



Source: Author's elaboration on base Page M. J. *et al.* BMJ 2021.

The next stage (reports sought for retrieval, n = 105) involved retrieval of all texts and a more careful assessment of methodological appropriateness

and thematic relevance. It is worth noting that a small number of duplicate records were identified at this stage ($n = 3$). This limited overlap was due to the use of a single database (Scopus) and four separate thematic searches (via keywords). Separation by domain initially prevented automatic detection of duplicates, which was resolved during eligibility screening.

3. Results

3.1. Literature distribution

Data extracted from the selected studies were synthesised using a narrative approach, given the heterogeneity of study designs, geographical contexts, and methodological approaches. The synthesis was structured thematically along the four main dimensions defined in the research framework: (1) biodiversity, (2) water use efficiency, (3) carbon cycle, and (4) animal welfare. Each study was categorized based on its thematic focus and geographical location, selecting only European studies.

A total of 765 studies were initially retrieved from Scopus after keyword filtering. The thematic distribution highlights a predominant focus on water use (49.4%), followed by biodiversity (29.5%), animal welfare (12.6%), and carbon (8.5%). A temporal analysis reveals a shift in research interest: while the link between environmental dimensions such as grazing and biodiversity or water use has been explored for over a decade, most studies on carbon sequestration and animal welfare are more recent, with over 90% of articles in these categories published after 2010 (Table 3).

Table 3 - Temporal distribution of literature

Thematic Area	No. of Articles	% of Total	Articles 2010-2025	% of Category
Pasture grazing & biodiversity	227	29.5%	184	81%
Pasture grazing & water use	377	49.4%	265	70%
Pasture grazing & carbon farming	65	8.5%	63	96%
Pasture grazing & animal welfare	96	12.6%	88	92%
Total	765	100 %	598	–

Source: Author's elaboration.

This suggests a growing awareness of the role of pasture-based livestock systems in climate change mitigation and the sustainability of livestock farming.

Another dimension explored was the geographical distribution of the literature (Table 4). Of the 764 studies, only 260 (34%) focused on European countries, revealing a significant knowledge gap related to the four explored dimensions of grazing, particularly in relation to water use and carbon sequestration. Thematic areas such as animal welfare (52.1%) and biodiversity (54.2%) have a relatively larger share of EU-based studies, while water use lags significantly behind (18.3%), despite its relevance in a context of increasing climate variability and water stress in southern Europe.

Table 4 - Geographical distribution of the literature

Thematic Area	No. of Articles	EU Articles	% EU of Total
Pasture grazing & biodiversity	227	123	54.2%
Pasture grazing & water use	377	69	18.3%
Pasture grazing & carbon farming	65	18	27.7%
Pasture grazing & animal welfare	96	50	52.1%
Total	765	260	34.0%

Source: Author's elaboration.

The preliminary evidence emerging from this review highlights the evolving role of grazing systems across multiple sustainability dimensions in the European context. While the environmental role of pasture-based livestock farming has long been acknowledged in terms of biodiversity and water dynamics, emerging challenges such as climate change mitigation, greenhouse gas emissions, and ethical livestock management are gaining increasing attention. However, the geographic and thematic imbalance in the literature suggests a need for greater integration between sustainability dimensions and for enhanced focus on European systems, particularly in water governance and carbon-related practices.

3.2. Narrative synthesis

The following narrative synthesis presents the key findings emerging from the selected studies, organized according to the four sustainability dimensions examined in this review. Given the heterogeneity of study designs, geographic contexts, and methodological approaches, results are discussed thematically to highlight recurring patterns, relevant contrasts, and emerging insights. The synthesis focuses on how pasture-based livestock system have been studied in relation to each dimension, offering a comprehensive overview of their environmental and animal welfare implications across different European contexts.

3.2.1. Grazing and biodiversity

Pasture grazing plays a central role in the conservation of biodiversity across European landscapes. Numerous studies confirm that grazing, when properly managed, enhances both plant and habitat diversity, especially in semi-natural and marginal environments.

Moderate grazing intensity, for instance, has been associated with increased plant and pollinator richness (Freschi *et al.*, 2015), and with improved habitat heterogeneity in low- input pastures (Tonn *et al.*, 2019). In Mediterranean systems, Candel-Pérez *et al.* (2024) and Fracchiolla *et al.* (2017) demonstrate how intensive or unmanaged grazing reduces plant richness, favouring disturbance-tolerant species. By contrast, targeted restoration interventions such as mowing or reseeded (Ponzetta *et al.*, 2010; Sitzia *et al.*, 2010) have proven effective in reversing biodiversity loss in abandoned grasslands. Similar dynamics emerge in Polish meadows, where grazing influenced species abundance and beetle community composition (Szyszko-Podgórska *et al.*, 2024; Czarnecki *et al.*, 2015), and in Sweden, where the reintroduction of grazing restored functional invertebrate assemblages (Steiner *et al.*, 2016).

Animal biodiversity and habitat structure also benefit from appropriate grazing patterns. Schmitz & Isselstein (2020) and van Klink *et al.* (2016) show that grazing regime, more than species, determines structural diversity and ecosystem function. Dumont *et al.* (2020) found that pasture size altered vegetation patchiness, while Fleurance *et al.* (2016) noted positive insect responses to moderate stocking rates. Furthermore, Wróbel *et al.* (2020) highlight how moderate sheep grazing sustains both plant richness and pastoral value in mountain ecosystems. Landscape-level perspectives reinforce these findings. Plieninger *et al.* (2015) identify wood-pastures as biodiversity hotspots tied to cultural values. In a broader EU context, climate

change adds additional complexity Dibari *et al.* (2015) report reduced pasture suitability in the Apennines, threatening grazing-dependent biodiversity. Similarly, Lennartsson & Westin (2023) document how the loss of traditional seasonal grazing affects grassland resilience. At policy level, Roeder *et al.* (2010) and Asheim *et al.* (2020) argue for improved incentives to support pasture-based systems, while Phelps & Kaplan (2017) call for better land-use frameworks integrating biodiversity goals.

Finally, the role of local breeds and traditional practices emerges clearly. Studies from Agradi *et al.* (2023), and Verduna *et al.* (2020) link transhumance and autochthonous livestock to greater landscape heterogeneity and ecological sustainability. Potenza & Fedele (2011) emphasize that well-managed grazing, aligned with agri-environmental rules (e.g. GAEC) of Common Agriculture Policy (CAP), supports floristic richness even in marginal terrains.

3.2.2. Grazing and water use

The management of grazing systems plays a pivotal role in shaping water use efficiency (WUE), with direct implications for soil conservation, hydrological dynamics, and reduced irrigation demand in livestock production. Several studies confirm that that well-managed grazing, such rational grazing, particularly in semi-arid regions, can optimize water use without compromising animal productivity. For instance, Ates *et al.* (2013) showed that deficit irrigation (50–75%) in pasture-based sheep systems improved WUE while maintaining both yield and animal performance.

Beyond water requirements, grazing significantly influences soil structure and hydrological functioning. Moret-Fernández *et al.* (2011) reported that grazing alters the hydro-physical properties of soils, notably reducing infiltration rates and increasing bulk density, particularly in non-gypsiferous substrates. Similarly, Minea *et al.* (2022), observed that small ruminants' grazing intensified surface runoff, reduced infiltration, and increased erosion in hilly and mountainous terrains, ultimately affecting local water balances. Despite such potential risks, appropriately managed grazing can promote hydrological stability and improve resource efficiency. In semi-arid Mediterranean pastures characterized by chalky soils, Moret- Fernández *et al.* (2021) demonstrated that intensive livestock grazing significantly reduced surface water infiltration due to trampling-induced crusting, while having minimal impact on soil matrix water retention. In contrast, moderate grazing intensity did not negatively affect soil hydraulic properties, indicating its potential suitability as a sustainable management strategy for soil conservation under these specific drought conditions.

From a livestock behavior standpoint, Tsiobani *et al.* (2023) observed that water availability influences buffalo spatial distribution in Mediterranean pasture systems, as animals tend to cluster near water points, an effect with notable implications for grazing patterns and landscape pressure. Pasture-based systems also contribute to reducing overall water consumption in meat production. According to Dillon *et al.* (2018), in recent decades, permanent grasslands in Europe have declined by 14%, leading to an increased reliance on irrigated crops for livestock feed. Comparative analyses of production systems indicate that water use to produce 1 kg of beef is 30-50% lower in grazing-based systems compared to intensive systems. Furthermore, grazing contributes to improved soil moisture and reduced evaporation, thereby decreasing the need for artificial irrigation. In support of this, modeling by Simionesei *et al.* (2018) on Portuguese montado systems confirmed that irrigation can increase biomass yield, but also raised transpiration, suggesting that grazing management needs to balance productivity with water use. Grazed pasture, being the lowest-cost and rain-fed feed source in temperate Europe, enhances the self-sufficiency and environmental sustainability of dairy systems by reducing reliance on externally irrigated feed crops and buffering against water-related constraints (Hennessy *et al.*, 2020). Finally, Bernués *et al.* (2011) emphasized that sustainable grazing practices contribute to water security by reducing irrigation needs and improving the resilience of Mediterranean farming systems. Extending the grazing season from 252 to 300 days has been shown to decrease the need for irrigation water and improve the forage self-sufficiency of livestock farms.

3.2.3. Grazing and Carbon Cycle

A growing body of empirical and theoretical research demonstrates that well-managed pasture-based systems play a significant role in enhancing carbon sequestration and mitigating greenhouse gas (GHG) emissions in a variety of agroecological contexts. Tölgyesi *et al.* (2023) highlight the multifunctional benefits of sparse trees in temperate tree pastures in Hungary and Romania, where they achieved increased carbon stocks and biodiversity without compromising livestock productivity. These findings are consistent with those of Smetanová *et al.* (2019), who report that traditional extensive grazing in the Czech Republic maintains higher soil carbon levels than abandoned lands, resulting in benefits for biodiversity and landscape conservation. Complementary findings from Poland show that rotational grazing of deer improves forage quality and alters plant chemical composition (Kulik *et al.*, 2023), while also modulating soil chemical and enzymatic properties (Futa *et al.*, 2024), albeit with a reduction in total organic carbon

during the winter. Studies focusing on carbon footprints also point to the benefits of grazing systems. Morais *et al.* (2018) report lower greenhouse gas emissions per kg of product in extensive grazing systems using local breeds, from the Azores showing a carbon footprint of 0.83 kg CO₂e/kg of milk, among the lowest in Europe. Morais *et al.* (2025) further highlight the variability of GHG emissions (15-124 kg CO₂e/100 g protein), noting that pasture-based systems consistently outperform in terms of emissions reductions. Hessle and Danielsson (2024) estimate that the restoration of semi-natural grasslands in Sweden can be achieved through favourable conservation status, strategic reductions in livestock density rates, and partial mowing. Carswell *et al.* (2024) report that reseeded pastures with legume-rich swards improves nitrogen use efficiency in beef and sheep systems, without significantly increasing productivity, while also enhancing carbon sequestration in established swards.

O'Brien *et al.* (2016) provide life-cycle assessment evidence that moderate intensification improves carbon efficiency in Irish sheep systems, although the results are highly dependent on assumptions regarding soil carbon sequestration. At the system design level, Barron *et al.* (2021) propose an integrated assessment framework for pasture-based dairy sheep farming systems in Spain, identifying soil carbon sequestration as a key sustainability indicator. Meanwhile, Pauler *et al.* (2023) demonstrate that carbon storage in mountain pastures is influenced by topography and climate (e.g., slope, temperature), with higher forage productivity correlating with greater carbon storage but reduced biodiversity, highlighting key ecosystem trade-offs. Recent work by Zhu *et al.* (2023) also confirms that high-resolution satellite data combined with eddy covariance flux towers can reliably extrapolate carbon fluxes at the field scale in managed European grazing systems, offering promising tools to monitor and assess pasture-based climate mitigation strategies.

3.2.4. Grazing and Animal Welfare

Hesselmann *et al.* (2025) demonstrate that allowing dairy cows to graze on multispecies swards supports natural foraging behavior and individual dietary self-selection, enhancing welfare through behavioral autonomy. Similarly, Molle *et al.* (2022) emphasize the role of planned rotational grazing (PTG) in supporting welfare by improving mobility, milk quality, and promoting natural behaviors. The traditional knowledge of shepherds, as documented by Rivera *et al.* (2022), also contributes to welfare, with the use of over 200 medicinal plants for animal care in transhumant systems. The influence of grazing intensity and management was assessed by Crossley *et al.* (2022),

who reported only minor welfare differences between treatment groups, with better locomotor conditions and comfort observed in cows with longer grazing periods. Likewise, Crump *et al.* (2019) found that overnight pasture access improved cow welfare by enhancing lying time, activity, and behavioral synchrony. However, temporary indoor confinement, as shown by Enriquez-Hidalgo *et al.* (2018), negatively affected lying behavior and locomotion, especially in Jersey cows, while O'Driscoll *et al.* (2019) observed reduced lying behavior due to limited pasture allowance. Environmental enrichment and infrastructure also play a key role. Delaby *et al.* (2020) highlight how hedgerows and wooded areas provide shade and shelter, improving thermal comfort and reducing disease risk. Turini *et al.* (2025) confirms this by showing that access to water and shade during hot periods mitigates haemoconcentration and metabolic stress in sheep, compared to animals exposed to harsher conditions. Technological solutions were explored by Marchegiani *et al.* (2025), who report that Precision Livestock Farming (PLF) tools enhance welfare via real-time health monitoring and optimized grazing management, although adoption remains limited. Similarly, Bosona & Gebresenbet (2021) suggest that mobile automated milking systems can promote cow-calf contact and reduce stress in pasture-based setups. McCormick & Stokes (2023) note that GPS collars, if well-managed, offer benefits in extensive systems despite potential welfare concerns related to invisible or fluctuating boundaries. Behavior-based metrics are gaining ground but still face challenges. Aubé *et al.* (2023) found that avoidance distance at pasture (ADP) is not yet a reliable individual-level indicator for human-animal relationship assessment. O'Leary *et al.* (2020) observed that mild and moderate lameness in cows did not consistently correlate with behaviour patterns, suggesting limitations in current accelerometry-based detection. Research in other species reinforces the welfare potential of pasture-based systems. Battini *et al.* (2021) adapted the AWIN (Welfare Indicators Network) protocol for goats and identified generally good welfare, despite concerns about body condition and water access. Agradi *et al.* (2023) and Niero *et al.* (2022) confirm that well-managed alpine and summer pastures support animal health and milk quality without negative impacts on udder health. Welfare implications of landscape use were examined by Larraz *et al.* (2024) who used GPS data to analyze habitat preferences of free-grazing sheep, suggesting better alignment of resource distribution with animal behavior. In a similar ecological context, Rutherford *et al.* (2021) highlight that incorporating surplus male dairy calves into pasture-based beef production systems represents a more welfare-friendly alternative to practices such as long- distance export. Strand *et al.* (2019) highlight a concret concern in outfield systems, predation by large carnivores increases stress, injury, and mortality among sheep, suggesting that welfare benefits

of grazing systems are context dependent. Grodkowski *et al.* (2023) further emphasize that organic certification alone does not always guarantee superior welfare, especially when compared to well-managed conventional systems.

Finally, Ripamonti *et al.* (2024) report no significant welfare differences between cattle raised in silvopastoral and open pasture systems, as evidenced by stable cortisol levels. Avondo *et al.* (2013) link pasture-based feeding to enriched milk and cheese quality, with bioactive compounds that not only enhance product value but may also support animal health.

4. Discussion

While this review focused on the environmental and animal welfare impacts of pasture-based livestock systems in Europe, it is essential to contextualize the findings within a broader sustainability framework, including economic viability and global perspectives.

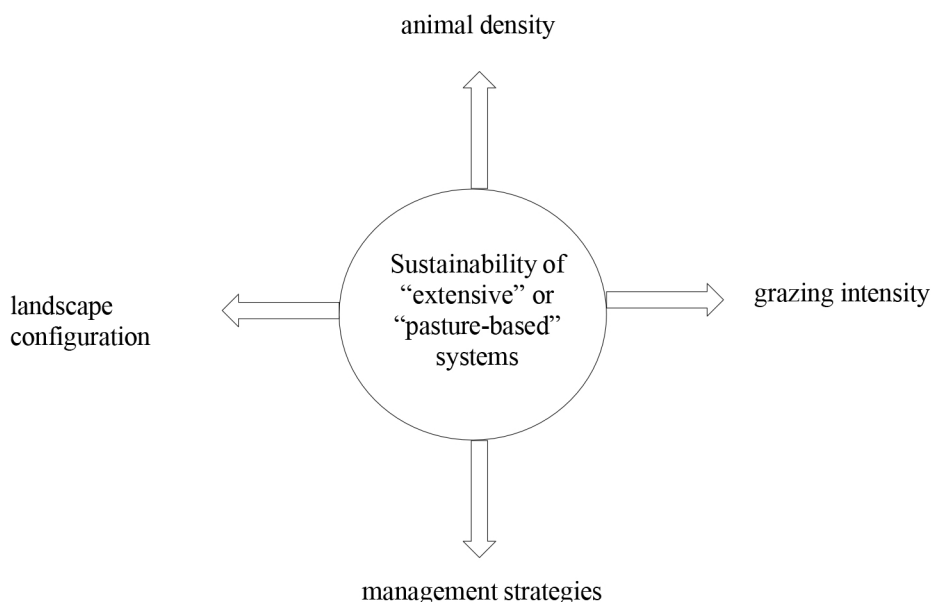
Evidence from non-European studies, in line with this review, highlights substantial variability in sustainability outcomes even among comparable grazing systems. As Broom (2021) argues, the mere classification of a system as “extensive” or “pasture-based” does not ensure sustainability; rather, outcomes depend on context-specific factors, including grazing pressure, animal density, pasture design, and management strategies. For instance, the same rotational grazing model may lead to biodiversity gains in one context and neutral or even negative effects in another, depending on how it is implemented (Ripoll-Bosch *et al.*, 2013). This calls for adaptive and locally informed grazing strategies rather than blanket recommendations.

Moreover, although our review restricted data inclusion to European studies, relevant global literature offers valuable insights that reinforce and expand upon our conclusions. For example, silvopastoral systems in Latin America have demonstrated that integrating tree cover into grazing landscapes can yield positive outcomes for biodiversity, productivity, and animal welfare (Broom *et al.*, 2013; Broom, 2017). These systems offer functionally similar models to Mediterranean agroforestry and could inspire design adaptations in Europe’s southern regions. Additionally, Broom (2022) proposes the use of sustainability scoring to assess the balance of trade-offs across environmental, animal, and economic dimensions a tool potentially adaptable to European contexts.

Crucially, the economic sustainability of grazing systems must be further emphasized. Although often overlooked in environmental reviews, financial viability is essential for long-term adoption by farmers. Studies by Bernués *et al.* (2014) highlight that pasture-based systems contribute to rural livelihoods and resilience, especially in marginal areas where alternative agricultural

models are less feasible. These systems also tend to show lower dependence on external inputs and greater resilience to market volatility, due to self-sufficiency in forage and reduced feed costs (Toro-Mujica *et al.*, 2015; Ripoll-Bosch *et al.*, 2013). Furthermore, as FAO (Chará *et al.*, 2019) notes, despite lower short-term productivity, these systems offer robust long-term benefits for food security and socio-economic stability under climate stress.

Figure 2 - Factors influencing the sustainability of extensive or pasture-based system



Source: Author's elaboration.

Conclusions

This review substantially confirms the contribution of well-managed grazing systems to global agro-environmental sustainability. Properly managed livestock farming systems based on pasture can offer significant benefits across all key sustainability dimensions: environmental, economic, climatic and animal welfare. The analysed scientific evidence indicates that practices such as rotational grazing, holistic management, agro-livestock integration, and adapting grazing practices to local ecological and climatic conditions can improve water use efficiency (WUE), optimise hydrological

dynamics, increase organic carbon sequestration in the soil, and preserve biodiversity without compromising livestock performance. In particular, adopting strategies such as deficit irrigation in pastoral systems in semi-arid regions has been shown to significantly reduce water consumption while maintaining comparable yields, thereby contributing to the ecological resilience of these areas. Conversely, the structure and management of pastures have a profound influence on the physical, chemical and enzymatic properties of the soil, thus confirming the interdependence between livestock practices, soil health and environmental quality. Furthermore, recent research highlights the importance of breed-specific grazing behaviour, grazing time distribution and vegetative structure in determining animal performance and the overall sustainability of systems. Another important factor is animal welfare. Extensive grazing encourages natural behaviour and improves feeding autonomy, promoting better physical and behavioural health in line with the principles of the One Health framework. In particular, in low-input farming, animals play a central role as efficient converters of non-edible plant biomass into animal-based food. For instance, dairy cows transform grass into milk, supporting the circular use of resources and contributing to food security. Increasing the proportion of grazed forage in the annual feed plan is associated with lower production costs, higher profitability, and greater farm resilience. However, these benefits do not occur automatically and depend on several factors, including grazing intensity, infrastructure quality, soil and climate conditions, landscape, and political and institutional support. Integrating traditional knowledge with advanced technological tools, such as sensors, GPS tracking, decision support systems and precision farming technologies, offers concrete prospects for adaptive pasture management in response to climate change and increasing environmental variability. These emerging tools offer promising opportunities to improve the monitoring and optimisation of interactions between animals, vegetation and soil. However, there are still obstacles to adoption and specific challenges, including water scarcity, predation risks and land fragmentation, which require contextualised, multisectoral solutions. In light of this evidence, it is clear that extensive livestock systems can represent a strategic ecological safeguard for landscape regeneration, soil fertility improvement and climate change mitigation, rather than being a threat to the environment. Future agricultural development strategies should therefore recognise the functional role of grazing within an integrated ecosystem approach, promoting targeted support policies and investments in transdisciplinary research, as well as coordinated actions at local, national and global levels. Only through such a systemic, multi-level vision will it be possible to exploit the full regenerative potential of pastoral systems and contribute concretely to achieving global climate, environmental and socio-economic objectives.

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Giulia Pastorelli

Researcher, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: giulia.pastorelli@crea.gov.it

Based at the MASAF technical office within the National Rural Network, she contributes to rural development policies relating to the implementation of the Common Agricultural Policy (CAP) in Italy. Her research focuses on the economic analysis of CAP measures and specifically on animal welfare, organic farming, the circular economy, and biodiversity conservation.
<https://orcid.org/0009-0002-3295-0302>

Ilaria Falconi

Research technologist, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: ilaria.falconi@crea.gov.it

She is a member of the expert group of the European carbon farming. She is a member of the ENRD group of experts on carbon farming. She is a member of the working groups for the National Ecological Transition Plan. She is a member of the EU expert group “Sustainability and quality in agriculture and rural areas - Methane emissions subgroup”.

Maria Assunta D'Oronzio

Senior researcher, CREA Research Centre for Agricultural Policies and Bioeconomy, Potenza (Italy)

E-mail: massunta.doronzio@crea.gov.it

She contributes to rural development policies related to the implementation of the Common Agricultural Policy (CAP) in Italy. Her research focuses on the economic analysis of supply chains, the sustainability of agricultural production, precision and digital agriculture, the circular economy and the conservation of biodiversity. She is the author and co-author of numerous publications and has presented at various national and international conferences.

Raffaella Pergamo

Senior researcher, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: raffaella.pergamo@crea.gov.it

Based at MASAF's technical office within the National Rural Network, she contributes to rural development policies related to the implementation of the Common Agricultural Policy (CAP) in Italy. Her research focuses on the economic analysis of supply chains, the sustainability of agricultural production, precision and digital agriculture, the circular economy and the conservation of biodiversity. She is the author and co-author of numerous publications and has presented at various national and international conferences.



Sustainable water management in viticulture under climate stress: Irrigation requirements and potential of controlled water deficit

Veronica Manganiello^a, Silvia Chiappini^a, Sofia Galeotti^{*,a},
Luigi Tarricone^a, Raffaella Pergamo^a

^a CREA Council for Agricultural Research and Economics, Italy

Abstract

Climate change is forcing a fundamental revision of water management in agriculture, particularly in Mediterranean viticulture. In Italy, rising average temperatures, irregular rainfall patterns, and the frequent occurrence of extreme events are reducing water availability and quality, compromising both yields and the quality of grape and wine production. This study presents a technical and scientific analysis of the current state of irrigation in Italian vineyards, integrating data from the 7th General Agricultural Census by ISTAT (2020) with information from the SIGRIAN system, and adopting a geospatial approach to estimate the actual water requirements of grapevines. Furthermore, the benefits of Regulated Deficit Irrigation (RDI) are explored as a means to increase water use efficiency without compromising enological parameters. The results highlight significant territorial differences in water needs and irrigation management, underscoring the necessity for adaptive policies and site-specific technologies.

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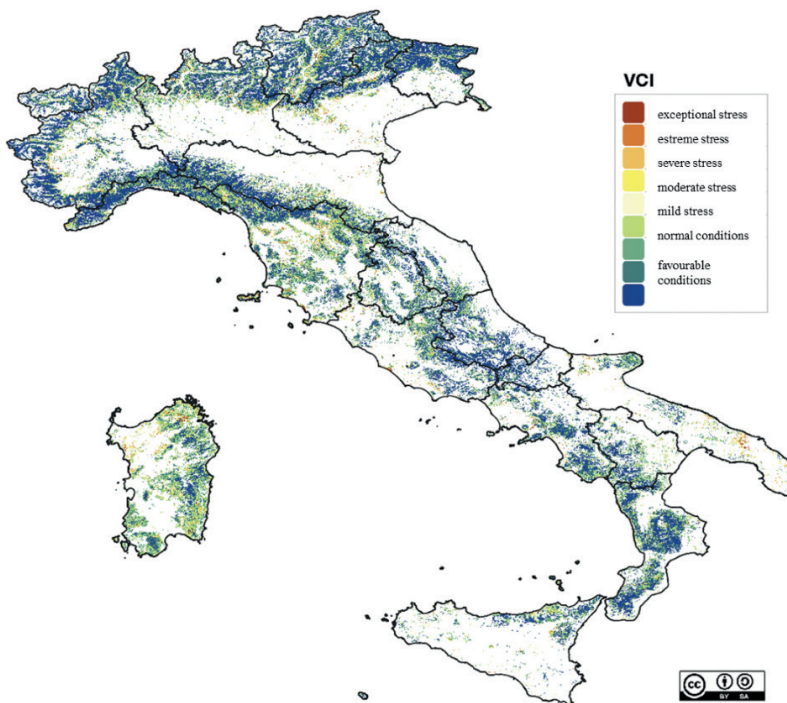
Valeria Borsellino
Søren Marcus
Pedersen

* *Corresponding author:* Sofia Galeotti - CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy). E-mail: sofia.galeotti@crea.gov.it.

Introduction

The Italian wine sector, one of the most significant worldwide in terms of vineyard area, added value, and territorial identity, is currently severely threatened by increasing climate instability. According to data from the Copernicus Climate Change Service, 2024 was the warmest year ever recorded in Europe. Italy has also shown clear signs of this warming trend. During the summer of 2024, many areas in southern Italy and along the Mediterranean coasts experienced temperatures exceeding 38 °C, while the 2024-2025 autumn-winter season was characterized by anomalously persistent warmth. Water stress, resulting from both low precipitation and increased evapotranspiration, negatively affects vegetative growth, phenology, and grape must quality. These impacts are also detectable through the analysis of vegetation indices such as the Vegetation Condition Index (VCI) (Figure 1), which highlighted particularly severe criticalities in the southern regions and the islands (Magno, 2025).

Figure 1 - Vegetation Condition Index (VCI) – June 2025



Source: CNR IBE Drought Observatory (2025).

As a result of the increasing pressure exerted by climate change on water resources, a significant rise in irrigation demand is expected for the main Mediterranean crops, including maize, wheat, and grapevines, with estimated increases ranging from 10% to 16% between 2035 and 2065. This trend is exacerbating water scarcity at the national level, intensifying competition among various water uses – agricultural, domestic, and energy-related – and jeopardizing the sustainability of agricultural production. Within this context, viticulture emerges as one of the most vulnerable crops to climate variations, owing to its high sensitivity to water and heat stress and the pivotal role of enological quality along the production chain.

Italian wine producers are currently facing profound structural and environmental transformations that impact the entire production cycle, from varietal and rootstock selection and water resource management to grape maturation for the determination of wine quality attributes. Recent studies have investigated these processes extensively. For instance, Alba *et al.* (2024) demonstrated that global warming is altering grapevine phenological cycles, directly affecting grape composition and consequently wine quality. Meanwhile, Esposito *et al.* (2024) underscore the critical role of technological innovation and institutional governance in fostering integrated and sustainable management of agricultural water resources. With climate change becoming increasingly apparent, the scientific community is intensifying research on sustainable and climate-resilient grapevine varieties and viticultural practices aimed at mitigating the adverse effects of changing climatic conditions. Di Vita *et al.* (2024) provide a noteworthy example within this research domain, focusing specifically on consumer perception and acceptance of innovative strategies designed to enhance the adaptability of viticulture to climate change. The rapid advancement of climate change necessitates a systematic examination of viticulture, both in Italy and Europe. Gerbi and De Paolis (2025) highlight how agronomic conditions of the main Italian wine-growing areas are substantially altered, leading to imbalances between technological and phenolic maturation, early harvest times and a worsening of the balance between sugars, organic acids and aromatic compounds. From a medium-long term perspective, it is therefore strategic to also act on the genetic front. The international literature has been reviewed by Baltazar *et al.* (2025) and they have highlighted how varietal selection, and the introduction of more resilient clones or cultivars can serve as fundamental tools for adapting to climate change. Another critical problem is the scarcity of water resources: the intensification of stressful situations requires adaptation strategies such as emergency irrigation, which can only buffer such situations but highlight problems of economic and ecological sustainability, especially in a scenario of competing uses (Bentivoglio *et al.*, 2024).

In response to these challenges, this study aims to provide a comprehensive analysis of the current state of vineyard irrigation in Italy,

with the goal of identifying effective adaptation strategies to cope with increasing climate variability. Particular attention is given to the potential of advanced irrigation technologies, emphasizing the role of smart irrigation systems and Regulated Deficit Irrigation (RDI) as promising approaches to enhance water use efficiency while maintaining enological quality.

The methodological framework integrates official data sources, including the 7th General Agricultural Census (ISTAT, 2020) and technical-operational datasets from the National Information System for Agricultural Water Resource Management (SIGRIAN). This integration enables a spatially detailed reconstruction of irrigated vineyard areas and their actual water requirements, distinguishing between collective and autonomous water supply systems.

Beyond quantifying irrigated surfaces, the study estimates irrigation volumes required for grapevine cultivation through spatially explicit models that incorporate climatic, topographic, and soil parameters. Given the increasing meteorological uncertainty, adopting harmonized national methodologies is crucial for improving the accuracy of irrigation demand estimations, facilitating interregional comparisons, and ensuring consistency in territorial-scale assessments.

The findings constitute a valuable knowledge base to better inform adaptation strategies, investment planning, and water resource allocation, aligning with the objectives of the Common Agricultural Policy (CAP) and the European regulatory framework on sustainable water management (Díaz *et al.*, 2021; Kyriakopoulos *et al.*, 2023).

Finally, although climate change represents a significant challenge for the viticulture sector, it simultaneously acts as a catalyst for the adoption of technical and managerial innovations. This study also explores how irrigation practices in viticulture are evolving in response to increasing water scarcity and examines the contribution of smart technologies, including RDI systems, in enhancing resource use efficiency and sector resilience.

1. Economic and territorial evolution of irrigated viticulture

Climate change is driving profound structural and functional transformations in Italian viticulture, a strategic sector for national agriculture both economically and in terms of identity. Rising average temperatures, increased frequency of extreme events (such as prolonged droughts, heatwaves, and intense rainfall), and growing inter- and intra-annual climate variability are significantly affecting vine phenology, grape quality, and agronomic practices adopted by winegrowers.

Among the most tangible effects is a progressive shift of vineyards towards hilly or mountainous areas, in an effort to mitigate thermal stress and preserve the organoleptic characteristics of wine production. This shift is

associated with local ecosystem imbalances, potentially impacting the socio-economic system linked to high-quality wine production (Guadagno, 2012).

To assess the recent evolution of irrigated viticulture in Italy, an analysis was conducted using data from the 6th and 7th General Agricultural Censuses (ISTAT, 2020).

Regarding structural aspects, the 2020 Agricultural Census data indicate over 52,000 farms in Italy with irrigated vineyard areas. However, the territorial distribution of these farms is highly uneven, reflecting regional differences in irrigation intensity and production characteristics. This analysis adopts the territorial classification based on ISTAT's official macro-geographical areas: North-West, North-East, Centre, South, and Islands.

Northeastern Italy remains the area with the highest concentration of irrigated vineyards, hosting nearly half of Italy's irrigated wine farms, led by Veneto (over 10,000 farms), followed by Trentino-Alto Adige and Emilia-Romagna. This high concentration reflects the area's strong viticultural specialization, supported by an efficient irrigation infrastructure system.

In Southern Italy, the distribution is heavily concentrated in Apulia, which alone accounts for over one quarter of the national total. Other southern regions such as Campania, Calabria, and Abruzzo also show a significant presence of irrigated farms, albeit in smaller numbers.

Central Italy exhibits a more limited presence of irrigated vineyards, both in absolute and relative terms. Viticulture in these areas tends to be less dependent on irrigation and often characterized by smaller farm sizes. The most representative regions are Lazio and Tuscany.

Finally, in Northwestern Italy, a relatively modest yet homogeneous presence of irrigated vineyards is observed across Piedmont, Lombardy, Liguria, and Valle d'Aosta. The major islands (Sicily and Sardinia) also have a significant number of irrigated farms, consistent with the historical and productive importance of the viticulture sector in these regions (Table 1).

Table 1 - Farms with irrigated vineyard areas (n.) - Year 2020

Italy	Farms (n.)	%
North-West	2,289	4.3
North-East	25,661	48.4
Centre	1,593	3.0
South	16,504	31.2
Islands	6,931	13.1
Total	52,978	100.00

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020).

The intracensal comparison reveals a significant increase in irrigated vineyard areas, which grew from 176,007 hectares in 2010 to 223,779 hectares in 2020 (+27.1%). In contrast, the total irrigated area across all crops experienced a contraction of 2.5%, decreasing from 2,418,921 to 2,358,264 hectares during the same period.

This trend confirms the growing importance of irrigation in the viticulture sector, likely attributable both to increased exposure to water stress events and to the need to meet the high-quality standards demanded by the market. Furthermore, this expansion can be interpreted as indicative of a process of technical modernization and increasing specialization among Italian wine-producing farms (Table 2).

Table 2 - Irrigated areas for crops – vines (ha). Years 2010 and 2020

Crops	Irrigated area 2010 (ha)	Irrigated area 2020 (ha)	Variation 2010/2020 (%)
Vines	176,007	223,779	27.1
Total	2,418,921	2,358,264	-2.5

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020).

The disaggregated analysis of irrigated vineyard areas, based on data from the 2020 General Agricultural Census, allows for an in-depth examination of the territorial dynamics characterizing the growth of the viticulture sector during the 2010-2020 decade. The territorial classification, based on the official ISTAT macro-geographical areas, highlights a strong concentration of irrigated vineyard surfaces in the North-East and South.

Among individual regions, Apulia confirms its leading position with 64,589 hectares (28.9% of the national total), followed by Veneto with 51,511 hectares (23.0%) and Sicily with 25,638 hectares (11.5%). Significant irrigated areas are also found in Emilia-Romagna (25,697 hectares, 11.5%), Friuli-Venezia Giulia (15,026 hectares, 6.7%), and Trentino-Alto Adige (12,541 hectares, 5.6%).

The aggregated distribution by macro-area shows that:

- North-East regions (Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, Emilia-Romagna) account for 46.8% of the national irrigated vineyard area (approximately 104,787 hectares);
- South regions (Abruzzo, Molise, Campania, Apulia, Basilicata, Calabria) total 73,113 hectares (32.7%);

- Islands (Sicily and Sardinia) collectively reach 32,702 hectares (14.6%);
- Centre (Tuscany, Umbria, Marche, Lazio) amounts to 9,229 hectares (4.1%);
- North-West (Piedmont, Valle d'Aosta, Liguria, Lombardy) totals 4,458 hectares (2.0%).

Based on these data, it can be stated that the North-East represents the geographical area with the highest concentration of irrigated viticulture, covering nearly half of the national extent. This is followed by the South and the Islands, which together account for approximately 47% of the total. This distribution reflects the combination of climatic factors, infrastructural availability, and regional specialization in wine production (Table 3).

Table 3 - Irrigated area with vines (ha) - Year 2020

Italy	Irrigated area (ha)	%
North-West	4,458.33	1.99
North-East	104,775.61	46.82
Centre	9,229.63	4.12
South	72,613.46	32.45
Islands	32,702.02	14.61
Total	223,779.05	100.00

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020).

In Italy, a very large share of irrigated vineyard areas – approximately 95% – lacks specific information on the type of irrigation system used, according to data from the 2020 Agricultural Census. This information gap represents a significant obstacle to assessing the technical and environmental performance of irrigation systems employed in the wine sector.

Among the declared types, the most common are:

- sprinkler irrigation, adopted in a minority yet notable portion of the reported areas;
- micro-irrigation, typically associated with drip or low-flow systems, offering potentially high efficiency in terms of water savings;
- surface runoff irrigation, a traditional technique still present in some areas.

Less suitable methods, such as flooding, are marginal and statistically negligible. The limited diffusion of documented advanced techniques, and especially the large share of unclassified areas, highlight the need to update and enhance existing information systems to support more informed and sustainable irrigation decisions (Table 4).

Table 4 - Irrigation systems - Year 2020

Irrigation systems	No irrigation systems (ha)	Surface runoff and lateral infiltration (ha)	Submersion (ha)	Aspersión (ha)	Micro-irrigation (ha)	Other systems (ha)	Total (ha)
Vines	212,199.88	1,445.92	51.76	7,484.85	1,384.55	1,212.09	223,779

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020).

The intercensal analysis of the number of farms with irrigated vineyard areas active in both 2010 and 2020 allows the evaluation of the structural stability of the Italian irrigated viticulture sector, as well as the identification of possible dynamics of abandonment, reconversion, or business reorganization that occurred over the decade.

Overall, 35,930 farms with irrigated vineyards were active in both censuses. Their regional distribution highlights greater continuity in well-established and highly specialized wine-producing areas, such as:

- Apulia (9,254);
- Veneto (6,505);
- Emilia-Romagna (4,405);
- Sicily (3,369).

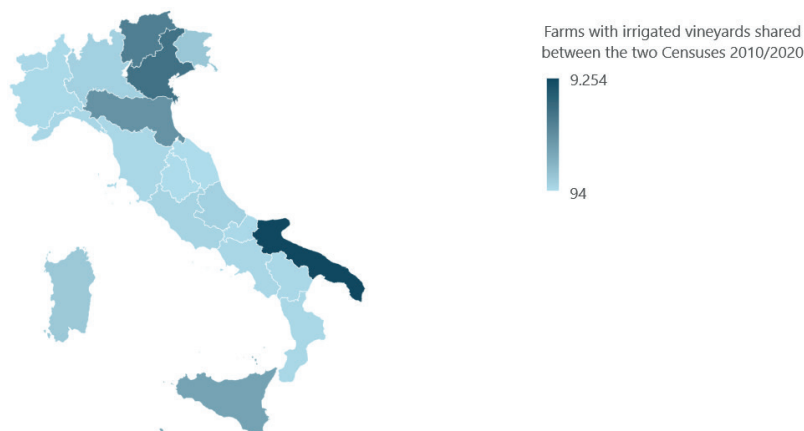
These territories exhibit a stable production structure, supported by a consolidated viticultural tradition and relatively organized irrigation systems.

Conversely, regions such as Umbria (94 farms), Marche (100 farms), Molise (213 farms), and Aosta Valley (296 farms) show much lower levels of business continuity. This reduced persistence can be interpreted either as an indicator of a lower incidence of irrigation in local vineyards or as a sign of productive restructuring and crop conversion processes.

Overall, the northern and north-central regions show greater stability in the number of irrigated vineyards, whereas the South presents a more heterogeneous situation. Apulia represents a significant exception due to its high number and continuity of farms, while other southern regions – particularly Calabria and Basilicata – display lower levels, reflecting a less structured incidence of irrigation within the local production structure (Figure 2).

From an economic perspective, to estimate the potential annual value of Italian wine production, the average Standard Output (SO) indicator was adopted. This metric, calculated based on yields and average market prices, is standardized at the European level and enables comparisons of economic productivity across crops, farming systems, and territorial contexts, providing a useful reference for structural analyses and profitability assessments.

Figure 2 - Distribution of farms with communal irrigation systems – 2010-2020



Source: CREA data processing based on data from the ISTAT General Agricultural Census, 2010-2020 (2025).

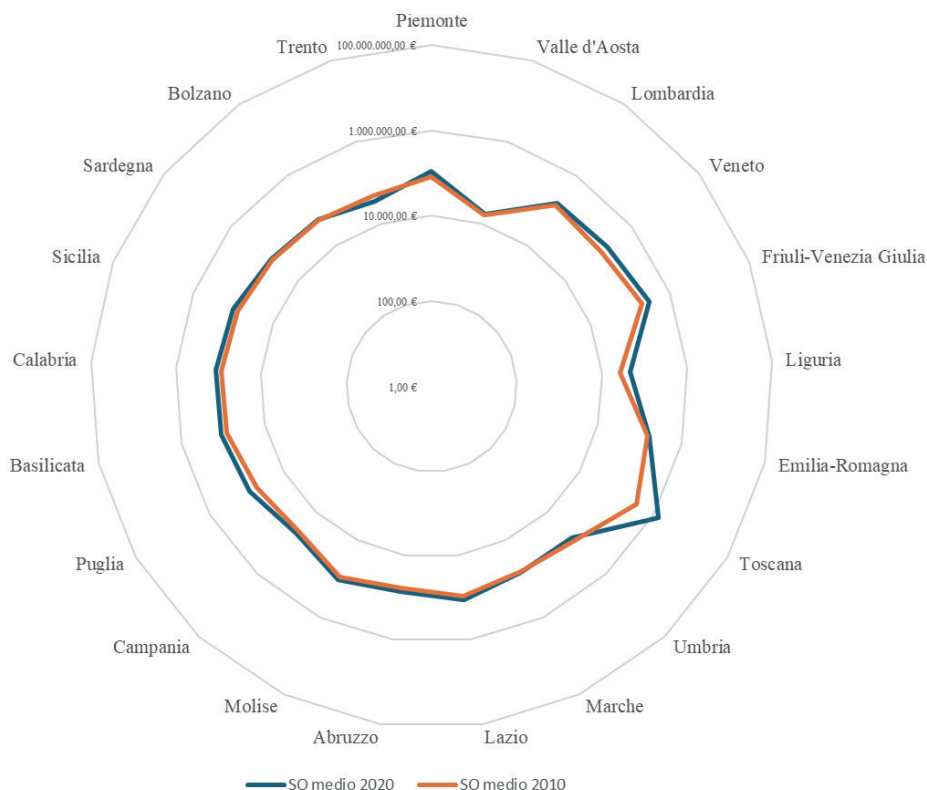
Specifically, the estimate considered the set of farms active with irrigated vineyard areas in both 2010 and 2020, to evaluate the evolution of economic productivity over the decade under consistent structural conditions. At the national level, the average SO value for these farms registered a significant increase of +29%, reflecting a general process of strengthening competitiveness and enhancing the commercial value of the sector.

Among the regions showing the most dynamic performance, Tuscany stands out with an SO increase of +75.8%, followed by Veneto, Friuli-Venezia Giulia, and Apulia. These results indicate an evolutionary process affecting both productive aspects and those related to the quality and marketing of wines, in a context increasingly oriented towards high added-value markets.

Conversely, negative trends were observed in some areas, including Umbria and the Autonomous Province of Trento, which recorded a decrease in average SO of -20.6% and -39.4%, respectively. These trends may be associated with specific transformations in the production fabric, changes in market outlets, or difficulties in technological reconversion.

Overall, farms located in the North-East and North-Central regions tend to show higher average SO levels compared to those in the South. However, some southern realities, particularly Apulia, show encouraging signs of economic growth, confirming the existence of competitive development pathways even in historically less structured contexts (Figure 3).

Figure 3 - Average of Standard Output of irrigated farms with wine in common. Years 2010-2020



Source: CREA data processing based on data from the ISTAT General Agricultural Census. 2010-2020 (2025).

2. Materials and methods

The objective of the developed methodology is to estimate the actual irrigation water requirements of vineyards in Italy through a spatially explicit and standardized approach at the national scale, using the year 2020 as the temporal reference for the analysis. Given the strategic importance of viticulture within the Italian agricultural system and its high vulnerability to climate change impacts, it is essential to have reliable and harmonized analytical tools to support irrigation planning and guide effective adaptation strategies.

The adopted approach is based on the integration of census and agro-climatic data, aiming to overcome information fragmentation and provide

a coherent and comparable estimate of irrigation volumes required by vineyards across different territorial contexts. This standardization is particularly important to ensure a homogeneous assessment of actual irrigation demand at the national level, facilitating comparisons between regions and the identification of priority interventions from the perspectives of efficiency and sustainability (Andrenelli *et al.*, 2025; Ortuani *et al.*, 2019).

2.1. Materials: WebGIS SIGRIAN e ISTAT

The analysis is based on the integration of two main data sources: the National Information System for the Management of Water Resources in Agriculture (SIGRIAN) and the official dataset of the Italian National Institute of Statistics (ISTAT). The objective is to coherently estimate the actual irrigation water requirements of Italian viticulture at a territorial scale.

WebGIS SIGRIAN

SIGRIAN constitutes the main geographic information system (GIS) for the national irrigation sector, developed and managed by CREA – Policies and Bioeconomy (CREA PB). It collects, archives, and makes available both alphanumeric and spatial information related to water management in agriculture, through collaboration among Regions, reclamation consortia, and other managing bodies. The data are organized in a geodatabase structured by territorial units, enabling the association of technical variables (e.g., flow rates, volumes, crops) with specific portions of the national territory.

The spatial unit adopted for this study is the irrigation district¹, defined as the elementary portion managed by each Consortium. For each district, the official shapefile available in the SIGRIAN WebGIS was used, to which the corresponding Annual Specific Volume (ASV) values, expressed in m³/ha/year, were associated. The ASV represents the average annual volume of water distributed per hectare, calculated based on the actual pedoclimatic, crop, and management conditions of the district. Therefore, it is a direct indicator of real irrigation water requirements, useful for a quantitative and spatially explicit representation of irrigation demand at the national scale.

1. Division of the irrigation area and therefore of the Local Agency for Water Management, whose criteria vary greatly. In general, the subdivision is based on the development of the distribution network, i.e., the district includes an area supplied by its own distributor (CREA PB, 2020).

ISTAT

ISTAT represents the main official source of statistical data in Italy. In the context of the present study, data from the 7th General Agricultural Census (2020) were utilized, with particular reference to the irrigated Utilized Agricultural Area (UAA) by crop and by municipality.

These data enabled the quantification of the spatial distribution of irrigated vineyard areas across the entire national territory, providing essential information for the calculation of territorial irrigation requirements. The association between irrigated vineyard UAA data (at the municipal level) and the ASV derived from SIGRIAN allowed for the estimation of total irrigation volumes by geographic area, and the construction of a synoptic and standardized framework of irrigation pressure in the Italian viticultural sector.

2.2. Vineyards irrigation requirements

The methodology developed in this study is structured into four main phases, aimed at estimating the actual irrigation requirements of vineyards in Italy through a standardized geospatial approach:

1. classification of water supply modes, distinguishing between areas managed collectively, through Irrigation Water Services (IWS)² and those under Self-Supply (SS)³;
2. definition of homogeneous areas at the national level based on climatic, physiographic, biogeographic, and hydrographic characteristics, through the overlay of environmental variables (altitudinal bands, ecoregions, river basins);
3. assignment of a unique average ASV value to vineyards within each homogeneous area, based on SIGRIAN data;
4. calculation of the specific irrigation requirement for vineyards as the product of the municipal-level irrigated UAA and the average ASV value corresponding to the respective area.

For the agricultural component, data from the 7th General Census of Agriculture were used, including:

- the irrigated UAA by crop category, available at the municipal level;

2. The set of activities and infrastructures for the supply and distribution of water for irrigation purposes, managed according to criteria of efficiency, sustainability, and current regulations.

3. Farms that independently meet their irrigation water needs by using their own water resources, such as wells, rainwater harvesting, or small reservoirs, without relying on external water supply services.

- the official ISTAT altitudinal bands⁴;
- the Italian ecoregions⁵, hierarchically subdivided into subsections, sections, provinces, and divisions (according to the national classification).

These data were integrated with geospatial information provided by SIGRIAN 2020, in particular the shapefile of irrigation districts, each associated with an ASV expressed in m³/ha/year per crop. Through vector overlay in a GIS environment, an intersection was performed between the polygons of the SIGRIAN districts and the ISTAT (2020) municipal administrative boundaries, thus enabling the assignment to each municipality (or portion thereof) of the prevailing water supply modality (Collectively, thus through IWS – or SS) (Galeotti *et al.*, 2025; Manganiello *et al.*, 2022).

However, in some areas of the country, SIGRIAN data are incomplete or missing. To overcome this limitation, homogeneous areas were delineated by overlapping altitudinal bands and ecoregions to extend the average ASV value of known districts to contiguous territories with similar pedoclimatic conditions (Ahmadpour *et al.*, 2022; Busschaert *et al.*, 2022). In the absence of data at the subsection level, a hierarchical criterion was applied to extend the average to higher levels (subsection → section → province → division).

Calculation formula

The irrigation requirement for vineyards was then calculated first at the municipal level and subsequently aggregated by macro-areas, as the product of the irrigated vineyard area and the associated mean ASV value, according to the following expression (1):

$$\frac{\text{Total Irrigation Requirements}_{\text{Geographical area}}}{\text{Unit Irrigation Requirements}_{\text{vineyard, municipality}}} = \sum \left(\text{Area}_{\text{vineyard, municipality}} \cdot \right) \quad (1)$$

Where:

- $\text{Total Irrigation Requirements}_{\text{Geographical area}}$ = The total irrigation requirement for vineyards in the considered geographical area was calculated as the sum of the irrigation needs (expressed in m³/year).
- $\text{Irrigated Area}_{\text{vineyard, municipality}}$ = Irrigated vineyard area (ha) in the municipality;

4. Main Geographical Statistics of Municipalities-ISTAT.

5. Areas identified based on a hierarchical and divisive classification of the territory into units with increasing levels of homogeneity, consistent with specific combinations of climatic, biogeographic, physiographic, and hydrographic factors that influence the presence and distribution of different species, communities, and ecosystems. Classification of Municipalities according to Italian Ecoregions – ISTAT.

- *Unit Irrigation Requirements*_{vineyard,municipality} = ASV for vineyards in the considered municipality (m³/ha/year).

3. Results and discussion

The methodology described in Section 2.2 enabled the results summarized in Tables 5 and 6. The national irrigation water requirement for grapevine cultivation in 2020 was estimated at 1,122,037,753.37 m³/year, resulting from the combined contributions of IWS and SS sources. Specifically, as shown in table 5, the IWS system accounted for 516,520,454.76 m³/year, corresponding to 46.03% of the national requirement, while SS irrigation (Table 6) represented the predominant share with 605,517,298.60 m³/year (53.97%). The spatial distribution of irrigation water requirements shows a clear predominance of North-East Italy area in both supply systems. This area is the main consumption basin, with 474.2 million m³/year irrigated through IWS (91.81% of the volume distributed through the network) and 470.4 million m³/year under SS irrigation (77.69% of the total SS). This concentration reflects both the significant extension of vineyard areas in the North-East and the high unit irrigation requirement, 8,681.66 m³/ha/year for IWS and 8,112.33 m³/ha/year for SS, respectively.

Southern Italy ranks second in terms of total irrigation volumes for both systems, with percentages lower than those of the North-East (3.46% for IWS and 10.6% for SS). In this area, lower unit requirements are also observed,

Table 5 - Unit and total irrigation water requirements per geographical area through Irrigation Water Service (IWS)

Geographical area IWS	Area (ha)	Unit Irrigation Requirements (m ³ /ha/year)	Total Irrigation Requirements (m ³ /year)	Total Irrigation Requirements (%)
Centre	443.99	2,608.11	448,293.07	0.09
Islands	4,491.67	1,257.58	6,266,776.80	1.21
North-East	55,327.55	8,681.66	474,206,497.05	91.81
North-West	1,940.55	7,840.31	17,751,574.43	3.44
South	16,313.97	2,969.54	17,847,313.41	3.46
Total	78,517.73	6,726.29	516,520,454.76	100.00

Source: CREA processing of ISTAT General Agricultural Census data (2020) and SIGRIAN (2020).

Table 6 - Unit and total irrigation water requirements per geographical area under Self-Supply Irrigation System (SS)

Geographical area SS	Area (ha)	Unit Irrigation Requirements (m ³ /ha/year)	Total Irrigation Requirements (m ³ /year)	Total Irrigation Requirements (%)
Central	8,785.64	5,086.57	15,995,964.73	2.64
Islands	28,210.35	1,167.99	34,076,177.42	5.63
North-East	49,448.06	8,112.33	470,433,753.58	77.69
North-West	2,517.78	8,665.86	20,801,149.44	3.44
South	56,299.49	4,722.59	64,210,253.42	10.60
Total	145,261.32	6,437.02	605,517,298.60	100.00

Source: CREA data processing based on data from the ISTAT General Agricultural Census (2020) and SIGRIAN (2020).

with values of 2,969.54 m³/ha/year for surfaces served by IWS and 4,722.59 m³/ha/year for those under SS.

Central Italy stands out for a marginal irrigation demand in both systems, with volumes below 450,000 m³/year for IWS (0.09% of the total) and approximately 16 million m³/year for self-supplied irrigation (2.64%). However, although Central Italy presents the lowest overall irrigation demands, the Islands register the minimum values of unit irrigation requirements.

Overall, the data highlight a marked geographical gradient in the irrigation water requirements of vineyards, attributable to differences in the distribution of vineyard areas, regional climatic conditions, and irrigation practices adopted across the different supply systems.

3.1. Advanced irrigation techniques and Regulated Deficit Irrigation (RDI)

Regulated Deficit Irrigation (RDI) in viticulture is an increasingly studied and applied agronomic strategy aimed at efficiently managing water resources while improving grape quality. Although grapevines are well adapted to the hot and dry Mediterranean climates, water scarcity remains a major constraints limiting photosynthesis, growth, and productivity. The effects of water stress do not manifest immediately but gradually impact plant development, varying according to the phenological stage at which they occur. For example, early-season water deficits can reduce shoot growth or

cause flower abortion, whereas excessive irrigation during the final ripening stages may lower grape quality by reducing sugar content. Therefore, the use of RDI techniques rely on targeted irrigation interventions limited to specific phases of the vine's life cycle, aiming to induce moderate stress that enhances grape quality without penalizing productivity. Effective application requires precise monitoring of the plant's water status. While soil-based indicators may be imprecise, physiological indicators such as stem water potential and stomatal conductance provide more direct and reliable information. Modern viticulture, especially in warm-arid contexts and under changing climate conditions, increasingly focuses on strategic water use. Deficit irrigation techniques not only help save water resources but also enhance the qualitative potential of grapes by increasing phenolic compound concentrations and improving the organoleptic characteristics of wine. In this context, every irrigation decision – from timing to water volume supplied – must be carefully calibrated based on vineyard-specifics and climatic conditions, aiming to improve water use efficiency and making viticulture more sustainable and resilient. Several studies have demonstrated that RDI, combined with monitoring systems (e.g., soil moisture sensors, water balance predictive models), can reduce water use by 25% to 40% while maintaining stable yields (Ahmadpour *et al.*, 2022; Ortuani *et al.*, 2019). However, its effectiveness is strongly influenced by local factors (climate, cultivar, soil type) and requires attentive and flexible agronomic management. In the Italian context, the adoption of RDI techniques remains limited but growing, especially in areas with restricted water access or where high-quality objectives are pursued (Losciale *et al.*, 2024). Although original experimental data were not analyzed in this study, the discussion is based on evidence from scientific literature. The following section presents the main results from reviewed studies and described indices, focusing on agronomic and economic aspects of viticulture and irrigation management, with the goal of deriving concluding remarks and practical insights.

4. Conclusions and limitation of the work

Italian viticulture is currently in a critical phase of adaptation because of increasing climatic pressures, such as reduced rainfall, increased evapotranspiration, and more frequent extreme weather events. These factors are transforming the water cycle in many wine-growing regions, making irrigation increasingly necessary, even in areas that have traditionally not relied on it. Non-irrigated vineyards are particularly vulnerable to prolonged droughts and heatwaves, which have a negative impact on yield, grape quality and the physiological health of the plant. In this context, accurate

and detailed knowledge of the water requirements of vines is fundamental to developing sustainable irrigation strategies and effective public policies for water resources management. Quantifying irrigation requirements precisely allows water application to be optimised, reducing waste and preserving increasingly scarce water resources. This information is also essential for implementing innovative agronomic practices such as RDI, which involves strategically modulating the water supply during sensitive phenological stages to improve water use efficiency and fruit quality.

Spatial analyses based on ISTAT and SIGRIAN datasets confirm the expansion of irrigated areas by 27.1% between 2010 and 2020. This growth underscores the increasing dependence of the Italian wine sector on water resources, particularly in north-eastern regions where advanced infrastructure enables the intensive use of irrigation technologies. However, this evolution also highlights the increasing territorial heterogeneity of irrigation needs, driven by climatic, pedological, varietal and infrastructural factors.

In this context, an analytical and methodological approach capable of operating at a fine territorial scale – i.e. at the level of the winegrowing micro-region – is indispensable. Collecting climatic data (e.g. precipitation, temperature, evapotranspiration, extreme events), soil data (e.g. available water capacity, texture, useful depth), agronomic data (e.g. varieties, rootstocks, phenology, cultivation practices) and socio-economic data (e.g. costs, regulatory constraints, access to technology) enables the creation of water balance models tailored to specific environments and vineyards.

These models, fed by field sensors, localised meteorological data and digital technologies such as GIS, DSS and IoT, enable more accurate estimates of actual water requirements and facilitate the implementation of adaptive, localised irrigation strategies.

The study therefore proposes an innovative methodology for estimating the irrigation requirements of vines based on harmonised national-scale datasets. Data uniformity is a key development in this study, overcoming one of the main issues encountered in large-scale irrigation planning so far: information heterogeneity and fragmentation. Integrating data from official sources (ISTAT, SIGRIAN) provides a consistent national-level overview, useful for supporting policymakers in defining targeted, science-based strategies. These strategies align with the United Nations Sustainable Development Goals (SDG 6: Clean Water and Sanitation; SDG 13: Climate Action) and the priorities of the 2023-2027 Common Agricultural Policy, which promotes climate adaptation, resource efficiency, and the adoption of innovative technologies. However, the use of data still faces significant limitations in terms of availability, quality, and consistency of sources. The European Water Resilience Strategy aims to overcome these challenges by promoting a

more robust and integrated information base, which is essential for accurate planning and sustainable management of water resources across all sectors.

In this context, the European Water Resilience Strategy 2025 further emphasizes the importance of a ‘Water Efficiency First’ approach. The aim is to improve water use efficiency by 10% by 2030 through integrated governance, innovation, and research measures (EU, 2025). Aligned with these objectives, the Common Agricultural Policy (CAP) financially supports investments in precision irrigation technologies and digital agriculture, encouraging the adoption of smart systems that combine production efficiency and environmental sustainability.

The proposed methodological framework can therefore provide a solid scientific basis for guiding these investments and promoting the development of Irrigation Advisory Services (IAS), which can provide farmers with localised, data-driven recommendations. However, limitations remain, particularly with regard to the spatial resolution of the available data. Aggregating information by macro-areas (e.g. ISTAT ecoregions) inevitably results in a loss of local detail and risks overlooking important intra-territorial differences in actual irrigation demand.

In conclusion, accurately assessing the water needs of vines and adopting targeted, evidence-based irrigation techniques is crucial for ensuring the sustainability, quality and resilience of Italian viticulture. Only a scientifically based, technologically advanced, and territorially differentiated approach can effectively address the challenges posed by climate change and the growing scarcity of water resources.

Conflicts of interest

None. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Veronica Manganiello

Research technologist, CREA Research Centre for Agricultural Policies and Bioeconomy, Naples (Italy)

E-mail: veronica.manganiello@crea.gov.it

The author holds a master's degree in biotechnology and a PhD in Economy, Management, and Quantitative Methods, with a research focus on Circular Economy. She is responsible for the SIGRIAN database (National Information System for Water Resources Management in Agriculture) and collaborates on various projects related to agricultural water resource management, with particular attention to environmental and agricultural policies. She also coordinates several institutional agreements and initiatives at both national level and within river basin authorities, aimed at improving the governance and sustainable use of water resources in agriculture. She is co-author of several scientific and technical publications on water use in agriculture.

<https://orcid.org/0000-0003-0348-6600>

Silvia Chiappini

Researcher, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: silvia.chiappini@crea.gov.it

The author holds a master's degree in economics, management, finance and business law and a PhD in Quantitative Methods for Economics and Territory. She started working in 2016 at CREA PB. Her research has focused on rural districts and rural development policies. Her areas of expertise include community programming, sustainable agriculture and managing water resources for irrigation. She has participated in working groups and permanent observatories on water use and carried out analysis and evaluation of national and community policies related to irrigation and environmental sustainability. She has provided technical and scientific support for public policies by analysing and developing proposals for integrated water resource management in agriculture that align with rural development objectives and environmental policies. She has also participated in conferences and seminars.

<https://orcid.org/0009-0006-8763-6766>

Sofia Galeotti

Technical Collaborator-VI Level, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: sofia.galeotti@crea.gov.it

The author holds a master's degree in Agricultural and Environmental Sciences and a PhD in Economics, Management and Quantitative Methods. She started working in 2020 as a research fellow at CREA-PB, focusing on strategies for water resource management in agriculture.

<https://orcid.org/0009-0001-8903-3997>

Luigi Tarricone

Senior researcher, CREA Research Centre for Viticulture and Enology, Turi (Italy)

E-mail: luigi.tarricone@crea.gov.it

He holds a master's degree in Agricultural Sciences. He started working in 1991 at CREA-VE, focusing on grapevine certification and after on eco physiological aspect of grapevine management.

<https://orcid.org/0000-0002-6186-430X>

Raffaella Pergamo

Senior researcher, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: raffaella.pergamo@crea.gov.it

Based at Ministry of Agriculture, Food Sovereignty and Forests technical office within the National Rural Network, she contributes to rural development policies related to the implementation of the Common Agricultural Policy (CAP) in Italy. Her research focuses on the economic analysis of supply chains, the sustainability of agricultural production, precision and digital agriculture, the circular economy and the conservation of biodiversity. She is the author and co-author of numerous publications, and she has presented at various national and international conferences.

<https://orcid.org/0000-0002-0770-2633>



Irrigation reuse of urban treated wastewater: A qualitative analysis to support crop production in Campania

Marica Furini^{*a}, Veronica Manganiello^a, Raffaella Pergamo^a,
Olga Addimanda^a, Valeria Battaglia^a, Antonio Manzoni^a, Sofia Galeotti^a,
Manal Hamam^a, Marianna Ferrigno^a

^a CREA Research Centre for Agricultural Policies and Bioeconomy, Italy

Abstract

The sustainability of the agricultural sector is closely linked to the ability of territorial system to effectively address the challenges of water resource management in the context of climate change.

The reuse of treated wastewater is increasingly recognized as a key strategy for ensuring a sustainable water supply in agriculture.

This study proposes an innovative methodological approach aimed at identifying the Utilised Agricultural Area (UAA) potentially irrigable with treated wastewater, with particular attention to high value crops certified as Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) in the Campania region.

The methodology is based on the integration of data from three main sources: National Information System for Water Management in Agriculture (SIGRIAN) for mapping irrigated areas; European Environmental Agency (EEA) database linked with National Information System for the Protection of Italian Waters (SINTAI) for classifying wastewater treatment plants; and Italian Agricultural Payments Agency (AGEA) for identifying land use in irrigated areas. This approach enables the association, in accordance with Water Reuse Regulation (EU) 2020/741, of the water quality class required for each crop

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* *Corresponding author:* Marica Furini - Research technologist - CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy). E-mail: marica.furini@crea.gov.it.

with that one potentially available from wastewater treatment plants, also taking into account the existence of suitable distribution infrastructures.

The results of the analysis highlight that the proposed methodology, applied to agricultural sector in Campania, with a focus on high-quality production, can effectively guide public policies in promoting targeted infrastructure investments. These investments aim to protect areas most vulnerable to drought and support high value crops, particularly certified ones, through the adoption of advanced technological solutions and integrated water resource planning, which are key to ensuring the resilience and long-term prosperity of the regional agricultural sector.

Introduction

In recent decades, access to water resources has become increasingly challenging due to environmental, climatic, and human pressures (Scanlon *et al.*, 2023). Agriculture, highly dependent on water and a major driver of its quality and quantity, is among the most vulnerable sectors (Ingrao *et al.*, 2023). According to the EEA, about 20% of Europe's territory and 30% of its population face water stress, with droughts causing annual economic losses of up to €9 billion, excluding ecosystem damage (EEA, 2020, 2021). Southern Europe and the Mediterranean, already characterized by limited and irregular water availability – especially in summer – are expected to face worsening conditions due to climate change. The EEA projects up to a 40% reduction in summer river discharge in southern and southwestern Europe under a 3°C warming scenario (EEA, 2021). Rising temperatures, changing precipitation patterns, and more frequent extreme weather events are reducing crop yields and altering crop distribution, severely impacting agricultural production and infrastructure (EEA, 2020).

Sustainable freshwater management is essential for Sustainable Development Goals (SDG), as emphasized by UN SDG 6 (Clean Water and Sanitation) and its links to SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land) (United Nations, 2015, 2016). In Europe, the Water Framework Directive (WFD) has regulated water quality since 2000, aiming to ensure high standards for freshwater resources. More recently, the European Green Deal, thanks to a package of strategies¹, has prioritized

1. *In primis* the Biodiversity Strategy for 2030, the European Climate Law, the Farm to Fork Strategy, and the recently-adopted Nature Restoration Regulation, among others.

sustainable and resilient water management as key to achieving climate neutrality by 2050 (Koundouri *et al.*, 2024).

Climate change is expected to increase irrigation needs by 20% (EEA, 2021), adding pressure on agriculture, which must produce more with fewer inputs to meet growing food demand. In this context, treated wastewater reuse is increasingly viewed as a viable alternative water source for irrigation in several EU countries (Blanco-Gutiérrez & *et al.*, 2021; Hamam *et al.*, 2024; McLennan *et al.*, 2024). Across Europe, WasteWater Treatment Plants (WWTPs) capable of producing water for reuse are mainly located in coastal and southern areas, as well as densely populated northern regions. Treated wastewater is primarily used for agricultural purposes, as well as for urban and industrial uses. Agriculture accounts for about 25% of freshwater withdrawals in Europe (Farabegoli, 2023; United Nations, 2017).

The EU has actively promoted treated wastewater reuse in agriculture, especially in water-stressed areas, culminating in the Water Reuse Regulation (WRR (EU) 2020/741) (Ramm *et al.*, 2024). This regulation sets minimum quality standards for reuse in irrigation, protecting human and animal health and the environment (Hamam *et al.*, 2024). It aligns with the European Green Deal and the Circular Economy Action Plan (Berbel *et al.*, 2023; Maffettone *et al.*, 2024).

Reuse potential depends on technological factors (e.g., advanced WWTPs), agronomic factors (crop type, irrigation methods), and managerial aspects – particularly the presence of infrastructure and entities responsible for distributing reclaimed water. Reuse is most effective where well-structured irrigation services and networks already exist, reducing the need for new distribution investments (Drei *et al.*, 2025).

Following the WRR (EU) 2020/741, Italy is updating national legislation with a new Presidential Decree to extend reuse provisions beyond the EU regulation, including industrial wastewater reuse (with exceptions) and additional uses (Farabegoli, 2023).

Given the WRR (EU) 2020/741's recent introduction, scientific literature on treated wastewater reuse under these new rules is limited, especially regarding actual or potential use for crops (Hamam *et al.*, 2024).

Several studies have analyzed, from a technical and economic perspective, the potential of reusing treated urban wastewater to meet irrigation needs (Birol *et al.*, 2010; Mancuso *et al.*, 2022; Ventura *et al.*, 2019). However, such research has generally focused on the quantitative aspect, both for treated wastewater and irrigation requirements, often neglecting the crop context, which is instead a crucial element in effective reuse planning.

In this regard, this study proposes a methodology to investigate the potential for wastewater reuse in irrigation, employing a qualitative approach that integrates agronomic, technological, and managerial factors in assessing

reuse potential. This research was developed within SMACC project, funded by Ministry of Agriculture, Food Sovereignty and Forests (MASAF) under Development and Cohesion Fund. This innovative approach allows overcoming the traditional focus solely on quantitative aspects, providing a more comprehensive and realistic view of the opportunities and challenges associated with the sustainable management of wastewater in agriculture. As a case study, the methodology is applied in Campania, a region in southern Italy with diversified and high-value farming, but with limited research on water reuse.

The paper is structured as follows: first, an overview of Campania's agriculture, water resources, climate change, irrigation, and high-value crop production; second, a description of methods combining datasets on irrigation areas, WWTPs, and crops; finally, a presentation and discussion of results focusing on wastewater reuse potential for agricultural irrigation, particularly for high-value crops.

1. Agricultural and irrigation context in the Campania region

Campania, in southern Italy, features a Mediterranean climate with dry summers and mild, rainy winters (Burak and Margat, 2016; Mendicino *et al.*, 2008). Precipitation varies from 800 mm on the coast to 2,000 mm in mountainous areas (Busico *et al.*, 2017). The region's climatic attributes, coupled with its considerable morphological diversity, encompassing fertile coastal plains, hilly terrains, and mountainous landscapes, have historically facilitated the proliferation of intensive agriculture, marked by a high degree of crop diversification.

Indeed, agriculture in Campania is distinguished by the cultivation of esteemed crops, including PDO and PGI products, which are intricately connected to local traditions and the region's identity. Cereals, vegetables, and citrus fruits comprise more than 85% of the overall agricultural output in the Mediterranean region, although crops like olives and grapes represent a substantial portion of the agricultural production (Leff *et al.*, 2004).

The region produces iconic products, including San Marzano tomatoes, Annurca apples, and wines with the Controlled Designation of Origin (DOC) designation. Such crops require high-quality irrigation water, with strict limits on pollutants to ensure food safety and environmental sustainability.

The official statistics demonstrate the significant value of crops, including many with PDO and PGI labels, as an essential component of the regional agricultural economy. With 63 PDO and PGI certified foods and wines, a value of 896 million Euros according to the Ismea-Qualivita Observatory, the agri-food production and the wine sector account respectively for 88.5% and 11.5% of the entire sector (Fondazione Qualivita, 2025).

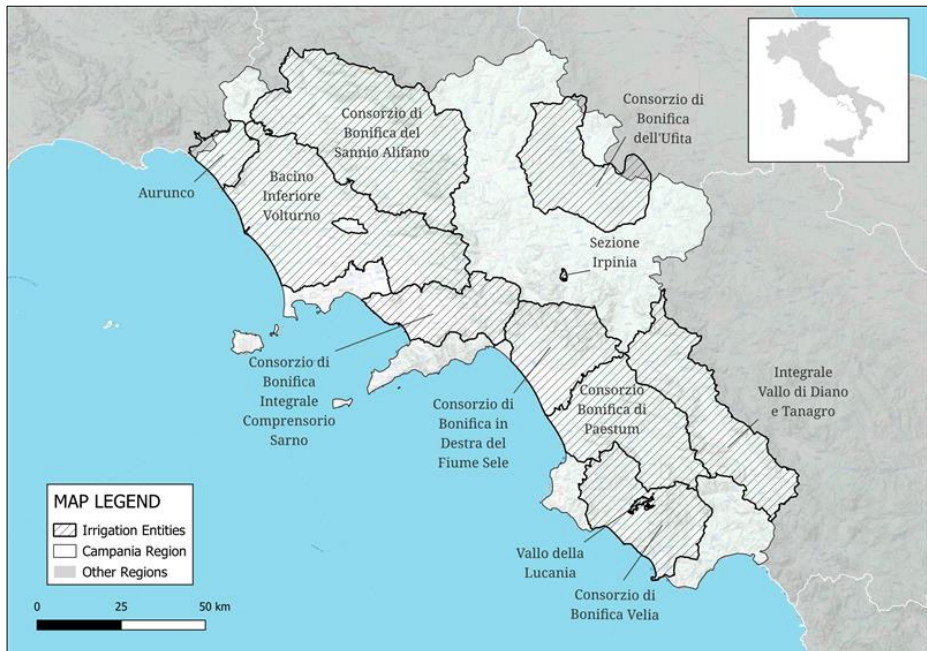
Agriculture in Campania is heavily dependent on irrigation, making it particularly vulnerable to climate change and increasing droughts, especially in the Piana del Sele and Cilento areas. Groundwater overuse and surface water pollution further exacerbate water scarcity (Cusano *et al.*, 2019; Mastrocicco *et al.*, 2021).

The irrigation of high-value crops needs high-quality water, which imposes strict limitations on salinity, sodium, heavy metals, nitrates, and microbiological pollutants to ensure production quality, food safety, and soil sustainability (Bordbar *et al.*, 2025), preserve soil structure and yields (Ayers and Westcot, 1985), avoiding environmental and health hazards (Paranychanakis *et al.*, 2015; Pedrero *et al.*, 2010).

Despite having the highest water availability in the Southern Apennine River Basin, Campania transfers significant volumes to neighboring regions, resulting in inter-regional dependencies. The irrigation system relies on a combination of surface watercourses (e.g., Volturno, Sele) and aquifers, which are managed by 11 irrigation consortia across the region.

The management of the irrigation network in the Campania region is currently delegated to 11 irrigation entities (Figure 1).

Figure 1 - Maps of irrigation entities in the Campania region



Source: SIGRIAN, 2025.

Irrigation and reclamation consortia in Campania operate across approximately 100,000 hectares, serving regional agricultural enterprises. The territory is divided into irrigation districts based on water availability and distribution schemes, which define irrigated areas and guide strategic planning.

These consortia manage about 67% of the region and oversee 70% of irrigated land through public systems, underscoring the strategic role of irrigation in the regional economy.

Despite favourable conditions, agriculture in Campania faces growing challenges related to climate change, water scarcity, and aging infrastructure. Ensuring the sector's resilience requires not only the sustainable use of existing water resources but also the development of alternative, reliable sources (Colella *et al.*, 2021).

Improving water-use efficiency and promoting reuse solutions are essential to protect agricultural productivity, food security, and environmental sustainability (Braca *et al.*, 2019).

2. Materials and methods

The WRR (EU) 2020/741 establishes minimum quality requirements for the use of treated wastewater in agriculture, based on a site-specific risk management plan. These requirements are determined by comparing the treatment level achieved at the WWTP (resulting in a water quality class from A to D) with the quality required for target crops and irrigation systems (Joint Research Centre, 2017; 2022).

The WRR (EU) 2020/741 defines four water quality classes (A, B, C, D), linked to both crop categories and irrigation methods (Figure 2). It authorizes the reuse of treated municipal wastewater for three crop groups:

- food crops consumed raw;
- processed food crops (post-harvest treatment required);
- non-food crops.

The regulation also introduces indicative treatment requirements:

- Class A: secondary treatment, filtration; and disinfection;
- Classes B, C, D: secondary treatment and disinfection.

The quality class can be adjusted using accredited additional barriers, such as specific irrigation methods that reduce crop exposure to pests. However, the actual classification depends on microbiological parameters, not only on the treatment applied (Figure 3).

Figure 2 - Classes of reclaimed water quality and permitted agricultural use and irrigation method

Minimum reclaimed water quality class	Crop category (*)	Irrigation method
A	All food crops consumed raw where the edible part is in direct contact with reclaimed water and root crops consumed raw	All irrigation methods
B	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	All irrigation methods
C	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	Drip irrigation (**) or other irrigation method that avoids direct contact with the edible part of the crop
D	Industrial, energy and seeded crops	All irrigation methods (***)

(*) If the same type of irrigated crop falls under multiple categories of Table 1, the requirements of the most stringent category shall apply.

(**) Drip irrigation (also called trickle irrigation) is a micro-irrigation system capable of delivering water drops or tiny streams to the plants and involves dripping water onto the soil or directly under its surface at very low rates (2-20 litres/hour) from a system of small-diameter plastic pipes fitted with outlets called emitters or drippers.

(***) In the case of irrigation methods that imitate rain, special attention should be paid to the protection of the health of workers or bystanders. For this purpose, appropriate preventive measures shall be applied.

Source: WRR (EU) 2020/741.

Figure 3 - Reclaimed water quality requirements for agricultural irrigation

Reclaimed water quality class	Indicative technology target	Quality requirements				
		E. coli (number/100 ml)	BOD ₅ (mg/l)	TSS (mg/l)	Turbidity (NTU)	Other
A	Secondary treatment, filtration, and disinfection	≤ 10	≤ 10	≤ 10	≤ 5	<i>Legionella</i> spp.: < 1,000 cfu/l where there is a risk of aerosolisation Intestinal nematodes (helminth eggs): ≤ 1 egg/l for irrigation of pastures or forage
B	Secondary treatment, and disinfection	≤ 100	In accordance with Directive 91/271/EEC (Annex I, Table 1)	In accordance with Directive 91/271/EEC (Annex I, Table 1)	–	
C	Secondary treatment, and disinfection	≤ 1,000		–	–	
D	Secondary treatment, and disinfection	≤ 10,000		–	–	

Source: WRR (EU) 2020/741.

The innovative element of the WRR (EU) 2020/741 is its fit-for-purpose approach – moving away from the precautionary “one-size-fits-all” model to a system based on risk assessment and proportionality, balancing safety with feasibility².

Data collection

To assess the reuse potential of treated wastewater in Campania, geospatial and technical data from three domains were integrated as shown in Table 1:

Table 1 - Data collection

Framework	Parameter	Database	File format	Reference year
Managerial	Irrigation area	SIGRIAN	Shapefile	2025
Technical	WWTP locations and treatments	EEA/SINTAI	Shapefile/excel	2020
Agonomic	Crop data	AGEA	Shapefile	2018

Source: Authors' elaboration.

2. Cf. the European Commission's Communication “Guidelines to support the application of Regulation 2020/741 on minimum requirements for water reuse” (2022/C 298/01).

Given the exploratory nature of this study, the use of data from different years was deemed appropriate, as the primary objective was to propose and test a methodological framework for qualitative and spatial investigation rather than to produce temporally consistent estimates.

WebGIS SIGRIAN

SIGRIAN is the reference database for the irrigation sector. It is a Geographic Information System managed by CREA PB and realized in collaboration with the irrigation and reclamation consortia and the Regions. It contains geographic and alphanumeric spatial data concerning irrigation features in collective irrigation areas: administrative boundaries, irrigated and irrigable areas, irrigation supply, hydrographic network, crop type, and climatic characteristics (Zucaro *et al.*, 2019). For the purposes of the analysis, the perimeter to date of the irrigation areas considered as the territorial reference unit for the survey was extracted from the SIGRIAN database.

EEA/SINTAI database

The European Environmental Agency database³, in connection with SINTAI⁴, contains the information transmitted by the Member States every two years, in compliance with Art. 15 of the Urban Wastewater Treatment Directive 91/271/EEC (UWWTD). In this way, the European Commission verifies the progress made by Member States in the field of purification and collection by periodically requesting information on agglomerations of 2,000 population equivalents (P.E.)⁵ or more.

Among the information (available in Excel and shapefile format), the following were used for this survey:

- *geographical location of the wastewater treatment plants*: latitude and longitude;
- *technical characteristics*: presence of primary, secondary, advanced treatment, disinfection, and filtration (required in Table 2 of the WRR);
- *activity status*: inactive, active, temporarily inactive;
- *design and incoming organic capacity*.

3. The European Environment Agency (EEA) is a European Union (EU) agency that provides independent information on the environment. Its primary role is to help the EU and its member and cooperating countries make informed decisions to improve the environment, integrate environmental considerations into economic policies, and support a sustainable transition.

4. SINTAI is the National Information System for the Protection of Italian Waters managed by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) open source which allows access, management and consultation of environmental information.

5. Which means the organic biodegradable load having a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day.

The data used refers to the year 2020, as submitted in 2022 by MS. This data does not vary significantly from year to year.

AGEA Graphical Cultivation Plan

The Graphical Cultivation Plan (GCP), managed by AGEA, graphically represents a farm's crops on a given territory with detailed information. The GCP, related to the year 2018 and in shapefile format, was processed using Geographic Information System (GIS) software. The georeferencing of each plot allowed for the agronomic framing of the area under study. Area-based CAP aid recipients compile the data, so they do not cover the entire national agricultural area, although they have a high degree of coverage. However, their potential lies in classifying each plot of land in such detail as to characterize each crop also with respect to its mode of consumption, allowing it to be linked to the crop categories envisaged by the WRR (EU) 2020/741.

For the purposes of the survey, the following parameters were used, relating to:

- *Land occupation (codi_occu)*: this identifies both specific vegetation cover and the absence of crops (e.g., durum wheat or set-aside land);
- *Use (codi_use)*: allows the indication of the prevalent use of a specific land occupation (e.g., Industry or canteen);
- *Use (codi_usage)*: identifies specific cultivation methods or specific information related to the land occupation (e.g., pot cultivation or rough grazing);
- *Quality (codi_qual)*: provides specifications on the indicated land occupancy (e.g., Early or Late).

Spatial analysis

To integrate previous quantitative analysis (Ferrigno *et al.*, 2023), this study adopts a qualitative approach to investigate the implementation of Regulation (EU) 2020/741 on wastewater reuse. Emphasis is placed on developing a spatially explicit method to assess qualitative compliance between supply and demand, addressing a research gap in the existing literature where such methodological integration remains limited.

Using GIS (QGIS and ArcGIS Pro), a geodatabase was created by overlaying:

1. SIGRIAN irrigated areas. The reference territorial units for the survey are the irrigation areas as currently registered in SIGRIAN. An irrigation area is a physical-administrative unit served fully or partially by an irrigation infrastructure system, identifying lands subject to irrigation. Managed by an irrigation authority, these areas are potentially connected to a water

distribution network. This characteristic was considered a key enabling factor for promoting wastewater reuse;

2. WWTPs with adequate treatment levels. WWTPs in the study area were classified based on the technological objectives outlined in Table 2 of the WRR (EU) 2020/741, allowing identification of plants potentially producing reclaimed water of quality classes A, B, C, or D. This classification is theoretical, as actual quality depends not only on treatment level but also on microbiological parameters, which were not considered here due to incomplete or unavailable data. Such parameters are better assessed through direct sampling for water-reuse risk management plans. Only WWTPs with an incoming load of $\geq 2,000$ P.E. were included, excluding smaller plants, due to factors affecting technical and economic feasibility, such as treatment line completeness and water production capacity;
3. Crop types and their respective water quality requirements. All crops listed in the AGEA 2018 GCP were compiled into an Excel file to categorize them according to the WRR (EU) 2020/741 crop categories, which are groups based on reclaimed water quality requirements. This classification followed the provisions of Table 2 (Figure 4) and Table 4.2 (Figure 5) from the document *Guidelines to support the application of the WRR on minimum requirements for water reuse* which further specifies reclaimed water quality classes according to crop type and intended use.

Only agricultural plots were retained; non-agricultural land was excluded. All crops were analysed as potentially irrigable in an extreme shortage scenario. Each crop was associated with its minimum required water quality class, solely based on crop type, thus excluding mitigation barriers such as irrigation methods, as defined in Article 3(12) of the WRR (EU) 2020/741.

A specific focus was given to high-value PDO/PGI crops of Campania (e.g., Melannurca Campana PGI, Pomodoro San Marzano PDO). By intersecting crop layers with the official production areas defined in their specifications, it was possible to highlight branded plots that could potentially benefit from reclaimed water.

While the presence of a crop within a PDO/PGI area does not guarantee its branding status, for the purpose of this analysis, these areas were considered as proxies for high-value production.

Figure 4 - Suggested number of barriers needed for irrigation with reclaimed water, according to their quality

Category (1)	Irrigation of vegetables consumed raw (2)	Irrigation of vegetables after processing and pastures (3)	Irrigation of food crops other than vegetables (orchards, vineyards) and horticulture (4)	Irrigation of fodder and seeded crops (5)	Irrigation of industrial and energy crops (6)
A	0	0	0	0	0
B	1	0	0	0	0
C	3	1	1	0	0
D	forbidden	forbidden	3	1 (*)	0

The following definitions for each column in the table are in line with Table 1 of Annex 1 to the Water Reuse Regulation and are intended to help the reader find the crop category that broadly corresponds to the ISO categorisation, and thus identify which additional barriers may be needed:

- (1) Minimum reclaimed water quality class.
- (2) Food crops consumed raw where the edible part is in direct contact with reclaimed water and root crops consumed raw.
- (3) Processed food crops and non-food crops, including crops used to feed milk- or meat-producing animals.
- (4) Food crops consumed raw, where the edible part is produced above ground and it is not in direct contact with reclaimed water.
- (5) Food crops consumed raw, where the edible part is produced above ground and is not in direct contact with reclaimed water; processed food crops, and non-food crops, including crops used to feed milk- or meat- producing animals (in both cases, when drip irrigation or another irrigation method is used that avoids direct contact with the edible part of the crop). NB. The seeded crops mentioned here can be seeds for human consumption or for use as animal fodder.
- (6) Industrial, energy crops, and seeded crops (intended to produce seeds for sowing).

(*) Note from ISO 16075:2020: Edible seeds or seeds for sowing which have been irrigated for less than 30 days prior to harvesting. If the period before harvesting is equal to or higher than 30 days, then class D can be directly applicable without restrictions (i.e. without the need for additional barriers).

Source: WRR (EU) 2020/741. Guidelines to support the application of WRR (EU) 2020/741 on minimum requirements for water reuse (2022/C 298/01).

Figure 5 - Examples on how to calculate number and types of barriers based on type of crop and required reclaimed water quality classes

Crop category (Annex 1 Table 1 of the Regulation) (1)	Example crops (Table A.1 ISO 16075-2:2020)	Reclaimed water quality class (Annex 1 Table 1 of the Regulation)	Number of required barriers (Table 3 ISO 16075-2:2020 (3) = Table 2 of this Notice)	Possible accredited barriers (Table A.1 ISO 16075-2:2020 and Table 2 ISO 16075-2:2020 (4) = Table 3 of this Notice)	Number of barriers (Table 2 ISO 16075-2:2020 = Table 3 of this Notice)	Note
ALL FOOD crops consumed raw, where the edible part is in direct contact with reclaimed water, and root crops consumed raw	Leafy crops grown on the soil surface are eaten raw (e.g., lettuce, spinach, Asian cabbage, celery). Food crops ingested raw, which grow above ground, and the edible portion is <25 cm above the soil surface (e.g., pepper, tomato, cucumber, courgettes, young beans).	A	0	–	0	–
		B	1	Sun-resistant cover sheet OR Additional disinfection in field (low level)	1	–
		C	3	High-level disinfection + Sun-resistant cover sheet	2+1	–
				Subsurface drip irrigation, where water does not ascend by capillary action to the ground surface + Sun-resistant cover sheet*	3 (+1)	* Sun-resistant cover sheet is an extra barrier to prevent contact by the capillary action of drip irrigation. –
		D	Forbidden*	–	–	* In accordance with Table 3 ISO16075: 2020 and NOTE 3 of Table a.1: Effluents of medium quality (D) should not be used for the irrigation of vegetables.
	Food crops that can be ingested raw, which grow in the soil (e.g. carrot, radish, onion)	A	0	–	–	–
		B	1	Low level disinfection	1	–
		C	3	No combination of accredited barriers seems to be possible	–	–

Source: Guidelines to support the application of Regulation 2020/741 on minimum requirements for water reuse (2022/C 298/01).

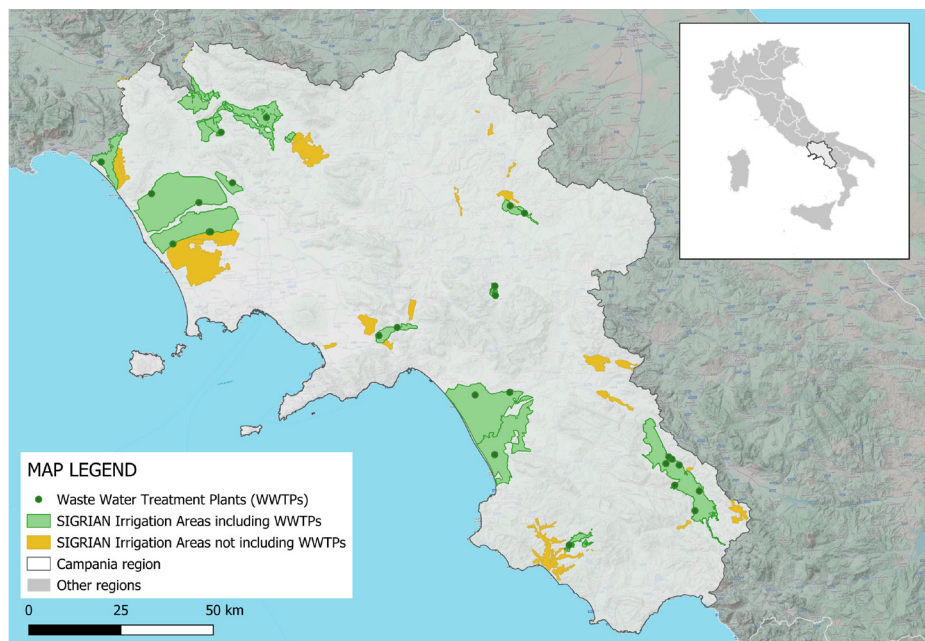
3. Results

The analysis relies on cross-sectional data from different years (SIGRIAN 2025, EEA/SINTAI 2020, AGEA 2018). Therefore, even if some of the data analyzed are unlikely to vary from year to year, the results provide a static snapshot of potential reuse, rather than actual or time-varying capacity. They should be read as indicative of spatial opportunities and constraints.

3.1. Characterisation of the study area

The Campania region comprises 40 irrigation areas, managed by 11 separate irrigation authorities. 12 areas contain at least one WWTP (Figure 6 and Table 2), totalling 26 WWTPs. All selected WWTPs can potentially produce class B, C, or D reclaimed water, indicating that additional treatment is required for crops that require class A water.

Figure 6 - Map of WWTPs included in irrigated areas in the Campania region



Source: Authors' elaboration.

Table 2 - List of WWTPs included in irrigation areas and their potential quality class according to the treatment applied

Reclamation and irrigation consortia	Irrigation Areas (ID Sigrian)	Irrigation Areas (SIGRIAN name)	WWTP (ID EEA)	WWTP (EEA name)	Potential quality reclaimed water
Bacino Inferiore Volturno	4160	Aurunco	IT15Q90000003455	Cellole Impianto di Baia Domizia Borgo Centore	BCD
	4946	DX-VOLTURNO	IT15Q90000003445	Vitulazio Impianto di Selva Via Fontana Pigna	BCD
			IT15Q90000003453	Falciano del Massico Impianto del Capoluogo Localita Casale	BCD
			IT15Q90000003464	Grazzanise Depuratore Comunale	BCD
	4947	SX-VOLTURNO	IT15Q15000000007	Villa Literno Ce Impianto Foce Regi Lagni	BCD
			IT15Q90000003454	Cellole Depuratore Localita Doccia	BCD
			IT15Q90000003563	Rotondi Impianto di Rotondi Via Patricelli	BCD
Paestum	4171	Paestum	IT15Q90000003617	Capaccio Sa Impiantovarolato	BCD
Sarno	4155	Paludi	IT15Q90000003628	Mercato S. Severino Frazione Costa Impianto Mercato S. Severino	BCD
			IT15Q90000003631	Nocera Superiore Impianto Comprensoriale	null
Sannio Alifano	4476	Sannio Alifano	IT15Q90000003439	Alife Impianto di Fusaro Vadolargo	BCD
			IT15Q90000003456	Pietramelara Depuratore Comunale	BCD
Ufita	4163	Ufita B	IT15Q90000003587	Frigento Impianto Frigento Localita Pila ai Piani	BCD
	4179	Macchioni	IT15Q90000003603	Sturno Impianto di Sturno	BCD
Destra del Fiume Sele	4164	Destra Sele	IT15Q90000003623	Battipaglia Sa Impianto Tavernola	BCD
			IT15Q90000003625	Eboli Sa Impianto Macchioncello	BCD
Reclamation and irrigation consortia	4144	Montella, Cassano, Montem	IT15Q11000000000	Montella Impianto di Montella Loc Ta Bagno Stratola	BCD
			IT15Q90000003571	Montella Impianto di Montella	BCD
Vallo di Diano e Tanagro	4165	VALLO DI DIANO E TANAGRO	IT15Q90000003634	Montesano Marcellana Buonabitacolo Impianto Capoluogo Peschiera	BCD
			IT15Q90000003636	Sala Consilina Impianto Localita Taverne	BCD

			IT15Q90000003637	Sala Consilina Impianto Loc Macchia dell'Aspide	BCD
			IT15Q90000003638	Sala Consilina Impianto Loc San Giovanni	BCD
			IT15Q90000003644	Teggiano Depuratore di Teggiano	BCD
			IT15Q90000003684	Padula Impianto del Capoluogo	BCD
			IT15Q90000003704	Sassano Impianto Via Limiti	BCD
Vallo della Lucania	4487	Vallo	IT15Q90000003477	Vallo Della Lucania Impianto Localita Ischitella	BCD

Source: Authors' elaboration.

From an agronomic point of view, the study area is characterized by a total UAA of 53.638,70 hectares, made up of about 70% by the ten prevailing crop types shown in Table 3.

Table 3 - Prevalent crop types in the Campania region

CROP	UAA (ha)	UAA (%)
Meadow	6.819,38	12,71
Mais	5.278,47	9,84
Arable land	5.229,49	9,75
Tomato	5.186,93	9,67
Oats	4.844,84	9,03
Ryegrass	4.786,64	8,92
Hazel	2.055,07	3,83
Strawberry	1.401,44	2,61
Alfalfa	1.296,96	2,42
Sulla	1.034,39	1,93
SubTotal	37.933,61	70,72
Other crops	15.705,09	29,3
Total	53.638,70	100,0

Source: Authors' elaboration.

Crop types have been categorized into 12 categories according to the WRR (EU) 2020/741 and its accompanying guidance document. As it turns out, about 94% of the UAA can be attributed to five crop categories (Table 4).

Table 4 - Crop categories as per WRR (EU) 2020/741 of the survey area (in order of occurrence)

Crop category Reg 741/2020 (WRR)	UAA (ha)	UAA (%)
Fodder crops for feed for milk- or meat-producing animals (e.g., alfalfa)	20.709,37	38,6
Food crops grown above ground where the edible portion is <25 cm above the soil surface, eaten cooked or processed (e.g., aubergine, pumpkin, green beans, artichoke)	9.593,78	17,9
Industrial, energy crops, and seeded crops (intended to produce seeds for sowing)	7.808,47	14,6
Food crops that grow above ground, such as > 50 cm or more above the ground with edible skin (orchard for fruits with edible skin: apple, plum, pear, peach, apricot, persimmon, cherry, citrus fruits, dates; or orchard for fruits eaten after peeling: mango, avocado, papaya, pomegranate). Orchard for fruits eaten after processing (e.g., olives)	7.440,34	13,9
Leafy crops grown on the soil surface are eaten raw (e.g., lettuce, spinach, Asian cabbage, cabbage, celery). Food crops ingested raw, which grow above ground and the edible portion is <25 cm above the soil surface (e.g., pepper, tomato, cucumber, courgettes, young beans).	4.824,34	9,0
Subtotal	50376,3	94,0
Other crop category	3.262,40	6,1
Total	53.638,70	100,0

Source: Authors' elaboration.

Table 5 represents the UAA and the corresponding percentages for each water class in the Campania region. The preponderant part, more than 60%, is made up of crops for which at least one water class B is required.

Table 5 - Minimum class of reclaimed water required in hectares and % of UAA

Required water class	UAA (ha)	UAA (%)
A	4.968,04	9,3
B	32.932,26	61,4
C	7.440,34	13,9
D	8.298,06	15,5
Total	53.638,70	100,0

Source: Author's elaboration.

Having defined the qualitative supply and demand in the study area, it is possible to correlate the two pieces of information to define the potential for reuse.

3.2. Reuse potential

By correlating the potential quality of treated wastewater with the minimum water quality requirements of different crops, the reuse potential of treated wastewater in the study area can be assessed from multiple perspectives.

The first area-based approach identifies zones where the water supply falls short of demand, highlighting vulnerable areas for targeted interventions to boost irrigation from alternative sources.

The first, area-based approach, examines which crops would be most affected under extreme drought due to their high-quality water needs, revealing specific agricultural vulnerabilities and resilience. However, this method overlooks the spatial distribution of crops, which may be fragmented and served by different treatment plants.

To overcome this, a third, mixed approach, combines both area-based and crop-based analyses, focusing on specific zones or crop types – such as PDO and PGI products – allowing a more detailed and nuanced assessment.

Area-based approach

Table 6 presents the analysis results from the irrigation area perspective. Over 70% of the UAA considered in the study is potentially irrigable with treated wastewater. In areas served by at least one WWTP, the potentially irrigable UAA exceeds 90%, except for the Destra Sele irrigation area, where only 60% of the area is potentially irrigable. The remaining area consists of crops requiring Class A water, which could be irrigated after WWTP

upgrades and/or the implementation of suitable additional barriers at the supply point.

This approach provides a valuable tool for strategic infrastructure planning and helps identify priority WWTPs for reuse investments, as outlined in Art. 5 of Ministerial Decree 185/2023 and the forthcoming Presidential Decree.

Table 6 - Assessment of the irrigation potential of any WWTPs included in the irrigation areas

Irrigations area	UAA (ha)	WWTP (n° - potential class quality water)	UAA potential irrigable (%)	UAA no irrigable (%)
Montella, Cassano, Montemarano	138,47	2 BCD	96,9	3,1
Paludi	45,86	BCD, null*	93,0	7,0
Aurunco	1.239,92	BCD	95,5	4,5
Ufita B	619,10	BCD	98,0	2,0
Destra Sele	8.308,38	2 BCD	60,9	39,1
Vallo di Diano e Tanagro	2.646,71	7 BCD	98,4	1,6
Paestum	5.133,13	BCD	92,6	7,4
Macchioni	223,41	BCD	97,6	2,4
Sannio Alifano	7.127,66	2 BCD	99,7	0,3
Vallo	249,14	BCD	99,4	0,6
Dx-Volturno	10.611,90	3 BCD	97,7	2,4
Sx-Volturno	5.578,81	3 BCD	97,4	2,6
28 remaining irrigations area	11.716,21	None	0,00	100,0
Total	53.638,70		70,4	29,6

* WWTPs that do not have the minimum level of treatment required by European regulations to produce water that can be reused for irrigation purposes.

Source: Authors' elaboration.

Crop-based approach

By applying the analysis to individual crops or categories, Table 4 can be expanded into Table 7, which distinguishes UAA located in irrigation areas including a WWTPs from those without available reclaimed water classes in it (n.d.), highlighting the potentially irrigable share.

For example, 93,42% of “nut trees”, which require Class B water, are potentially irrigable as they lie within irrigation areas including a WWTPs producing Class B water.

The most disadvantaged category is “Industrial, energy, and seed crops for sowing – non-food nursery”, which requires only Class D water, yet only 52,78% of their UAA is in irrigation areas, including WWTPs.

The analysis also shows that crops needing Class A water are currently not irrigable with reclaimed wastewater anywhere in the study area, as no WWTP produces this water quality class.

Table 7 - Distribution of crop categories in relation to the presence of WWTPs and the quality class produced by it. Evaluation of irrigation potential with reclaimed water

Crop category Reg 741/2020	Total UAA (ha)	Required water class	Class of water available	SAU (ha)	Irrigable UAA	Irrigable UAA (%)
Orchard for nuts (e.g., almonds, pistachios)	869,15	B	BCD	811,97	YES	93,42
		B	n.d.	57,19	NO	
Food crops that grow above ground, such as > 50 cm or more above the ground with edible skin (orchard for fruits with edible skin: apple, plum, pear, peach, apricot, persimmon, cherry, citrus fruits, dates; or orchard for fruits eaten after peeling: mango, avocado, papaya, pomegranate). Orchard for fruits eaten after processing (e.g., olives)	7.440,34	C	BCD	5.042,58	YES	67,77
		C	n.d.	2.397,76	NO	
Food crops that can be ingested raw, which grow in the soil (e.g., carrot, radish, onion)	143,70	A	BCD	83,28	NO	–
		A	n.d.	60,42	NO	
Food crops grown above ground that can be eaten after drying and cooking (dry beans, lentils)	72,05	B	BCD	48,42	YES	67,20
		B	n.d.	23,63	NO	
Food crops grown above ground where the edible portion is <25 cm above the soil surface, eaten cooked or processed (e.g., aubergine, pumpkin, green beans, artichoke)	9.593,78	B	BCD	6.612,75	YES	68,93
		B	n.d.	2.981,03	NO	
Food crops grown on the soil that can be eaten raw after peeling (e.g., watermelon, melon, pea)	1.486,25	B	BCD	1.392,46	YES	93,69
		B	n.d.	93,79	NO	

Food crops eaten cooked that grow in the soil (e.g., potato)	201,65	B	BCD	125,92	YES	62,44
		B	n.d.	75,73	NO	
Fodder crops for feed for milk- or meat-producing animals (e.g., alfalfa)	20.709,37	B	BCD	17.123,68	YES	82,69
		B	n.d.	3.585,69	NO	
Industrial, energy crops, and seeded crops (intended to produce seeds for sowing – no food plant nursery)	462,36	D	BCD	244,03	YES	52,78
		D	n.d.	218,33	NO	
Industrial, energy crops, and seeded crops (intended to produce seeds for sowing – food plant nursery)	27,22	D	BCD	22,72	YES	83,46
		D	n.d.	4,50	NO	
Leafy crops grown on the soil surface are eaten raw (e.g., lettuce, spinach, Asian cabbage, cabbage, celery). Food crops ingested raw, which grow above ground and the edible portion is <25 cm above the soil surface (e.g., pepper, tomato, cucumber, courgettes, young beans)	4.824,34	A	BCD	4.081,47	NO	
		A	n.d.	742,87	NO	
Industrial, energy crops, and seeded crops (intended to produce seeds for sowing)	7.808,47	D	BCD	6.333,21	YES	81,11
		D	n.d.	1.475,26	NO	
Total	53.638,70			53.638,70		70,39

Source: Authors' elaboration.

Mixed approach to the PDO and PGI case study

Specifically, PDO and PGI products in the fruit and vegetable sector were analyzed, assuming that all the crops within the municipal boundaries defined in the production regulations for each product are certified production. Results show that while over 70% of the regional UAA is potentially irrigable (Table 6), this drops to 42% for the branded crops examined (Table 9).

Only Carciofo di Paestum PGI and Nocciola di Giffoni PGI have their entire UAA irrigable. Conversely, Cavolfiore della Piana del Sele PGI, Cipollotto Nocerino PDO, and Rucola della Piana del Sele PGI cannot be irrigated without adopting risk-reduction measures, as the supplying WWTPs do not produce the required Class A water.

Ciliegia di Bracigliano PGI and Melannurca Campana PGI can be partially irrigated with reclaimed water, limited to UAA portions within irrigation areas served by WWTPs. Similarly, Pomodoro San Marzano dell'Agro Sarnese-Nocerino PDO irrigation depends on water quality class – Class A for fresh consumption and Class B for industrial use.

Table 9 - Campania high value crops from and irrigation potential with reclaimed water

Campania's high-value crops	Irrigations area	Class of water available	Class of water required	UAA (ha)	Potential irrigation	Irrigable UAA (%)
ARTICHOKE	Destra Sele	BCD	B	67,83	YES	
	Paestum	BCD	B	75,12	YES	
Total				142,95		100,00
CAULIFLOWER	Destra Sele	BCD	A	109,08	NO	
	Paestum	BCD	A	23,24	NO	
Total				132,32		0,00
CHERRY TREE	Labso		C	0,73	NO	
	Paludi	BCD	C	2,86	YES	
	S. Anna - S. Lucia		C	0,29	NO	
Total				3,88		73,63
ONION, INCLUDING LONG-TYPE VARIETIES (ECHALION)	Paludi	BCD	A	2,63	NO	
Total				2,63		0,00
APPLE TREE	Sannio Alifano	BCD	C	35,27	YES	
	Valle telesina		C	2,65	NO	
	SX-REGI LAGNI		C	31,09	NO	
	DX-VOLTURNO	BCD	C	117,04	YES	
	SX-VOLTURNO	BCD	C	6,21	SI	
Total				192,26		82,45
HAZELNUT TREE	Paludi	BCD	B	0,33	YES	
Total				0,33		100,00
TOMATO (San Marzano)	Labso		A	1,94	NO	
			B	0,22	NO	
	Sarno - S. Valentino - S.		A	1,23	NO	
	Paludi	BCD	A	0,22	NO	
		BCD	B	0,63	YES	
	Bottano		A	0,10	NO	
Total				4,34		14,60
ROCKET	Destra Sele	BCD	A	186,36	NO	
	Paestum	BCD	A	61,10	NO	
Total				247,46		0,00
Total Region				726,18		42,04

Source: Authors' elaboration.

A significant issue arises regarding the availability of treated wastewater for irrigating Campania's PDO and PGI crops. Many of these high-value crops are partially or entirely excluded from reuse irrigation due to the lack of required water quality or adequate distribution infrastructure. This limitation poses a serious challenge, especially in extreme drought conditions, given the economic and strategic importance of these productions for the region.

In 2023, Melannurca Campana PGI generated €11.5 million in turnover (€2.1 million from exports), followed by Pomodoro San Marzano dell'Agro Sarnese-Nocerino PDO (€8.5 million) and Rucola della Piana del Sele PGI (€2.1 million) (ISMEA & Fondazione Qualivita, 2023).

This gap between economic value and access to alternative water sources highlights the urgent need for targeted infrastructure improvements and protective measures to ensure the sector's resilience and competitiveness amid growing water scarcity.

4. Discussion and conclusions

Water scarcity, combined with the growing and constant demand for water in agriculture, is expected to increase the need for non-conventional water sources, particularly reclaimed wastewater. The regulated and monitored use of treated wastewater helps preserve freshwater resources, alleviates pressure on natural reserves, and strengthens the resilience of agricultural systems. From a purely quantitative point of view, full recycling of wastewater would cover between 38% and 53% of what is needed for Italian irrigation (Fondazione Utilitatis, 2024). This estimate doesn't consider qualitative aspect.

In line with the provisions of the WRR (EU) 2020/741 focused on water quality standards, the methodology proposed in this study – applied to the Campania region – seeks to establish a transferable and replicable framework for linking the quality classes required by different crops with those supplied by WWTPs. The integration of multiple datasets enabled the identification of areas currently unsuitable due to either insufficient water quality or the lack of appropriate distribution infrastructure.

The focus on high-value crops offers a valuable tool for strategic infrastructure planning, targeting both increased agricultural resilience and the protection of PDO and PGI-certified products, which are central to the identity and agri-food economy of Campania and Italy. Crop failure in such contexts not only results in yield loss but also carries significant economic consequences related to quality certifications and brand reputation. In these cases, where produce is often consumed fresh and unprocessed,

the main challenge lies in meeting strict requirements for irrigation water quality – either through investments in WWTPs or by adopting multi-barrier approaches at the supply point.

To date, the few Regions that have identified in their Water protection plans the WWTPs already intended for reuse, need to be updated in accordance with the new regulatory provisions (SNPA – Sistema nazionale protezione ambiente, 2024).

To support this process, methodologies such as the one presented here are essential for identifying current limitations in reuse practices and guiding targeted investment strategies.

The results highlight two key areas for improvement: (1) the capacity of treatment plants to produce water of sufficiently high quality, and (2) the availability of an operational distribution network – such as irrigation consortia or water management entities – that can coordinate reuse across existing infrastructures or, at minimum, manage supply efficiently. This type of assessment is fundamental for determining the technical and economic feasibility of agricultural water reuse, as it considers the entire reuse chain – from production and storage to distribution and field application – at both national and regional scales.

The upgrade of WWTPs is a priority for the reuse (Fondazione Utilitatis, 2024) also addressed by Italian National Recovery and Resilience Plan. Investments on irrigation networks for the distribution of treated urban wastewater were included as eligible actions in the long-term investment strategy of Ministry of Agriculture, Food Sovereignty and Forests (MASAF) (Ferrigno & Zucaro, 2023), receiving approximately the 3% of the available budget for the period 2018-2023 (source: DANIA – National Database of investments for Irrigation and Environment). The Italian CAP Strategic Plan for the 2023-2027 programming period, gives the possibility for funding these interventions, where compliant with WRR (D'Alicandro, 2024).

The proposed methodology is flexible and applicable from various analytical perspectives. It can be replicated in other regions and at different territorial scales, as it relies on data that are uniformly structured and collected across the national and European levels – thanks to databases developed in line with EU policies such as the WRR (EU) 2020/741.

The methodology will be further developed to support the creation of a comprehensive national database that incorporates additional factors influencing the reuse of treated wastewater for irrigation, such as predominant irrigation methods, the presence of environmental constraints (e.g., nitrate-vulnerable zones), and the availability of storage facilities. Furthermore, the quantitative dimension, concerning the balance between the amount of treated wastewater potentially provided by WWTPs and the irrigation requirements in the surrounding areas, is a relevant and parallel

line of research, which lies beyond the primary scope of this study. A cost-benefit assessment based on the value of the affected crops could be an additional future direction for expanding and integrating the methodology applied here.

Conflicts of interest

None. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Marica Furini

Research technologist, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: marica.furini@crea.gov.it

She holds a Master's degree in Conservation and management of the natural, environmental and cultural asset, cum laude, at University of Ferrara. I currently work at CREA-PB, Rome, as a technologist (from July 2022), focusing on water resources management, in particularly about the reuse of reclaimed wastewater for the agricultural irrigation.

<https://orcid.org/0009-0002-4171-8599>

Veronica Manganiello

Research technologist, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: veronica.manganiello@crea.gov.it

The author holds a Master's degree in Biotechnology and a PhD in Economy, Management, and Quantitative Methods, with a research focus on Circular Economy. She is responsible for the SIGRIAN database (National Information System for Water Resources Management in Agriculture) and collaborates on various projects related to agricultural water resource management, with particular attention to environmental and agricultural policies. She also coordinates several institutional agreements and initiatives at both national level and within river basin authorities, aimed at improving the governance and sustainable use of water resources in agriculture. She is co-author of several scientific and technical publications on water use in agriculture.

<https://orcid.org/0000-0003-0348-6600>

Raffaella Pergamo

Senior researcher, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: raffaella.pergamo@crea.gov.it

Based at MASAF's technical office within the National Rural Network, she contributes to rural development policies related to the implementation of the Common Agricultural Policy (CAP) in Italy. Her research focuses on the economic analysis of supply chains, the sustainability of agricultural production, precision and digital agriculture, the circular economy and the conservation of biodiversity. She is the author and co-author of numerous publications, and has presented at various national and international conferences.

Olga Addimanda

Technical Collaborator-VI level, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: olga.addimanda@crea.gov.it

She is a graduate Agro-technical expert in Environmental Sciences with a first-level Master's degree in Sustainable Management of Protected Areas. I have gained experience in strategies for adapting to climate change, and since March 2024 I have been working at CREA-PB in Rome as a Technical Collaborator, dealing with water resource management and the reuse of urban wastewater in agriculture.

Valeria Battaglia

Technical Collaborator-VI level, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: valeria.battaglia@crea.gov.it

She holds a Bachelor's graduate in Environmental Sciences with a thesis in Applied Geology. I currently work at CREA-PB as a Technical Collaborator since December 2024, focusing on the reuse of urban wastewater in agriculture and supporting DANIA database (Italian National Database of Investment for irrigation and environment).

Antonio Manzoni

Researcher, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy); Sant'Anna School of Advanced Studies, Pisa

E-mail: antonio.manzoni@crea.gov.it

He holds a Master's Degree in Law, and a Ph.D. in Agricultural and Environmental Law. I currently work at CREA-PB, Rome, as a researcher (from March 2024), focusing on water resources management, the EU Common Agricultural Policy, and sustainable food systems.

Sofia Galeotti

Technical Collaborator-VI level, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: sofia.galeotti@crea.gov.it

She holds a Master's degree in Agricultural and Environmental Sciences and a PhD in Economics, Management and Quantitative Methods. I started working in 2020 as a research fellow at CREA-PB, focusing on strategies for water resource management in agriculture.

<https://orcid.org/0009-0001-8903-3997>

Manal Hamam

Research technologist, CREA Research Centre for Agricultural Policies and Bioeconomy, Rome (Italy)

E-mail: manal.hamam@crea.gov.it

She holds a master's degree in food science and technology, an advanced master's degree in Agricultural Economics and Policy, and a PhD in Agricultural, Food, and Environmental Science. Since March 2024, she has been working at CREA-PB in Rome as a research technologist, focusing on water resource management and sustainable agri-food systems.

Marianna Ferrigno

Senior Research technologist, Council for Agricultural Research and Economics - Research Centre for Agricultural Policies and Bioeconomy (CREA-PB)

E-mail: marianna.ferrigno@crea.gov.it

The author holds a degree in Environmental Engineering and a Master's degree in Sustainable development and Corporate social Responsibility. She is a Senior Technologist at CREA - Research Centre for Agricultural Policies and Bioeconomy

(CREA-PB), involved in research and technical assistance to Ministry of Agriculture on water use in agriculture, and on planning of water related agricultural policies and public investments for irrigation, in coordination with environmental policies for water. She is Responsible of DANIA database (Italian National database of investment for irrigation and environment). She is the author of several publications and panelist at national and international conferences about water policies and supporting databases. She is coordinator of SMACC project, “Accordo di Cooperazione MASAF-CREA per la ricerca e il supporto istituzionale in merito alle misure di adattamento del settore agricolo ai cambiamenti climatici”, funded by MASAF under Development and Cohesion Fund.

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Special Issue: The Future of Agriculture and Food Industry – Trends and Challenges Guest Editorial

**Mariantonietta Fiore^a, Roberto Leonardo Rana^a, Le Thi Hong Anh^b,
Ho Thanh Tri^a**

^a University of Foggia, Department of Economics, Italy

^b Ho Chi Minh City University of Industry and Trade, Vietnam

Introduction

Agriculture and the food industry are facing unprecedented challenges caused by population growth, climate change, and resource constraints. Global demand for food is expected to increase by nearly 50% by 2050, while arable land and freshwater resources continue to decline (FAO, 2022). These dynamics require innovative and sustainable solutions to ensure food security for all while preserving environmental integrity.

At the same time, digital transformation, biotechnology, and consumer awareness are reshaping the agri-food sector. Digital technologies, including blockchain, artificial intelligence (AI), and precision farming, are enhancing transparency and efficiency in agricultural value chains (Rana *et al.*, 2021; Fiore *et al.*, 2021). Moreover, the COVID-19 pandemic revealed the vulnerability of global supply chains and emphasized the need for resilient and localized food systems (OECD, 2021).

Recent studies emphasize that innovation in the agri-food sector must be framed within a broader paradigm of sustainability and circular economy. According to Galati *et al.* (2024a, 2024b), the transition toward sustainable food systems requires not only technological innovation but also organizational and social changes that promote resource efficiency, waste reduction, and value co-creation among stakeholders. The integration of circular business models – whereby by-products and waste streams are transformed into new resources – represents a strategic pathway to enhance

competitiveness while reducing environmental impacts. In this context, the alignment between digital innovation and circular strategies promotes the development of smart, sustainable agri-food networks that can respond dynamically to global challenges.

Furthermore, the rise of “conscious consumption” and the demand for traceable, high-quality, and ethically produced food are encouraging firms to adopt transparent and data-driven practices (Galati *et al.*, 2024). Through digital tools such as AI, blockchain, and the Internet of Things (IoT) systems, consumers are increasingly integrated into the value creation process, influencing production choices and sustainability strategies. This participatory model not only strengthens trust and brand reputation but also contributes to building resilient food ecosystems rooted in innovation, responsibility, and shared value creation.

Undoubtedly, blockchain, IoT, and AI technology have been recognized as drivers of innovation in various fields, contributing to the creation of a more sustainable world. Indeed, they contribute to reducing bureaucracy and incentivizing environmentally friendly behavior among customers (Rana *et al.*, 2019). However, these technologies should be used carefully since they could contribute to increasing unsustainable activities. For instance, Bitcoin, a cryptocurrency based on blockchain technology, appears to be environmentally unsustainable due to its high energy consumption (Giungato *et al.*, 2017). Moreover, the production and application of AI technology significantly contribute to the exploitation of natural resources and the release of substantial carbon emissions (Bux *et al.*, 2024).

Although these problems, blockchain, IoT, as well as IA, have great potential to improve the sustainability of the agricultural supply chain. However, their diffusion requires some improvements to infrastructure and connectivity, as well as digital literacy among the agricultural stakeholders in the supply chain. Clearly, public administrations, in conjunction with intergovernmental organizations and scholars, play a crucial role in providing guidance toward sustainable agriculture (Rana *et al.*, 2021).

This Special Issue, titled “The Future of Agriculture and Food Industry – Trends and Challenges”, was conceived to provide a platform for sharing new insights into how innovation, digitalization, and sustainability interact in shaping the future of agri-food systems. It collects theoretical and empirical research that highlights the interplay between economic growth, environmental protection, and technological change, particularly in emerging economies such as Vietnam (Nguyen & Pham, 2023).

Furthermore, the transition toward sustainable food systems requires behavioral, managerial, and policy innovations. The integration of green human resource management (Yong & Fawehinmi, 2020), sustainable investment (OECD, 2023), and responsible consumption patterns (Sharma

et al., 2021) is essential for achieving the Sustainable Development Goals (SDGs), particularly 2, 9, 12, and 13. By emphasizing these dimensions, this Special Issue aims to contribute to the global debate on sustainable agricultural transformation and the transition toward greener and more inclusive food systems (Fiore *et al.*, 2019; Jayanama *et al.*, 2021).

An Overview of Papers Presented in the Special Issue

This Special Issue comprises four selected papers that explore diverse aspects of the transformation of the agri-food sector toward sustainability, innovation, and resilience. Together, these studies offer new insights into how consumers, organizations, and policymakers can drive the transition toward a more sustainable and technology-driven food economy.

1. Non-nutritive Sweeteners: Factors Influencing the Choice of University Students in Vietnam write by Thao Nguyen *et al.* This paper examines the behavioral and socio-demographic factors influencing Vietnamese university students' choices regarding non-nutritive sweeteners. Using survey data and multivariate analysis, it identifies perceived health benefits, peer influence, and lifestyle orientation as key determinants of health. Findings suggest that greater awareness and nutrition education can foster healthier consumption choices among young people in developing countries.

2. A Proposed Framework for Blockchain Technology in Vietnamese Domestic Pepper Supply Chain Regarding Authenticity and Traceability write by Le *et al.* Focusing on the pepper industry – a strategic export sector of Vietnam – this article proposes a blockchain-based framework for enhancing authenticity and traceability. The model integrates stakeholders, including farmers, exporters, and certification authorities, demonstrating how blockchain reduces fraud, enhances transparency, and fosters consumer trust. The study emphasizes the significance of digital technologies in ensuring food safety and enhancing market competitiveness.

3. Green Human Resource Management Practices and Sustainable Performance in Vietnam's Agriculture: The Mediating Role of Green Innovation and Green Culture write by Nhung *et al.* This study examines the role of green human resource management (GHRM) in enhancing sustainable agricultural performance, with a focus on the mediating effects of green innovation and organizational culture. Using structural equation modeling (SEM), the authors confirm that GHRM practices promote environmental responsibility and innovation-driven growth. The paper highlights the crucial role of human capital and corporate culture in facilitating green transformation.

4. Agricultural Development versus Environmental Sustainability: FDI, Carbon Emissions, and Global Warming in Vietnam's Economy

write by Toai Doan *et al.* This macroeconomic analysis investigates the relationship between agricultural growth, foreign direct investment (FDI), and environmental degradation. The study finds that while FDI enhances productivity and modernization, it can increase carbon emissions if not aligned with green policies. Results underscore the need to integrate climate-conscious investment frameworks to ensure that Vietnam's agricultural expansion remains both economically viable and environmentally sustainable.

Collectively, these contributions demonstrate how Vietnam's agri-food sector reflects broader global trends toward balancing growth with sustainability, highlighting opportunities for innovation, policy reform, and capacity building.

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Non-nutritive sweeteners: Factors influencing the choice of university students in Vietnam

Nguyen Thi Thao^a, Vu Hong Son^a, Ngo Xuan Bach^a, Tran Phuong Linh^a,
Nguyen Thi Minh Tu^a, Le Thi Hong Anh^{*,b}

^a Hanoi University of Science and Technology, Vietnam

^b Ho Chi Minh City University of Industry and Trade, Vietnam

Abstract

This study explores the factors that influence Vietnamese university students' food choices when it comes to products containing non-nutritive sweeteners (NNSs). Drawing on consumer behavior theory and insights from focus group discussions, a conceptual model was developed with five independent variables – Health Perception, Acceptance, Product Properties, Beliefs, and Availability – and one dependent variable – Food Choice. A survey was then conducted both online and offline with 1,849 responses and further reduced to 936 valid responses after two rounds of data cleaning. Data from the survey were analyzed for reliability, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and structural equation modeling (SEM). The results confirmed a good model fit with strong convergent and discriminant validity. Three factors significantly influenced food choices were: Acceptance ($\beta = 0.463$), Health Perception ($\beta = 0.235$), and Availability ($\beta = 0.141$), with Acceptance being the most influential. These findings offer valuable insights for businesses and organizations aiming to promote NNS-containing products more effectively. Understanding the key drivers behind students' food choices can help stakeholders tailor their products and communication strategies to better meet consumer needs and encourage healthier dietary habits.

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* Corresponding author: Le Thi Hong Anh - Ho Chi Minh City University of Industry and Trade, Vietnam. E-mail: anh1th@huit.edu.vn.

Introduction

Sugar is a crystallized, water-soluble organic molecule that has the general formula $(CH_2O)_n$, having essential role in food manufacturing, such as flavor enhancement, energy production, preservation, structure and aesthetic application, processing facilitation. However, there is evidence that the excess consumption of sugar can be prone to some diseases and disorders such as oral illness, non-communicable diseases, disorder of the biliary system, risk in cognitive function and some issues during pregnancy (Arshad *et al.*, 2022). In purpose of limiting those risks, WHO has released the guidance for adults and children that state crucial recommendations on reducing free sugar intake to less than 10% of total energy intake and throughout the life course (*Sugars Intake for Adults and Children*, n.d.). In Vietnam, to reduce the excess of sugar in sugar-sweetened beverages SSBs, the National Assembly has passed the amended Law on Special Consumption Tax for 10% on sugary drinks with sugar content over 5g/100ml (*Sugary Drinks, Alcohol, and Cigarettes to Face Higher Taxes in Vietnam*, n.d.). Under the pressure from regulatory bodies, health organizations, and the increased interest of consumers in health, businesses have to figure out strategies to reduce the impact of sugar on their products. One popular idea is to use substituting sweeteners to replace the sweet taste in the product, leading to a reduction in sugar content. In general, sweeteners are food additives (coded with an E-number), which are used to mimic the sweet taste of sugar in the product. Based on commercial purposes, there are some criteria for sweeteners to be fulfilled, including adequate sweetening capability, satisfactory aftertaste, non-carcinogenic and non-mutagenic, appropriate price, thermostable and produce minimal to no calories (Gupta, 2018).

Although non-nutritive sweeteners have been widely used in the food industry, many consumers remain concerned about this additive. Young consumers, who are impacted by the media and market trends, are among the demographics that should be worried about. Their awareness, perceptions and behavior in choosing products containing NNS can be influenced by many factors: psychology, nutritional knowledge, taste sensation, brand image, or perceptions of “food safety”. To remove customers’ psychological barriers, businesses need to determine appropriate promotional strategies based on previous academic evidence. Furthermore, governments and international organizations are also interested in understanding young population decision-making on foods containing NNSs, to create suitable policies on a broad basis.

In Vietnam, in-depth studies on consumer behavior for products containing non-nutritive sweeteners are quite limited. Therefore, research on factors affecting the behavior of choosing these products is not only essential

in terms of academics but also highly practical, contributing to support businesses, legislators and health organizations in building development strategies, nutrition communication and raising public awareness. Accordingly, the topic “Research on factors that influence the choice of non-nutritive sweeteners among university students” is a significant field of study that is appropriate for the current practical context and has high application value in the area of food technology and public health.

1. Background

1.1. Non-nutritive sweeteners

Non-nutritive sweeteners (NNSs) are high-intensity sweeteners (can be thousands of times sweeter than sucrose – a table-top sugar) and have non-caloric value. This term does not include sugar alcohol, or polyols (e.g., sorbitol, maltitol, xylitol), a category of sweeteners that can also be used to mimic the sweet taste of sugar in foods and beverages. In some research, there is a misconception that NNSs refers to artificial sweeteners. Artificial sweeteners are the subset of NNSs, which refer to synthetic, non-caloric sweeteners created through chemical processes in laboratories. NNSs are also included of natural sources, for instance, Stevia is derived from plants.

Although sugars, polyols and NNSs all contribute to sweetness, their mechanisms are slightly different. Sweet taste perception begins with chemosensory cells in the tongue and gastrointestinal tract. In taste bud, there is an aggregate of 50–100 neuroepithelial cells, include type II cells that responsible for sweet, umami and bitter taste detection through G protein-coupled receptors (GPCRs). Taste 1 receptor family member 2 (T1R2) and taste 1 receptor family member 3 (T1R3) are two different GPCRs that make up the receptor that facilitate the detection of sweetness. Furthermore, the formation of T1R2/T1R3 homodimer can detect monosaccharides and disaccharides at high concentrations (Lee & Owyang, 2017). The difference is that while sugars bind selectively to the venus flytrap domain of the T1R2 subunit, exhibit partial agonism of the T1R2/T1R3 receptor, primarily interacting with the transmembrane domain of T1R3. On the other hand, various types of NNSs result in different binding sites. For example, NNSs with artificial sources are similar to sugar (but higher affinity), but for natural NNSs, they interact with T1R3 transmembrane domain (Servant *et al.*, 2010).

1.2. Regulation approval and implementation

Regulatory approval of NNSs varies globally, with bodies such as the Joint FAO/WHO Expert Committee on Food Additives (JECFA) or Food and Drug Administration (FDA). Since Aspartame is approved by FDA or recognized as Generally Recognized as Safe (GRAS), JECFA has yet to publish a formal safety evaluation. In Vietnam, regulations on the use of food additives and its Accepted Daily Intake (ADI), which include NNSs, are referred to JECFA, Fragrance and Extract Manufacturers Association of the United States and European Parliament and Council European Parliament and Council. According to the circular 24/2019/TT-BYT of the Ministry of Health, there are total of 8 substances that are approved to use in Vietnam, namely Acesulfame potassium (E950), Aspartame (E951), Cyclamate (E952), Saccharin (E954), Sucralose (E955), Alitame (E956), Steviol glycoside (E960), Neotame (E961).

NNSs have been more preference in the wide range of food industry as a sugar substitute, such as beverage, dairy products, chewing gum or confectionary. It is noticeable that different substances are used for their own specific product types. For instance, while Acesulfame potassium and Aspartame are commonly used in beverages, Sucralose is often added in baked goods. The market of foods containing NNSs is various in different regions and continents. The research assesses across 4 countries show that Mexico is leading in percentage of product with NNSs components (11%) compared to the US (4%), New Zealand (1%) and Australia (< 1%) (Dunford *et al.*, 2018). It is also noticeable that the US and Mexico had larger proportions of products containing NNSs and higher levels of total sugar concentrations compared to Australia and New Zealand. Another research in Brazil indicates that NNSs were found in 7.7% in total sample of 11,434 packaged product (Fagundes Grilo *et al.*, 2022). Beyond food manufacturing, NNSs also have crucial implementation in the pharmaceutical industry, including medicated lozenges, functional foods and vitamin/mineral chewable.

1.3. Awareness, perception and behavior of consumers

Food choices and the acceptance of NNSs are significantly influenced by consumer perception and awareness. When studying consumer knowledge, awareness and behavior, the research subjects are often low-calorie sweeteners or artificial sweeteners. Those studies often have confusion when combining sugar alcohol (polyols) and NNSs, but they are generally useful as a resource for consumer psychology. Products using NNSs as a partial sugar

substitute (or complete sugar substitute) are becoming increasingly popular, especially in sugar-sweetened beverages or confectionery products (Naveed *et al.*, 2024; Alharthi *et al.*, 2023; Jurcevic Zidar *et al.*, 2025). Consumers may consider the taste of products containing NNSs before consuming them. Some products have a bitter aftertaste when used, making customers feel unsatisfied (Naveed *et al.*, 2024; Daher *et al.*, 2022; Jaruga-Sękowska *et al.*, 2022). Consumers tend to be concerned about the use of artificial sweeteners and often consider stevia to be safe and consume it frequently (because stevia is naturally derived) (Naveed *et al.*, 2024; Alharthi *et al.*, 2023; Laja García *et al.*, 2022). In addition, aspartame or acesulfame K are also widely available on the market (Naicker *et al.*, 2024; Jurcevic Zidar *et al.*, 2025).

Intention to use products containing NNSs may change if consumers have more knowledge related to this substance. It can be motivation for consumers, since NNSs is commonly being marketing as healthy ingredients (Naveed *et al.*, 2024; Alharthi *et al.*, 2023; Jurcevic Zidar *et al.*, 2025). Furthermore, public knowledge of NNS's types, purposes, and safety features is still limited across a range of demographics, despite the increasing prevalence of NNS and food containing them worldwide. 2 items that are significantly correlated to consumers' behavior are age and gender. Some demographic disparities, including major of study, weight status or dietary can be involved in some research, but there is still much controversy and remain undefined due to different results for each topic.

While children and adolescents exhibit limited awareness about types of NNSs or health implications, because the use of these products is determined primarily by their parent; young population (18-35 years) demonstrate higher awareness and consumption of NNSs and foods containing products, driven by weight management goals and perceptions of modernity (Jurcevic Zidar *et al.*, 2025); Apergi *et al.*, 2024). Nonetheless, it is evident that this group shows conflicting beliefs, with some putting a higher priority on the benefit of energy reduction and others being caution on "artificial" sources. Middle-aged and older adults (45 years old and above) are more aware of the link between NNSs and chronic disease management (e.g., diabetes), but they are also more skeptical about their long-term safety and frequently prefer natural sweeteners (Alharthi *et al.*, 2023; Laja García *et al.*, 2022).

Women report higher awareness of NNS types (e.g., aspartame, sucralose) and greater consumption of food containing NNSs with motivation of weight control, even though they show greater concerns about safety, pointing to worries about "artificiality", metabolic consequences, and carcinogenicity (Alharthi *et al.*, 2023; Farhat *et al.*, 2021). In contrast, men prioritize performance and practicality about NNSs and food containing them. Even though they are less likely to associate NNS with health risks, they are more inclined to reject NNSs because of its aftertaste (Jurcevic Zidar *et al.*, 2025).

1.4. Consumer behavior

Consumers behaviour can be defined in numerous ways, but in general, it can be said that “consumer behavior is a marketing discipline that studies the behavior of individuals, groups or organizations and the processes they use to select, secure, use and dispose of products and services, experiences or ideas to satisfy needs and the impacts that these processes have on the consumers and society” (Adis, 2012). Kotler define consumer behavior as “the study of how individuals, groups, and organizations select, purchase, use, and dispose of goods, services, ideas, and experiences to satisfy their needs and wants” The strength of Kotler’s model is combining buyer characteristics (cultural, social, personal, and psychological aspects) with marketing stimuli (the 4Ps: product, price, place, and promotion). For that reason, it clarifies the “black box” of buyer psychology and provides useful insights into how outside efforts influence consumer behavior. The term “black box” is referred to cognitive process mediating between external marketing stimuli and observable behavioral responses.

The Theory of Planned Behavior (TPB) was the expansion of the Theory of Reasoned Action model (TRA) of Fishbein and Ajzen (1975), in which volitional behavior was described and predicted. It was defined as “the causal links from beliefs, through attitudes and intentions, to actual behavior; to understand the psychological determinants of volitional behaviors”. The basic assumption of this model is that people usually consider the information at their disposal and think through the consequences of their choices either directly or implicitly. There are 2 fundamental components: (1) attitudes toward the behavior, reflecting an individual’s positive or negative evaluation of performing a specific action based on expected outcomes and their desirability; and (2) subjective norms, capturing perceived social pressure from significant referents weighted by the individual’s motivation to comply with those expectations. The strength of the TRA theory is about providing mechanistic clarity, with attitudes derived from salient behavioral beliefs multiplied by outcome evaluations, while subjective norms emerge from normative beliefs multiplied by motivation to comply.

The use of non-nutritive sweeteners (NNS) as substitutes for traditional sugars remains a subject of ongoing debate, particularly concerning the appropriate dosage for safe and effective food consumption. Although the World Health Organization (WHO) has issued guidelines regarding their application, these recommendations appear to have limited reach and influence among younger consumer demographics. This research aims to understand young consumers by investigating the factors influencing attitude and the choice of food products containng NNS among university students in Vietnam. The study is guided by three specific objectives: (i) To develop

a model of factors influencing the choice of NNS containing products, (ii) To validate the hypotheses within the proposed model and (iii) To assess the impact of these factors on attitudes towards NNS-containing products among the target group.

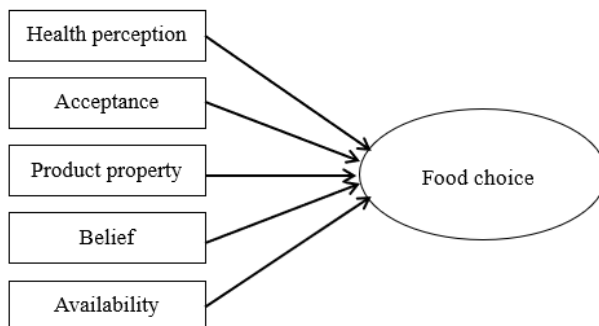
2. Materials and methods

2.1. Questionnaire design

The proposed research model is developed based on previous theoretical frameworks and model of consumers behavior (Figure 1). In developing the research model for this study, we have anchored our approach in the Theory of Planned Behavior (TPB), which assumes that people usually consider the information at their disposal and think through the consequences of their choices either directly or implicitly. This model includes three components: “Attitude” (an individual’s evaluative judgment of performing a specific action), “Subjective norms” (belief in other referent subjective to engage or refrain from a behavior) and “Perceived behavior control” (facilitators or obstacle that may lead to decision-making). The reference materials are prior to studies about factor impact on the selection of consumers. However, to ensure the selected factors within these constructs were contextually relevant to young Vietnamese consumers, the theoretical model was refined and validated through an inductive, qualitative phase. Prior to survey distribution, two focus group discussions were conducted with students aged 18-35 possessing background knowledge in nutrition, food science, and public health. After two sessions, we had identified 5 key factors and 21 items that influence attitude and subjective norms through a comprehensive literature review. These factors encompass personal concerns, product-related information, and external influences, precisely health perception, acceptance, property of products, belief, availability. Each item was measured on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree), which allows respondents to indicate the degree of their agreement and provides a reliable means of **quantifying** attitudes and perceptions related to food choice. According to Hair *et al.*, the minimum sample can be calculated by the ratio 5:1 of an observed variable plus 50, which is a total of 155 respondents.

Health perception forms a core component of attitude, encompassing the consumer’s evaluation of the health benefits that associated with NNSs, which directly impacts their consumption behavior. Acceptance relates to the consumer’s willingness to use products containing NNSs, whether intentionally or unintentionally, without being deterred by their presence, reflecting a behavioral intention that may not be driven by strong prior

Figure 1 - Proposed theoretical research model



Based on the proposed theoretical model, 5 hypotheses were developed as following:

H1: Health perception of NNSs is positively related to the consumers' choice of NNSs and foods product containing them*

H2: Acceptance of NNSs is positively related to the consumers' choice of NNSs and foods product containing them*

H3: Property of products contain with NNSs are positively related to the consumers' choice of NNSs and foods product containing them*

H4: Belief in NNSs is positively related to the consumers' choice of NNSs and foods product containing them*

H5: Availability of NNSs is positively related to the consumers' choice of NNSs and foods product containing them*

* At offline survey, tasting with sweet drink ginger flavored under form of spice-sugar to assess NNS health perception in a culturally familiar context provided by T2022-PC-095.

beliefs. The property of products, including price, origin, and sensory qualities, represents a central consideration in the formation of attitudes, as consumers assess these tangible attributes against their needs and preferences. Within the subjective norms construct of the TPB, belief captures the external impact of institutional, social, and cultural information on the consumer's trust and assessment of NNS products. Finally, availability serves as a critical dimension of perceived behavioral control, determining the physical and economic accessibility of these products and thus facilitating or constraining the translation of intention into actual purchase behavior. Together, these factors provide a comprehensive framework for understanding the variables behind food choices related to food containing NNSs.

2.2. Participants

The research is focused on youth participants taking universities' degrees aged 18-35 years old, who are voluntarily answering the survey. Although the

respondents were studying at universities in Hanoi and Ho Chi Minh City, they originally came from many different provinces across Vietnam, which strengthens the representativeness of the sample. Those with specialized knowledge in food, nutrition, medicine, chemistry, etc., as well as those who studied other majors, made up a diverse group of survey respondents. This target demographic was chosen because they have ready access to information, are vulnerable to new consumer trends, and tend to be more aware of concerns related to weight control and product nutrition. In addition, young consumers are also a potential customer group for products using non-nutritive sweeteners. After conducting the survey, the sample consists of 1867 respondents over 1934 distributed survey, showing a response rate of 96.5%, reflecting the prominent level of interest of the participants. After cleaning data, there are 935 observations, including 627 female and 303 males (5 nonbinary).

2.3. Data analysis

Reliability analysis and Exploratory Factor Analysis (EFA) were involved in SPSS 26.0. A scale is considered reliable if its observed variables have a Corrected Item-Total Correlation greater than 0.3; Cronbach's Alpha coefficient greater than 0.7. Also, the Cronbach's Alpha when item deletes can be lower than basic coefficient of its factor. For EFA, some indexes to consider are Kaiser-Meyer-Olkin (KMO) ≥ 0.5 , the significance (Sig.) coefficient of Bartlett test ≤ 0.05 , Eigenvalue ≥ 1.0 , and total variance explained $\geq 50\%$. Additionally, factor loadings of all observed variables must be ≥ 0.40 , and the difference between the cross-loadings factors must be > 0.2 .

AMOS 24.0 was used to conduct Confirmatory Factor Analysis (CFA) and Structure Equation Modelling (SEM). Model fit was examined in CFA, which include Chi-square/df (CMIN/df) ≤ 5 , Comparative Fit Index (CFI) ≥ 0.9 , Goodness-of-Fit Index (GFI) ≥ 0.9 , Tucker-Lewis Index (TLI) ≥ 0.9 , Root Mean Square Error of Approximation (RMSEA) ≤ 0.06 . In addition, reliability, convergence and discrimination can be guaranteed, with composite reliability (CR) ≥ 0.70 , Average variance extract (AVE) ≥ 0.50 , Maximum Shared Variance (MSV) $< \text{AVE}$ and $\sqrt{\text{AVE}} > \text{Inter - construct Correlation}$. SEM examines the relationships between factors representing factors influencing young consumers' choice of products containing non-nutritive sweeteners. While the p-value of Unstandardized Regression Weights is a crucial component of null hypothesis significance testing, its standardized estimate represents the strong or weak impact of independent factors on a dependent factor. The coefficient of determination R squared is calculated to predict the proportion of how dependent factors can be explained.

3. Results

3.1. Descriptive analysis

After conducting the survey in both online and offline formats, the total number of distributed surveys was 1934 and the total number of questionnaires collected was 1867 respondents, showing a response rate of 96.5% reflecting the prominent level of interest of the participants. The number of results collected is higher than the minimum sample size that is previously calculated in the above section (2.1). The data underwent a two-stage cleaning process before the final analysis. In the first stage, questionnaires were considered valid only if fully completed, which resulted in the removal of 18 incomplete responses and resulted in 1,849 valid cases. Most survey participants were university students aged 18-22 years old and females were overrepresented (64.5%). Over half of the participants reported having a normal weight (53.9%), while 8.5% were overweight and 2.5% obese. Table 1 shows descriptive analysis. In the second stage, additional exclusions were applied based on specific criteria, including respondents who reported no prior awareness of NNSs and those who provided identical responses across all survey items. Following this two-step procedure, the final data set consisted of 935 valid observations. Reliability test and Exploratory Factor Analysis (EFA).

Table 1 - Sample description

Socio-demographic characteristic		Frequency	Percentage
Gender	Male	303	32.4%
	Female	627	67.1%
	No answer	5	0.5%
Major of education*	Food & Nutrition	689	
	Medicine & Pharmacy	6	
	Others	249	
BMI status	Underweight	189	20%
	Normal	515	55%
	Pre-obesity	73	8%
	Obesity	12	1%
	No answer	146	16%

Independent variances: Table 2 shows the pattern matrix of exploratory factor analysis EFA of independent factors. The supplementary Table (in the appendix) provides detailed information of variables for each independent factors. Cronbach's Alpha coefficients of all factors ranged from 0.832 to 0.944, which implies that the factors have good internal consistency. The Corrected Item-Total Correlation of the items in the factor group are all greater than 0.3. Therefore, 21 items were conducted for EFA, with The Principal Component method for extraction and Varimax rotation were applied. The 1st EFA test revealed 3 cross-loading factors that have been

Table 2 - Pattern matrix of EFA of independent factors

Factor	Item	Component					Cronbach's alpha		CITC ^b
		1	2	3	4	5	General	IID ^a	
AV	AV2	0.900					0.934	0.907	0.867
	AV3	0.890						0.909	0.863
	AV4	0.887						0.909	0.861
	AV1	0.812						0.931	0.791
HP	HP2	0.874					0.898	0.859	0.802
	HP4	0.845						0.861	0.796
	HP3	0.831						0.879	0.748
	HP1	0.809						0.876	0.756
RI	RI2	0.908					0.926	0.876	0.868
	RI1	0.902						0.889	0.853
	RI3	0.879						0.912	0.824
AC	AC2	0.815					0.832	0.756	0.729
	AC1	0.791						0.797	0.651
	AC4	0.784						0.765	0.713
	AC3	0.690						0.827	0.571
ST	ST2	0.846					0.869	0.801	0.775
	ST1	0.816						0.826	0.745
	ST3	0.807						0.816	0.749
Bartlett's test of Sphericity	Approx. Chi-square		2146.095			Eigenvalues		1.186	
	Freedom degree (df)		231						
	Significance level (Sig.)		0.000			KMO		0.887	

Note: ^a Cronbach's alpha if item deleted; ^b Corrected Item-total correlation.

eliminated to ensure discrimination. Also, items of BE were extracted into 2 new groups, suggesting that 2 new factors were formed: “Reputable information” (RI) and “Social trust” (ST). For the 2nd EFA, the construct was validated, with the Kaiser-Meyer-Olkin was 0.887, and the Sig. value of Barlett’s test was 0.000. The lowest Eigenvalue was 1.186 at the 5th factor, and 79.478% of the data is explained through 5 factors.

Dependent variance: Reliability analysis shows strong internal consistency, with Cronbach’s Alpha coefficients exceeding 0.7, and Corrected Item-Total Correlations greater than 0.3. Therefore, no observed variables were removed from the analysis. The criteria for sampling adequacy in EFA test are accepted, with KMO = 0.909 > 0.5 and Sig. = 0.000 < 0.005. It indicates that the items are correlated with each other. A single factor is extracted, with 81.621% of the data is explained by 1 factor, and Eigenvalue is 4.081.

Table 3 - Pattern matrix of EFA of dependent factors

Factor	Item	Component	Cronbach's alpha		CITC ^b	KMO	0.909
		1	General	IID ^a			
FC	FC3	0.917	0.944	0.927	0.866	Eigenvalue	4.081
	FC4	0.917		0.927	0.866		
	FC5	0.914		0.928	0.862		
	FC2	0.901		0.931	0.844		
	FC1	0.867		0.939	0.796		
						Sig. of Bartlett test	0.000

3.2. Confirmatory Factor Analysis (CFA)

After conducting CFA, all of the structural criteria of model fit were fulfilled, with the result show acceptable to very good value (CMIN/df = 4.388; GFI = 0.911; CFI = 0.957; TLI = 0.949; RMSEA = 0.060; PCLOSE = 0.000) (Table 4). In addition, the scale also reveals a good evaluation on both reliability, convergent and discriminant validity (Table 5). The results of Table 5 show that: CR of each factor is greater than 0.7, so the scales ensure good reliability. AVE of each factor is greater than 0.5, indicating that convergence is guaranteed. MSV of each factor is lower than AVE, indicating that discrimination is guaranteed. In addition, (Font is displayed in bold format and grey theme) is greater than the correlation between that variable and other variables (Font is displayed in italic format and grey theme) in the model. To sum up, discrimination is guaranteed.

Table 4 - Model Fit Measures

Index	Criteria	Result	Rating
CMIN/df	≤ 5	4.388	Acceptable
GFI	≥ 0.9	0.911	Good
CFI	≥ 0.95	0.957	Very good
TLI	≥ 0.9	0.949	Good
RMSEA	≤ 0.06	0.060	Good
PLOSE		0.000	

Table 5 - Model Validity Measures

	CR	AVE	MSV	AV	HP	RI	AC	ST	FC
AV	0.935	0.783	0.206	0.885					
HP	0.900	0.692	0.285	0.298***	0.832				
RI	0.926	0.807	0.206	0.454***	0.235***	0.898			
AC	0.836	0.562	0.440	0.359***	0.477***	0.081*	0.749		
ST	0.873	0.696	0.324	0.361***	0.495***	0.263***	0.569***	0.834	
FC	0.944	0.771	0.440	0.409***	0.534***	0.191***	0.663***	0.499***	0.878

p-value < 0.001 is denoted by ***, p-value < 0.050 is denoted by *

3.3. Structural Equation Modeling (SEM)

The results of the SEM analysis, following the CFA, provide insights into the effects of the five factors on Attitude and Willingness to Try (Figure 2). The standardized parameters of the SEM model all meet the necessary criteria for SEM, indicating that the proposed model is a good fit for the actual data. The results of the SEM model, as shown in Table 6. After conducting confirmatory factor analysis (CFA) to test the fit of the scale to market data, data is analyzing structural equation modeling (SEM) to examine the relationships between factors representing factors influencing young consumers' choice of products containing non-nutritive sweeteners.

The unstandardized p-value of RI and ST is higher than 0.05, rejecting the hypothesis that "Reputable information" and "Social trust" are positively impact on the selection of NNSs and foods containing it. The estimate value of standardize regression weight demonstrate that factor "Acceptance" has largest impact on food choice (0.463), follow by "Health perception" (0.235) and "Availability". The coefficient of determination R squared is 0.525, which means that the predictors of FC explain 52.5% of its variance.

Figure 2 - Standardized SEM model

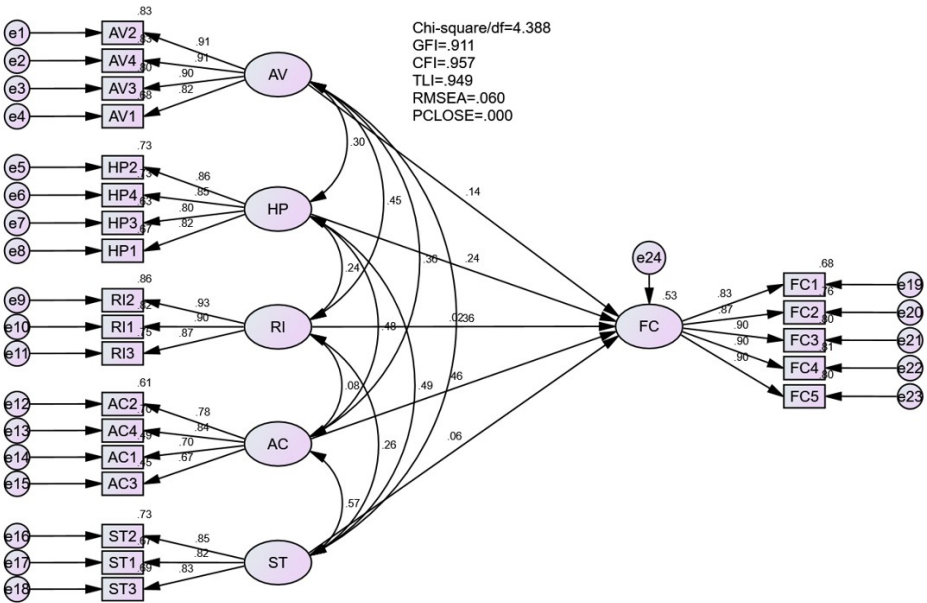


Table 6 - Regression Weights and Standardized Regression Weights

Relationships			Unstandardize p-value	Standardize Estimate
FC	←	AV	***	0.141
FC	←	HP	***	0.235
FC	←	RI	0.569	0.018
FC	←	AC	***	0.463
FC	←	ST	0.090	0.064

3.4. Discussion

During the focus group, information related to NNS was exchanged by the participants in a positive and constructive manner. Opinions on factors influencing the choice of NNS were discussed. Some interesting perspective mentioned by the participants may include: “when using sweets, I do not pay much attention to the ingredients that produce this taste”, “the taste is quite fake” or “products with big brands give me more trust”. This is similar to previous qualitative research in the UK (Tang *et al.*, 2021). However,

although the session can achieve consensus from various people, it remains limitation that lack of exploit the in-depth thoughts of everyone (Guest *et al.*, 2017). Therefore, it is possible to conduct focus group and individual interviews in parallel to better understand the knowledge and attitude toward NNSs. At the same time, the processes in the focus group discussion can be further developed according to the 6-step thematic analysis.

After conducting EFA, “Product property” factor was omitted from the model. When proposing the theoretical model, this factor included many variables surrounding the criteria of product quality. However, according to previous studies (Lru *et al.*, 2024; T Ha *et al.*, n.d.), these variables were separated into each individual factor (e.g., price, safety). Therefore, grouping them together may cause these items to be cross-loaded and eliminated.

According to SEM analysis, “Official information” and “Social trust” have no impact on choice in the model, showing that young people today are less interested or do not rely much on these sources of information in the consumer decision-making process. However, some studies have evident that factors such as the law will reinforce customers’ consumption decisions, or consumers often look for nutritional information on social media (Naveed *et al.*, 2024; Alharthi *et al.*, 2023; Jurcevic Zidar *et al.*, 2025). There are several explanations for this situation as follows: First, young people often prioritize personal experiences and real feelings over recommendations from official organizations such as WHO, FDA or nutrition experts. They tend to trust their intuition and consumption habits rather than learn about scientific information. Second, when conduct the survey, there was various conflicting information in Vietnam related to unhealthy and unsafe food. This resulted in the decline in consumers’ beliefs, which significantly affects their answer in the survey. Last but not least, lack of information verification and clarity of marketing on social networks, consequence in university students reduce their trust in sources from KOLs, online newspapers or celebrities. Although they are often exposed to digital media, they still have a certain level of caution. However, it should be noted that the effects of social trust and reputable information may vary depending on the country, food type, and information source used. For example, the research of traceable fresh food in Taiwan found that trust in the government had no direct impact on perceived healthiness and repurchase intention, while trust in the producer or certification had a significant impact (Wang *et al.*, 2021). Similarly, a UK study on the influence of social media influencers also found that trust in influencers sometimes did not increase but even decreased purchase intention (Adaba, 2025). This evidence suggests that the lack of impact found in the current study is not unusual but reflects the complexity and context-dependent nature of food consumption behavior among college students. Furthermore, according to a review on consumer trust in food and the food system,

consumers often rely on multiple trust signals, such as labeling, certifications, traceability, and assurances from relevant stakeholders, to assess food quality, especially when quality attributes cannot be directly observed (Hobbs, 2021).

Three factors “Acceptance”, “Health perception” and “Availability” were retained after data processing, demonstrating that they contribute to university students’ decisions to consume NNSs and foods containing them. Among them, “Acceptance” is the factor that has the greatest influence on consumer choice. This shows that part of the consumers think that their choice is obvious and willing to accept the presence, leading to them not paying attention to the ingredients on the packaging when choosing food. This is consistent with a previous study in Africa (Naicker *et al.*, 2024). In this regard, reputable organizations need to publish appropriate policies to raise consumer awareness of NNSs, as their use is becoming more and more popular. At the same time, “Health perception” and “Availability” are also related to customer choice, reflecting the trend of healthy eating and calorie control is increasingly, and the popularity and accessibility of NNSs and food containing in the market (e.g., supermarkets, stores, and e-commerce platforms).

The study provides a useful basis for future research with both practical and scientific implications. First, the findings can be applied to design and evaluate interventions or communication programs that aim to change awareness and consumption behavior among young people. In addition, longitudinal studies could be conducted to examine how attitudes and behaviors change when living conditions, social environments, and personal experiences shift, thereby clarifying the stability or variability of influencing factors. Furthermore, extending the research to other countries would allow comparisons of cultural and policy differences in food consumption decisions. Experimental studies could also be implemented to test the impact of warning labels, safety certifications, or recommendations from international organizations on consumer choices. Finally, linking consumer perceptions and behaviors with health indicators would provide stronger evidence on the relationship between trust, consumption decisions, and health outcomes.

In addition to the results achieved, this research topic still has certain limitations. Specifically, it focuses on the university students instead of young consumer group in Vietnam. The trend of consuming healthy foods is not only emphasized by the younger generation but also of interest to other age groups, particularly middle-aged and older adults. Broadening the scope to include different age groups and exploring these drivers more thoroughly would provide policymakers and food producers with a more comprehensive understanding of non nutrition sweeteners consumption in Vietnam.

Conclusions

This study developed a comprehensive model to understand the factors influencing food choice towards non-nutritive sweeteners containing products amongst students in Vietnam. The model includes 21 observed variables categorized into five factors influencing attitudes and three factors influencing food choice among universities students. The findings indicate that 3 factor “Acceptance”, “Health perception” and “Availability” were retained after data processing, demonstrating that they contribute to university students’ decisions to consume NNSs and foods containing them. Among them, “Acceptance” is the factor that has the greatest influence on consumer choice. This shows that part of the consumers think that their choice is obvious. These insights can guide local manufacturers and policymakers in developing strategies to enhance consumer acceptance and drive the transition towards sustainable dietary practices.

Future research should consider expanding the sample beyond university students to include diverse demographic groups for broader generalizability. Longitudinal studies could provide deeper insights into how consumer attitudes toward non-nutritive sweeteners (NNSs) evolve over time. Additionally, incorporating variables such as cultural influences, marketing exposure, and peer dynamics may offer a more comprehensive understanding of food choice behavior. Qualitative methods, such as in-depth interviews, could also complement survey findings by capturing nuanced consumer perceptions and motivations.

Acknowledgements

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Supplementary table

Description of factor-item

Factor	Code	Item
Health perception	HP1	The consumption of non-nutritive sweeteners or the intake of foods containing them could improve the quality of your diet
	HP2	The consumption of non-nutritive sweeteners or the intake of foods containing them could help improve body weight control
	HP3	The consumption of non-nutritive sweeteners or the intake of foods containing them could help you reduce the risk for diabetes
	HP4	The consumption of non-nutritive sweeteners or the intake of foods containing them could help you improve dental health
Acceptance	AC1	I think it is unimportant to check on the packaging whether a food contains non-nutritive sweeteners or not
	AC2	I have more important things to do than worry about non-nutritive sweeteners
	AC3	I can accept that certain foods contain non-nutritive sweeteners
	AC4	Non-nutritive sweeteners cannot be harmful; otherwise, they would not be contained in so many foods
Reputable information	RI1	Regulatory authorities and governmental agencies effectively evaluate and authorize foods containing non-nutritive sweeteners to ensure consumer safety
	RI2	I have confidence in the assessments and guidance of international organizations (e.g., FDA, WHO, EFSA, JECFA) and professional scientific associations regarding the use of non-nutritive sweeteners
	RI3	I trust the recommendations of nutritionists, medical practitioners, and public health experts about non-nutritive sweeteners and food containing them
Social trust	ST1	I consider information about non-nutritive sweeteners published in reputable nutrition and health blogs, mainstream media outlets, and professional social-media channels to be reliable
	ST2	I assume that endorsements of non-nutritive sweetener products by key opinion leaders (KOLs), influencers, and public figures reflect careful selection of safe, high-quality formulations

	ST3	When my friends or family members consume or recommend the use of foods containing non-nutritive sweeteners, I feel more assured about trying them myself
Availability	AV1	I can easily buy non-nutritive sweeteners and products containing them on e-commerce platforms
	AV2	I am able to find non-nutritive sweeteners and food containing them in my local area
	AV3	Non-nutritive sweeteners and food containing them are often available in supermarkets and retail store
	AV4	Non-nutritive sweeteners and food containing them are typically placed in easy-to-locate sections
Food choice	FC1	I intend to use foods containing non-nutritive sweeteners in the near future
	FC2	I will prioritize choosing food containing non-nutritive sweeteners over those with table sugar
	FC3	I am willing to purchase foods that contain non-nutritive sweeteners
	FC4	I will recommend foods containing non-nutritive sweeteners to my family and friends
	LC5	I plan to use non-nutritive sweeteners and foods containing them over the long term

Nguyen Thi Thao

Hanoi University of Science and Technology, Vietnam
Dai Co Viet Road, Hanoi, Vietnam
E-mail: thao.nguyenthi@hust.edu.vn

She holds Engineer degree in Food Engineering from Hanoi University of Science and Technology (Vietnam), a Master degree in Food Science and Technology from Ghent University, (Belgium), PhD degree in Food Science from Ehime University (Japan). Her research interests include food safety and quality management, healthy nutrition, food chemistry and food system.

Vu Hong Son

Hanoi University of Science and Technology, Vietnam
Dai Co Viet Road, Hanoi, Vietnam
E-mail: son.vuhong@hust.edu.vn

He holds Engineer degree in Food Engineering, Master degree and PhD degree in Food Technology from Hanoi University of Science and Technology (Vietnam). His research interests include food analyses, food safety and quality management, food chemistry and application of data analysis in consumer researches.

Ngo Xuan Bach

Hanoi University of Science and Technology, Vietnam
Dai Co Viet Road, Hanoi, Vietnam
E-mail: nxbach.190602@gmail.com

He holds Bachelor degree in Food Engineering, and pursuing a Master degree in Food Technology from Hanoi University of Science and Technology (Vietnam). His research interests include food sustainability and consumer behaviours.

Tran Phuong Linh

Hanoi University of Science and Technology, Vietnam
Dai Co Viet Road, Hanoi, Vietnam
E-mail: linhhttp03@gmail.com

She holds Bachelor degree in Food Engineering from Hanoi University of Science and Technology (Vietnam). Her research interests include food safety and consumer behaviours.

Nguyen Thi Minh Tu

Hanoi University of Science and Technology, Vietnam
Dai Co Viet Road, Hanoi, Vietnam
E-mail: tu.nguyenthiminh@hust.edu.vn

She holds Engineer degree in Food Engineering from University of Food Technology, Plovdiv, Bulgaria, a Master degree in Food Technology from Hanoi University of Science and Technology (Vietnam), and PhD degree in Food Science from Ehime University (Japan). Her research interests include Quality management in food industries, Flavor and natural products in food technology, Food authenticity and traceability.

Le Thi Hong Anh

Ho Chi Minh City University of Industry and Trade, Vietnam

140 Le Trong Tan Street, Ho Chi Minh City, Vietnam

E-mail: anhlth@huit.edu.vn

She holds Bachelor degree, a Master degree, and PhD degree in Food Technology from Ho Chi Minh City University of Technology (Vietnam). Her research interests include food safety, healthy nutrition and food authenticity.

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A Proposed Framework for Blockchain Technology in Vietnamese Domestic Pepper Supply Chain Regarding Authenticity and Traceability

Hoang Quoc Tuan^{*a}, Le Tuan Phuc^a, Pham Ngoc Hung^a, Lai Quoc Dat^b,
Nguyen Hoang Dung^b, Do Van Long^c, Cung Thi To Quynh^a

^a Hanoi University of Science and Technology, Vietnam

^b Ho Chi Minh City University of Technology, Vietnam

^c Vietnam Blockchain Corporation, Vietnam

Abstract

In this study, we examined the roles of foreign direct investment (FDI), skilled labour, and technical efficiency in determining the exports of the food and beverage industries in Indonesia. To address this issue, we utilised data from industry micro firms for the period 2010-2015. We applied the maximum likelihood estimation (MLE) technique to the logistic model and the stochastic frontier analysis (SFA). Findings revealed that the food and beverage industries are operating below the possible technical efficiency (TE). However, foreign direct investment, skilled labour, technical efficiency, and industrial concentration assert a significant positive effect on the probability of firms' exports. In the food and beverages sector and the beverages industry, firm size promotes exports; however, in the food industry, firm size has the opposite effect, reducing exports. The imported raw materials have an insignificant effect on the firms' probability of exporting. Interestingly, findings on the mediating roles of technical efficiency and industrial concentration, as well as technical efficiency and firm size, revealed an increasing influence on the probability of exporting. Skilled labour and

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Authenticity
Traceability

* *Corresponding author:* Hoang Quoc Tuan - School of Chemical and Life Science - Hanoi University of Science and Technology, Vietnam. E-mail: tuan.hoangquoc@hust.edu.vn.

firm size only positively promote exports in the foods and beverages sector and the food industry, but not in the beverages industry. These findings are novel and present an important pathway for policy-making related to the food and beverage industry, potentially shaping future strategies and initiatives in the Indonesian food and beverage sector.

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Introduction

The authenticity and traceability of agricultural and food products are becoming ever more necessary as globalization continues to increase the complexity of food supply chains (Wang *et al.*, 2020). Consumers and food manufacturers face challenges in selecting products that are both healthy and environmentally friendly, while avoiding unsafe or fraudulent food items. Adequate information regarding product brands, authenticity, usage, and preservation is essential.

Using transparency as a foundation, food supply chain traceability enables access to critical and accurate information about the origins and quality of products at any point in the supply chain. However, traditional traceability methods are mostly administrative and lack the use of chemical or biological analytical tools, which limits their reliability (Espiñeira & Santaclara, 2016). Although they allow for tracking product history, they fall short in establishing consumer trust due to the lack of transparency. Therefore, improving traceability systems to ensure both trust and authenticity is increasingly vital in the modern food economy.

1. Background

1.1. *Traceability in food supply chain*

Today, a lot of approaches have been developed and already applied for food supply chain traceability, ranging from simple methods such as traditional paper-based ones to advanced and innovative technologies (Olsen & Borit, 2018). However, less developed and/or even developing countries tend to prefer choosing traditional ones i.e. recording by paper documents rather than using cutting-edge techniques i.e. digital technology to perform traceability in the food supply chain (Islam & Cullen, 2021). Most of Vietnamese farmers are not familiar even with recording documents and exchanging them with wholesalers and/or traders who will buy their products.

This makes it difficult for them to participate in a complex computer or handphone-based system except pepper product companies that have their own farm or under their quality control (Pham & Dinh, 2020). Additionally, few applications have been developed specifically for food traceability since companies prefer to use their internal integrated information system to avoid overspending on an additional fee for external IT systems.

1.2. Blockchain applications in food traceability

Blockchain technology has been used to allow traders, retailers and consumers to trace and track the provenance of food products from their origins to stores and restaurants (Ellahi *et al.*, 2024). As a new trend, blockchain technology has much potential to become a realistic technological option to address the challenge of mining and managing information across the food supply chain. A blockchain is a decentralized, distributed, and oftentimes public, digital ledger consisting of records called blocks that are used to record transactions across many computers so that any involved block cannot be altered retroactively, without the alteration of all subsequent blocks (Iansiti & Lakhani, 2017). Blockchain technology can be characterized through five principles: security, peer-to-peer transmission, transparency with pseudonymity, irreversibility of records and computational logic (Andoni *et al.*, 2019; Schiller, 2017).

The first blockchain system applied to food supply chain was developed by Walmart and IBM company. They were running a trial to use a blockchain-backed system for supply chain monitoring for lettuce and spinach – all nodes of the blockchain were administered by Walmart and were located on the IBM cloud (Corkery & Popper, 2018). The results show that one cited benefit is that the system could enable the rapid tracing of contaminated food produce. Some analysts are less convinced that most consumers will be that interested in this traceability system (Gstettner, 2019).

The systems are purely a ‘supply chain’ with information being tracked far beyond the origin and quality of the product, including farming and processing parameters, shipping details, and more. The Internet of Things (IoT) has also been integrated into the blockchain to improve the efficiency of the food traceability system in the hope of building an open and comprehensive network of devices capable of organizing and self-organizing transparent data and resource sharing (Feng Tian, 2016; Madakam *et al.*, 2015). However, there are inherent limitations to the adoption of blockchain in food traceability (Cao *et al.*, 2023). For blockchain to work effectively, all parties and stakeholders must be involved. In addition, the integrity of the data is under the control of the data collector, and an authentication system is

required to prevent tampering (Li *et al.*, 2025). The lack of a unified system with clear standards and regulations is a major impediment to adoption (Feng Tian, 2016; Gstettner, 2019). Chemical and biological data of agricultural and food products are valuable information that should be integrated into the blockchain system to avoid human error and interference i.e. administrative information, information assigned to food objects by collectors' purpose. Moreover, as highlighted by recent studies, many misconceptions about the properties of blockchain in the agrifood sector persist, and its successful application requires careful design and governance. For blockchain-based traceability systems to be effective, structural and technological mechanisms such as consistency checking via smart contracts and frameworks for auditing and reliability assessment are essential prerequisites for collaborative blockchain data management (Rampone *et al.*, 2023).

Based on blockchain technology, the consumers and clients can trace and track the origin and journey of products, giving them trustworthy information about how the products were made, transported, and distributed to them (Ellahi *et al.*, 2024). All the information is totally transparent, therefore, blockchain traceability is the ideal tool for gaining consumers' trust in the brands (Dutta *et al.*, 2020). Blockchain is a novel technology that has been gaining a lot of attention and is expected to become the one transforming businesses across different industries including food sectors (Iftekhhar *et al.*, 2020; Lukacs *et al.*, 2025). In addition to blockchain technology, various analytical techniques can support food traceability systems. These include mass spectrometry, spectroscopic techniques, and separation techniques that enable the determination of food provenance (Esposito & Pezzolato, 2023). Such analytical methods provide an independent means of verifying traceability systems and help prove food product authenticity (Dou *et al.*, 2023). They also combat fraudulent practices and control adulteration, which are important issues for economic, religious, or cultural reasons.

1.3. Vietnamese black pepper sector

Pepper is one of six agricultural products of Vietnam with an export turnover of over USD 650 million per annum capable of competing in the international market. Annually, the pepper output reaches 240,000-300,000 tons, of which 95% of pepper is exported into foreign markets. According to preliminary data reported by the General Department of Vietnam Customs, pepper exports in 2020 reached 288,000 tons of all kinds of pepper. In September 2021, exports reached 15,336 tons of all kinds of pepper, down 2,300 tons, or 13.04 percent down from the previous month and down 2,916 tons, which is a decrease of 19.12% over the same period last year (Vietnam

Trade Promotion Agency Export Promotion Centre, 2020). Vietnamese pepper is widely known in the international market with big brand names such as Vĩnh Linh, Chu Se and Phu Quoc pepper. Vietnam pepper is exported to some major markets such as the USA, German, the Netherlands, India, Singapore, Russia and the Middle East. Like pepper of other exporters, Vietnamese pepper is divided into two types: black and white, of which black pepper accounts for 90% (Economy, 2024). Aiming at keeping the first export position in the world pepper market, Vietnam is actively speeding up the implementation of “cooperation between 4 parties” (Government, Entrepreneur, Farmer, and Scientist) in order to invest and transfer technology of pepper processing to the farmer, enhancing the productivity and quality for products with competitive price (Ly, 2024). In addition, the authenticity and traceability system is really concerning to ensure the Vietnamese pepper brands due to a lot of competition among pepper exporting countries in the region.

Although numerous studies have highlighted the potential of blockchain in food traceability, most existing research has focused on globally traded sectors such as fruits, meat, or seafood (Cao *et al.*, 2023; Ellahi *et al.*, 2024). Evidence from developing countries is still limited, especially where farmers have low digital skills and data systems are not well connected (Islam & Cullen, 2021). For Vietnam’s pepper industry, which is a key export but faces problems of quality and authenticity, there are almost no studies on how to apply blockchain effectively. In particular, no research has proposed a model that combines administrative data with chemical and biological data to make traceability more transparent and reliable. This gap shows the need for a new framework that fits the reality of Vietnamese pepper production and also meets international market requirements.

Based on the administrative as well as chemical and biological data gathered from multiple sources and the analysis of a case study, a research is conducted in Vietnam pepper chain with the aim at answering the research question: *How can blockchain resolve to address the traceability and authenticity issues in Vietnamese domestic pepper sector?* The paper will share the findings from the study and propose a new framework using blockchain to improve the traceability as well as authenticity including classify the quality grade of pepper products.

2. Research Methodology

2.1. Development of traceability framework

In this research, we identified the potential roles of blockchain technology integrated with rapid analysis instruments, specifically near infrared

spectroscopy (NIR), and their ability to be applied to traceability and authenticity systems in Vietnam's domestic pepper sector. The framework was designed through literature review, stakeholder consultation, and process mapping. It includes three layers: (i) data capture (farming logs, harvest, processing, transport, NIR results), (ii) analysis (NIR spectral processing and authenticity classification), and (iii) ledger (a permissioned blockchain to securely record events and generate QR codes for consumer trace-back).

2.2. Data information and research questions

Data were collected from multiple sources, including farmer and processor records, pepper samples, NIR measurements, transaction logs from the pilot blockchain system, and stakeholder interviews. The information and data analyses will serve as a foundation to propose a framework that is expected to answer the research question: *How can blockchain technology integrated with NIR be used to address the traceability and authenticity issues in Vietnamese domestic pepper sector?*

2.3. Pilot project

The pilot project implemented the proposed framework in Quảng Trị province. Agricultural logs, harvest activities, processing steps, and transport events were systematically recorded on a blockchain platform. Each transaction was linked with corresponding NIR results for authenticity verification. A QR code label was issued for selected batches, enabling end-to-end traceability demonstration from farm to market. The pilot also tested user adoption and system usability among local stakeholders.

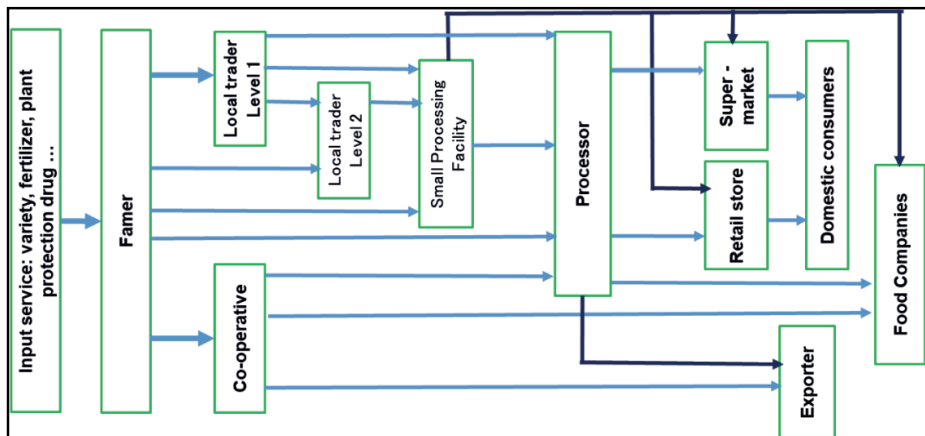
3. Results

3.1. Vietnamese pepper supply chain

The Vietnamese domestic pepper supply chain management follows a multi-stage supply chain system consisting of farmers, co-operative and/or local traders level 1, local traders level 2, small processing facilities, pepper processing companies, supermarkets and retailers, and exporters [18]. Figure 1 illustrates in detail the multiple stages involved in the pepper supply chain and their functioning. The primary stage of the pepper supply chain begins with farmers. After pre-processing steps such as cleaning and drying, dry

pepper is sold to local trader level 1. The remaining is sold to local trader level 2 and/or small processing facilities or directly to processing companies, either with or without intermediaries. The route depends on factors such as productivity, type of farmers (e.g., large or small landholders), and the capability of their business operations. At the processor stage, pepper is processed undergoes further processing such as re-drying, classifying quality grade, mixing, and storing. After processing, pepper processors sell their products to domestic customers such as retail stores, supermarkets, food companies, and export companies. Other actors in the supply chain sell to retail stores and supermarkets, which in turn sell to domestic consumers. Food companies may purchase pepper from co-operatives or directly from processors. In this supply chain, small processing facilities can also sell their products to retail stores, supermarkets, and food companies.

Figure 1 - Vietnamese domestic pepper supply chain^[18]



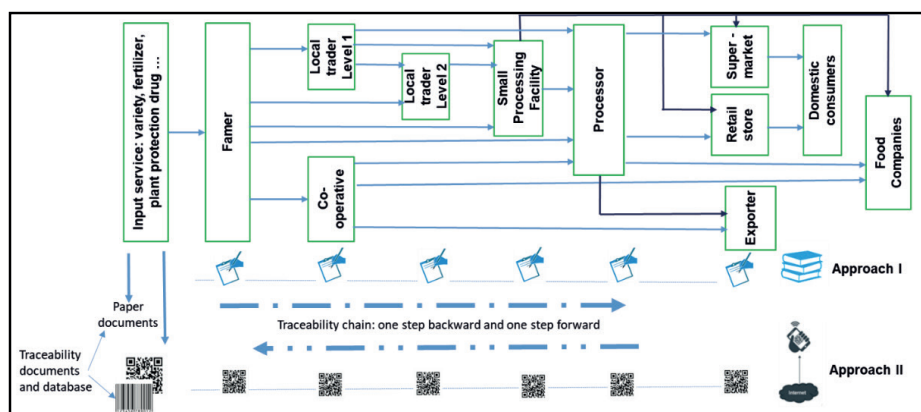
There are generally at least five or six supply chain agents between the farm-gate and the consumer or clients. Compared to supply chains of other agricultural commodities in Vietnam and to pepper supply chains in leading producer countries such as Brazil and India, the Vietnamese model is considerably longer and more fragmented. This extended structure results in several key limitations. First, the length of the chain leads to higher transaction costs, longer lead times, and reduced transparency, making it difficult to trace product origin and ensure consistent quality. Second, weak vertical coordination among actors especially between producers and downstream buyers limits information sharing, price transmission,

and incentives for quality improvement. Third, information asymmetry is common, with farmers lacking access to market data, export standards, and demand trends, thereby hindering their ability to adapt production practices effectively. Fourth, the adoption of modern technologies, such as digital traceability systems or logistics optimization tools, remains limited at the farm and early trade levels, reducing overall supply chain efficiency. Finally, the distribution of value along the chain is highly unequal; smallholder farmers, who bear much of the production risk, often receive only a small portion of the final market value. These structural inefficiencies pose significant challenges to the competitiveness and sustainability of Vietnam's pepper industry in the global market.

3.2. Traditional traceability model

A traditional pepper traceability system can record the whole circulation process of pepper, from planting, production, processing, warehousing, and to use by consumers (Figure 2). If fraudulent or unsafe pepper is discovered, it can be traced back to its source. However, paper-based traceability is time-consuming, especially when responding to information requests from consumers or clients. Although QR codes or barcodes have been introduced into IT systems to partially digitize traceability, these improvements are still limited in scope. Data in these systems is often manually input, lacks standardized formatting, and is centrally managed, making it vulnerable to

Figure 2 - Traditional traceability model in the Vietnamese domestic pepper supply chain



human error, tampering, or information loss. Moreover, traditional systems do not provide transparency across the entire supply chain, as consumers are typically granted access only to basic or limited details about the product. These systems also cannot confirm if a product is real or fake because they do not use scientific tests, like chemical or biological analysis.

The blockchain-based model proposed in this paper effectively addresses these shortcomings. It creates a decentralized and immutable ledger where all stakeholders in the supply chain directly enter and verify data through cryptographic mechanisms and smart contracts. Every transaction or change is traceable and cannot be altered retroactively, ensuring the integrity of information.

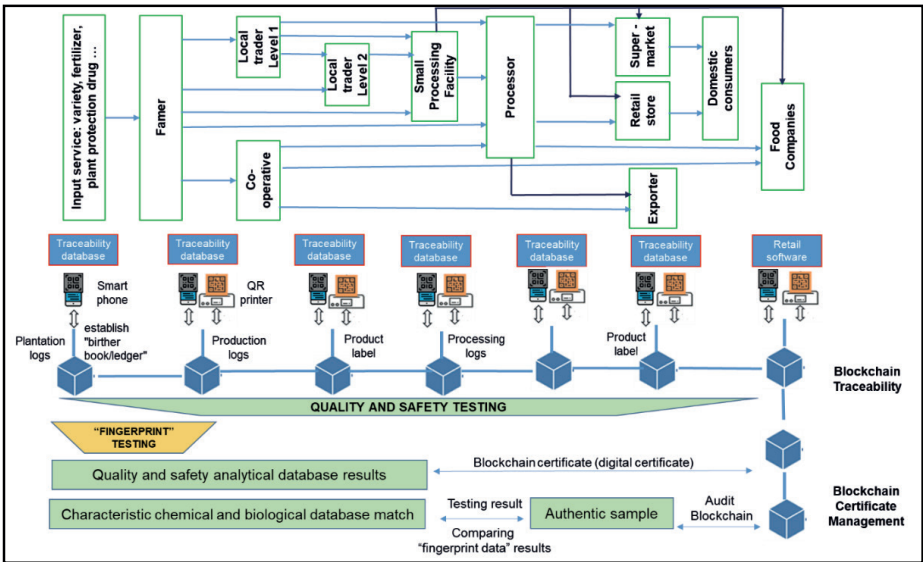
3.3. Proposed Framework for Traceability and Authenticity System

3.3.1. Overview of the Proposed Framework

At least two approaches have been developed and already applied for pepper supply chain traceability in Vietnam, ranging from simple methods such as traditional paper-based ones (approach I) to sophisticated technologies (approach II) such as using barcodes or QR codes for recording traceability database. We proposed a new framework for traceability as shown in Figure 3 for the Vietnamese domestic pepper supply chain, making use of blockchain, IoT and smart contracts. The traceability database includes not only administrative data and processing parameters but also data collected from multiple sources using analytical techniques -for example, characteristic chemical and biological data of pepper samples. Each technology has its benefits and limitations and ultimately no individual technology can single-handedly address all the issues surrounding authenticity, provenance and traceability. Therefore, we proposed propose that adopting a framework that integrates multiple technologies into a combined proactive solution could be the key to ensure authenticity, traceability and provenance of pepper products.

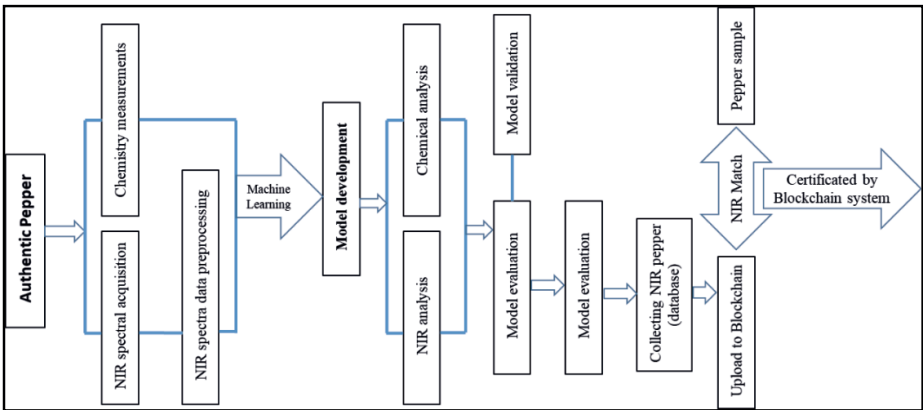
In this traceability system, all supply chain members mentioned in Figure 3, should have to register and provide the administrative information, production/processing parameters by themselves into the system, and match their unique identities and digital profiles stored in the blockchain system. The characteristic chemical and biological data of pepper such as essential oil, piperine, ash, fatty acid content, and DNA were studied and provided by independent analytical laboratories. Characteristic chemical data of authentic pepper from different origin regions were analyzed by spectrometric techniques i.e., such as near infrared spectroscopy (NIRS).

Figure 3 - Propose framework for a blockchain traceability system for pepper supply chain



Machine learning algorithms were used to build a predictive model based on collected ‘training data’ in order to determine the origin and quality of pepper samples (Figure 4).

Figure 4 - Schematic representation of the procedure for NIR spectroscopy integrated to blockchain



3.3.2. Technical Integration Architecture

The proposed system integrates various technologies into a unified framework to ensure real-time data capture, decentralized verification, and end-to-end transparency across the pepper supply chain. In addition to basic administrative data, supplementary information such as time-lapse footage from digital cameras, weather conditions, and GPS coordinates of farms is continuously collected and uploaded to the blockchain.

The architecture comprises four key technical components. First, **IoT devices and sensors** are deployed at the farm level to monitor environmental parameters (e.g., temperature, humidity, and location) and to capture visual records throughout the cultivation process. This data is transmitted via mobile networks or Wi-Fi to a centralized cloud gateway. Second, **NIR spectroscopy instruments** are used by local traders and processors to rapidly analyze the chemical composition of pepper samples. The resulting spectra are digitized and integrated into the blockchain through dedicated APIs. Third, a **permissioned blockchain ledger** (e.g., Hyperledger Fabric or Ethereum private network) securely stores all hashed data entries submitted by stakeholders along the supply chain, with access and authentication managed through digital signatures and private keys. Finally, **smart contracts** are used to automate transactions between parties, validating criteria such as product weight, moisture content, and chemical parameters before approving data submission or product transfer. Together, these components form a robust and transparent infrastructure that enhances trust and efficiency throughout the pepper supply chain.

3.3.3. Application Across the Supply Chain Stages

The blockchain-based traceability system can be explained in four main stages of a pepper supply chain, namely 1) Farmer: Plantation/At the farm; 2) Intermediaries trader: Procurement/local trader and co-operative; 3) Processing plant: small processing facility and processor; 4) Distribution and consumer/clients: retail store, supermarket and exporter; and at the food factories.

a. Stage 1 – Farmers: Plantation and Production

At the farm level, data about pepper cultivation is recorded using mobile applications and digital cameras. Time-lapse videos document the entire growing process, while farmers input information such as planting date, seed type, fertilizers, and pesticide usage. These records are cross-checked

with national standards or certification schemes such as Good Agricultural Practices (GAP) or Organic standards.

After harvesting, the pepper is cleaned, dried to a moisture content of 12–13%, and packed in bags. Each bag is labeled with a QR code or RFID tag containing a unique digital identity. This identity links to a blockchain profile that stores key information including soil and weather conditions, crop variety, planting and harvesting times, GPS location of the farm, and the farmer's personal information. Once the product is ready, a digital smart contract is created for the transaction between the farmer and the next supply chain actor, such as a trader or processor. This contract ensures transparency and automatically logs the product's transfer on the blockchain.

b. Stage 2 – Intermediaries: Traders and Co-operatives

When the pepper arrives at a trader's or cooperative's warehouse, workers scan the product tag to access the data previously uploaded by the farmer. This allows them to verify the origin and production details before accepting the shipment. Information about the trader, warehouse conditions, time of receipt, and product quantity is then added to the blockchain.

To ensure quality and safety, the pepper may undergo rapid testing using Near-Infrared (NIR) spectroscopy, and the analysis results are recorded on the system. Time-lapse cameras may continue to monitor storage conditions. If any issues are found, the data can be traced back to the farm instantly, and corrective actions can be taken quickly. This stage ensures that the product's journey is transparent and verifiable from its origin.

c. Stage 3 – Processors: Small Facilities and Processing Companies

After receiving the pepper, the processor will re-dry it if necessary, classify it by quality grade, mix the batches, and store the product. Information regarding all processing steps is stored on digital product records and updated on the blockchain. At this time, the quality and safety of pepper are also analyzed by the NIR instrument and updated in the blockchain. A time-lapse movie of the entire process will also be recorded. In addition, processing companies will enable QR codes with data such as identifiers, GPS or GLN (Global Location Number), administrative information, etc.

d. Stage 4 – Distribution and Consumers: Retailers, Supermarkets, Exporters

When processed pepper is sent to retailers, supermarkets, exporters, or food factories, each shipment's data continues to be updated on the blockchain. This includes logistics details, storage conditions, and delivery information. Retailers or exporters can scan the QR code on each package to view the full product history.

Consumers – whether domestic buyers or international importers – can access this information by scanning the QR code with a smartphone app. They are directed to a webpage that displays the product's origin, farming and processing standards, transportation details, and even time-lapse videos or lab test results if available.

They will be redirected to a web page with information that answers the following questions about a particular pepper product:

- What farm did the pepper used in this product come from? What agricultural standards (e.g., GAP, Organic, National Standards) were followed during cultivation?
- When and where was the product produced? What processing steps were followed, and how did the product reach its destination? What is the assessed quality of the product? What food safety standards (e.g., ISO, Organic) were followed during processing?
- When did this product arrive at the retailer, supermarket, or exporter, and when did it appear on the shelf or in the warehouse? In addition, consumers and food factories can access time-lapse videos and detailed chemical and biological analyses of the product on this webpage.

However, in fact, in the Vietnamese domestic market, the small retail model is still very popular next to supermarkets, convenience stores, and retailers. These small grocers cannot afford standard technology systems, even POS systems that scan QR codes on purchased products to update their status; while smartphones have become very popular gadgets. As a result, this feature is currently impractical for the entire domestic pepper supply chain. However, it is well-suited for export markets, where importers may require full traceability – especially during disruptions such as the COVID-19 pandemic. If scanning systems and digital infrastructure become standardized across the food sector, this model could eventually be expanded to apply to not only pepper but also other food supply chains and consumer products.

3.4. Empirical Validation and Initial Implementation Results

To evaluate the feasibility and effectiveness of the proposed blockchain-based traceability framework, a pilot implementation was carried out in collaboration with a pepper cooperative in Vinh Linh district, Quang Tri province, one of the major pepper-producing regions in Vietnam.

Figure 5 shows the automated blockchain data registration module, where each transaction is digitally signed and permanently recorded. Smart contracts validate each step automatically.

Additionally, Figure 6 presents the user log management interface, which helps supervisors monitor who entered what data and when ensuring traceability and accountability in human data input.

Figure 5 - Blockchain transaction logging and validation interface

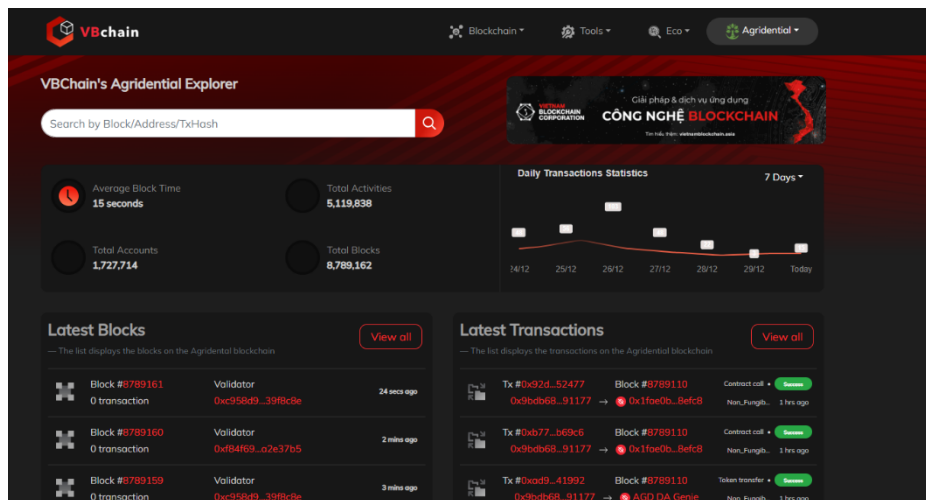


Figure 6 - Data transparency and personnel accountability screen

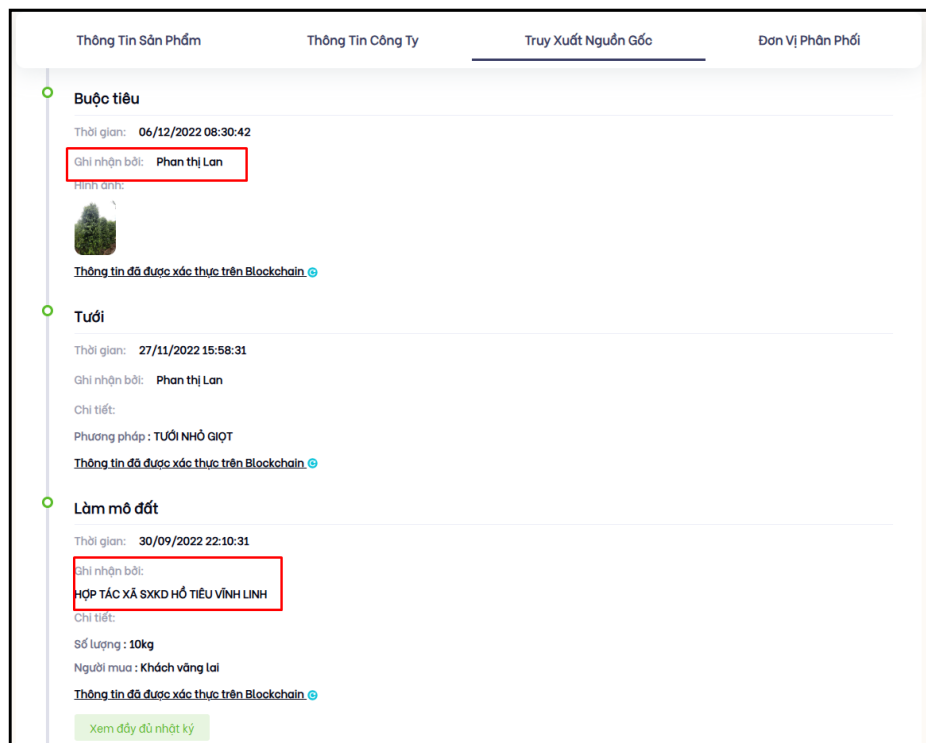
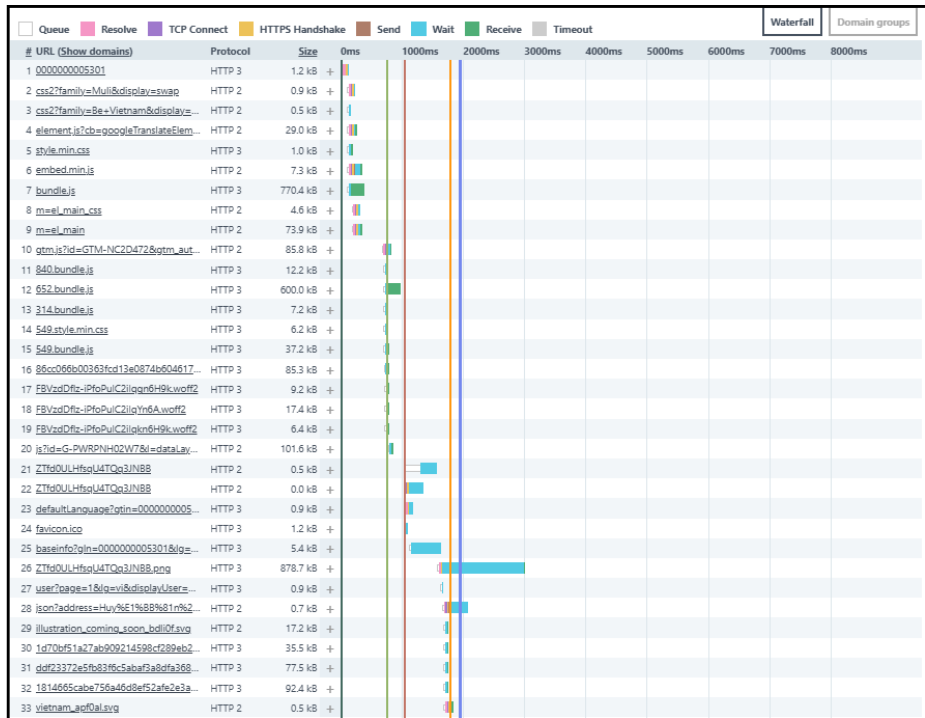


Figure 7 - Test results of the product traceability research site



The pilot system demonstrated strong performance and reliability, achieving an average transaction throughput of 520 tps, with a maximum of 1000 tps, a transaction confirmation time of 1.5 seconds, and synchronization latency of less than 3 seconds. During the testing phase, no occurrence of transaction failures was documented. Beyond its performance, the implementation ensured high security with no detected vulnerabilities, accurate and instant synchronization of records across the blockchain, and compatibility with existing devices and software. The framework demonstrated scalability and extensibility, exhibiting the capacity to accommodate elevated transaction volumes without compromising efficiency.

Building on the pilot results, the study compares traditional and blockchain-based traceability. In Vietnam, traditional systems are centralized and paper-based. They depend on intermediaries and fragmented manual records. Transparency is limited, and a traceability request may take 48-72 hours to process. These weaknesses reduce both efficiency and data reliability. Blockchain offers a different approach. It uses a decentralized

and immutable ledger that enables near real-time traceability. The system improves transparency, builds consumer trust, and connects multiple stakeholders. Compared with conventional methods, blockchain requires higher initial investment, mainly related to server setup and ongoing system maintenance. Over time, however, it reduces redundant verification and increases confidence in product information. More data and longer trials are still needed to validate the model and support further research. Even so, blockchain-based traceability is particularly relevant for enterprises seeking access to high-demand export markets such as the European Union and the United States.

These results strongly demonstrate the framework's readiness for practical deployment across both domestic and export-focused pepper supply chains. Future development will focus on enhancing system intelligence through AI-powered data analytics for real-time quality prediction, fraud detection, and supply chain optimization. Additionally, the platform will be extended with multilingual user interfaces to support ethnic minorities and international stakeholders, as well as integration with national certification databases (e.g., VietGAP, Organic Vietnam) to ensure seamless compliance verification. The long-term vision is to evolve this framework into a modular, open-source platform that can be adapted for traceability in other key Vietnamese agricultural products such as coffee, rice, and cashew nuts.

Conclusion

In this paper, a framework for a blockchain system was proposed, designed to ensure traceability and authenticity within the Vietnamese domestic pepper supply chain. Employing this system in the pepper supply chain offers several benefits: it ensures integral traceability and authenticity, fights fraud, and minimizes system errors. Beyond transaction records, the framework also integrates supplementary data such as time-lapse videos and chemical or biological analyses, which further enhance product verification. The novelty of this study lies in introducing one of the first blockchain-based models specifically designed for the Vietnamese pepper industry, with the unique integration of chemical, biological, and multimedia data. Nonetheless, the framework remains conceptual, and its implementation may face challenges, including high infrastructure costs, limited digital literacy among farmers, and scalability issues across larger supply networks.

Another benefit of blockchain is the elimination of human errors such as those made by farmers, traders and conventional pepper producers in Vietnam in the circulation of pepper. Consumers and clients now have reliable support tools to prove the traceability and authenticity of pepper

products, especially black pepper products with high commercial value, to regain their confidence. With sensors, digital cameras, analytical equipments and smart contracts are integrated into the system, businesses can save significant time and costs for human resources or intermediaries to control the quality, safety and traceability of their products. Furthermore, processors can be more assured that the standard procedures will be strictly followed by farmers or producers since this traceability system can trace back to a particular batch of pepper to its originating farm.

Regarding administrative management, the government can rely on the proposed traceability solution. This transparent, convenient, and, more importantly, realistic system can address pepper safety issues and fraud with limited risks of human error and tampering during information exchange, which is particularly crucial as competition in the pepper market increases among pepper-exporting countries. Future work will focus on implementing pilot projects and developing advanced technologies such as IoT and AI to enhance real-time monitoring, anomaly detection, and data integration. In addition, future studies should conduct a deeper comparison between the costs and benefits of traditional manual practices and the adoption of the proposed blockchain-based system, thereby providing more practical insights for stakeholder.

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Hoang Quoc Tuan

Department of Food Engineering, School of Chemistry and Life sciences, Hanoi University of Science and Technology, Vietnam

E-mail: tuan.hoangquoc@hust.edu.vn

He holds an Engineer degree (Hanoi University of Science and Technology, 2003), Master degree (University of Natural Resources and Life Sciences, Vienna University in Austria, 2011) and a Doctor degree (Hanoi University of Science and Technology, 2017). Lecture at the Hanoi University of Science and Technology since 2004. Current research interests: Food Authentication and Traceability; New food product research and development; Bigdata, AI, ML in Food technology.

Le Tuan Phuc

Department of Food Engineering, School of Chemistry and Life sciences, Hanoi University of Science and Technology, Vietnam

E-mail: phuc.letuan@hust.edu.vn

He holds an Engineer degree (Hanoi University of Science and Technology, 2021) and a Master of Science (Hanoi University of Science and Technology, 2023). Lecturer at the Hanoi University of Science and Technology since 2023. Current research interests: Consumer science and R&D of food products; Data analysis; Application of Artificial Intelligent, Machine Learning, Computer Vision and Natural Language Processing (NLP) in food authenticity, traceability and quality analysis; Application of IoT for automation and improvement of production efficiency, quality management in food industry.

Pham Ngoc Hung

Department of Food Engineering, School of Chemistry and Life sciences, Hanoi University of Science and Technology, Vietnam

E-mail: hung.phamngoc@hust.edu.vn

He holds a degree in Automation Control (Hanoi University of Science and Technology, 2005) and a PhD in Food Chemistry and Biotechnology (BOKU University, Vienna, 2015). Lecturer at the Hanoi University of Science and Technology since 2005. Current research interests: Solutions, technology, equipment, and R&D for food products; Application of blockchain, AI, and machine learning in identification, traceability, and supply chain development for food products; Research on technological solutions and digital transformation applications in agriculture; Application of automation to improve production efficiency in chemical, food, and biological fields; Dynamic simulation in biological and food processes.

Lai Quoc Dat

Ho Chi Minh City University of Technology, Vietnam

E-mail: lqdat@hcmut.edu.vn

He is an Associate Professor Doctor at Ho Chi Minh City University of Technology (Department of Food Technology). Professional field: Food Technology. Current research interests: Extraction and processing of materials to create high value-added products; Modelling in food technology; Rheological properties of systems and gels in food; Application of membrane technology in food technology; Application of freezing technology in food technology.

Nguyen Hoang Dung

Ho Chi Minh City University of Technology, Vietnam

E-mail: dzung@hcmut.edu.vn

He holds PhD in Food Technology at France. Current professional field: Food Technology. Current research interests: Sensory evaluation methods (descriptive, discriminative, expert); application of emotions and culture in sensory assessment; consumer behavior and food preferences; sensory properties of Vietnamese agricultural, aquatic, and livestock products; new product development (Koji fish sauce) and multivariate data analysis.

Do Van Long

Vietnam Blockchain Corporation, Vietnam

E-mail: longdv@vietnamblockchain.asia

He holds a Bachelor of Computer Science (Ho Chi Minh City University of Technology, VNU-HCM) and a Doctorate in Business Administration (Swiss School of Business and Management, Switzerland). Chairman of the Board - Chief Executive Officer (CEO) at Vietnam Blockchain Corporation with over 23 years of experience in senior management. Current professional interests: Innovative enterprise solutions (ERP, CRM, SCM), business intelligence, Blockchain services, and strategic business initiatives in agriculture, logistics, supply chain, fintech, and smart cities.

Cung Thi To Quynh

Department of Food Engineering, School of Chemistry and Life Sciences, Hanoi University of Science and Technology, Vietnam

E-mail: quynh.cungthito@hust.edu.vn

She holds an Engineer degree in Food Technology (Hanoi University of Science and Technology, Vietnam, 1995) and a Doctor degree (Ochanomizu University, Japan, 2009). Lecturer at the Hanoi University of Science and Technology since 2001. Current research interests: Quality management and Food safety; Blockchain technology and Big Data applied to the food supply chain; Characteristic odor compounds and bioactive compounds of herbs, spices, tropical fruits, and their applications in food technology; New Product Development (related to coffee, tea, rice, and mushroom products).

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Green Human Resource Management Practices and Sustainable Performance in Vietnam's Agriculture: The Mediating Role of Green Innovation and Green Culture

Nguyen Nhung^{*a}, Mai Thuy^a, Nguyen Phung^a

^a University of Finance and Accountancy, Vietnam

Abstract

The integration of economic development with environmental protection forms a crucial foundation for the sustainable development of society. In this context, Green Human Resource Management Practices (GHRM practices) activities play a bridging role in helping organizations improve sustainable performance while meeting the demands of customers, society, and environmental protection. This not only brings practical benefits to businesses in the agricultural sector but also significantly contributes to global sustainable development. Through a survey of 400 managers and staff in the agricultural sector of Vietnam and utilizing Smart PLS software for data analysis, the study demonstrates that Green Human Resource Management Practices positively impacts sustainable performance through two mediating factors: Green Innovation and Green Culture. These results provide an important practical basis to support managers and policymakers in the agricultural sector in building competitive advantages while creating long-term value for organizations and society. The findings offer actionable insights for implementing specific GHRM practices such as green recruitment, training, and performance assessment to enhance sustainable performance in Vietnam's agricultural context.

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Roberto Leonardo
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* Corresponding author: Nguyen Nhung - University of Finance and Accountancy, Vietnam.
E-mail: nguyenthihongnhung@tckt.edu.vn.

Introduction

The global economic context is facing unprecedented challenges related to climate change and environmental degradation, forcing industries to transition to sustainable development models (Popkova & Sergi, 2023). Among them, the agricultural sector, which is the foundation of food security and livelihoods for billions of people, is one of the largest pressures on ecosystems (FOOD & AFFORDABLE, 2022). In developing countries like Vietnam, agriculture not only plays a crucial economic role but also faces a dual challenge: it must enhance productivity to ensure growth while minimizing negative environmental impacts (Feng & Xu, 2025). Organic-oriented innovative behavior plays an important role in the agricultural sector (Lopes *et al.*, 2025).

This context demands a strategic change, not only in technology but also in the management of human resources-the core asset of every organization. Green Human Resource Management (GHRM) practices, an approach that integrates environmental goals into HRM activities, have emerged as a strategic tool to promote sustainable business performance (Amjad *et al.*, 2021). Empirical studies worldwide have demonstrated that GHRM practices positively impact environmental performance and overall organizational performance (Aloqaily & Al-Zaqeba, 2024). This mechanism of effect is often explained through mediating factors, where green innovation and green culture are considered the two most important pathways (Al-Alawneh *et al.*, 2024). A recent meta-analysis also confirms this consistent mediating role across various fields (Bindeeba *et al.*, 2025).

However, there is a noticeable lack of research on GHRM practices in the agricultural sector. Most existing empirical evidence comes from manufacturing and service industries in developed countries (Naseer *et al.*, 2023; Yong *et al.*, 2020). The agricultural sector, with its characteristics such as scale (primarily small and medium-sized enterprises), complex supply chains, and dependence on natural conditions, requires a distinct research perspective. Particularly in Vietnam, a country with an agricultural sector undergoing significant transformation, understanding how GHRM can promote sustainable performance through innovation and culture is an urgent yet underexplored requirement (Kaith & Sachdeva, 2024; Xie & Lau, 2023). To fill this research gap, our study poses two main questions: (1) Do green innovation and green culture play mediating roles in the relationship between GHRM practices and sustainable performance in Vietnamese agricultural enterprises? and (2) What theoretical foundations (Resource-Based View, Social Exchange Theory) can explain these relationships? By addressing these questions, the study not only contributes new empirical evidence to a relatively unexplored field but also provides important

managerial implications for policymakers and agricultural business management in Vietnam.

1. Literature Review and Theoretical Framework

1.1. Sustainable performance in the agricultural sector

Sustainable performance refers to an organization's ability to achieve long-term success by balancing economic growth, environmental protection, and social responsibility, thereby creating value for current and future stakeholders. Sustainable performance includes economic, social, and environmental effectiveness (Piwowar-Sulej & Iqbal, 2023). Specifically, economic effectiveness is reflected in an organization's ability to reduce costs related to purchasing materials, energy consumption, waste treatment, and fines for environmental incidents (Ekins *et al.*, 2016; Zhu *et al.*, 2008); social effectiveness refers to the organization's capacity to enhance community welfare, public health and safety, as well as occupational health and safety for employees (Paulraj, 2011); environmental effectiveness relates to reducing emissions, energy use, the use of hazardous materials, and complying with environmental standards (Laosirihongthong *et al.*, 2013).

In the agricultural sector, sustainable performance demonstrates the overall capacity of the agricultural system to maintain productivity and profitability while ensuring environmental integrity and promoting social development over the long term. This concept requires a balance between economic benefits and rational use of resources, minimizing adverse impacts on the ecological system, and improving rural livelihoods, thereby ensuring that agricultural activities not only meet current needs but also maintain the ability to serve the needs of future generations. Achieving sustainable performance is a pivotal factor for addressing emerging global challenges such as climate change, biodiversity loss, and food security (Muluneh, 2021).

1.2. Theoretical Underpinnings

This study is built on an integrated theoretical framework, primarily based on the Resource-Based View (RBV) and Social Exchange Theory (SET) to elucidate the complex relationships between GHRM practices, mediating variables, and sustainable performance.

According to the Resource-Based View (RBV), a company's sustainable competitive advantage arises from resources and capabilities that are valuable, rare, difficult to imitate, and non-substitutable (Taher, 2012). In

our context, GHRM practices is not merely a set of discrete activities but a strategic mechanism for building and developing “green human capital”. This capital, which encompasses employees’ knowledge, skills, and motivations regarding environmental issues, is an immensely valuable internal resource (Malik *et al.*, 2020). When companies invest in green recruitment, green training, and green rewards, they are cultivating a workforce capable of driving green innovation and fostering an environmentally supportive organizational culture (Mansoor *et al.*, 2021). These organizational capabilities (green innovation and culture) are challenging for competitors to replicate, thus creating sustainable competitive advantages and enhancing overall performance.

Meanwhile, Social Exchange Theory (SET) focuses on the reciprocal relationships between individuals and organizations (Cook *et al.*, 2013). SET posits that when employees perceive the organization’s concern and investment in goals they value (e.g., environmental protection), they are likely to respond with positive attitudes and behaviors that extend beyond their normal job roles. Specifically, GHRM practices send a strong signal that the organization is committed to sustainability. In response, employees feel obligated to contribute to this common goal, reflected in higher engagement, readiness to participate in green innovation activities, and proactive adherence to and dissemination of the organization’s green culture (Piwowar-Sulej & Iqbal, 2023). Therefore, SET provides a micro-level lens for interpreting the motivations that drive employees to become agents of sustainable change.

1.3. *Factors influencing Sustainable Performance in the agricultural sector*

1.3.1. GHRM practices

Green Human Resource Management (GHRM) practices encompass a set of policies and activities aimed at promoting resource efficiency, minimizing environmental impacts, and enhancing employee awareness and commitment to sustainable development goals (Renwick *et al.*, 2013; Jabbour & de Sousa Jabbour, 2016). These practices include green hiring, green training, and green performance assessment.

Firstly, green hiring is crucial for building an environmentally conscious workforce, improving organizational effectiveness (Mishra, 2017). Organizations should prioritize candidates with pro-environmental behaviors and assess their willingness to engage in ecological activities. This includes creating a green employer image through green job descriptions and interview guidelines, emphasizing environmental aspects throughout

recruitment (Al Kerdawy, 2019) a conceptual framework was proposed to list theoretical concepts of GHRM, CSEV and CSR to form hypotheses. Data were collected from 326 respondents occupying the highest managerial positions in the studied firms. Using a structural equation model (SEM). Additionally, fostering employee participation in green practices such as recycling is essential (Nasir *et al.*, 2023).

Secondly, green training involves ongoing education aligned with environmental management goals. Key aspects include knowledge management, raising environmental awareness, and implementing conservation practices. Green training is vital for developing human resource capacity and achieving sustainability objectives (Joshi & Dhar, 2020). Effective training programs should provide relevant resources and enhance employee engagement in green actions like waste management and energy saving (Imran *et al.*, 2021).

Finally, green performance assessment measures individual and organizational effectiveness based on environmental protection criteria. This assessment integrates environmental objectives into performance evaluation systems, promoting commitment to sustainable development (Anuradha & Srivastava, 2018). Studies show that GHRM practices positively influence sustainable performance by reducing waste and pollution (Mousa & Othman, 2020). GHRM practices enhance positive environmental outcomes and are essential for achieving sustainable performance, as emphasized by various researchers (Kramar, 2014; Bombiak & Marciniuk-Kluska, 2018; Ahmad, 2015). Managers, particularly in HR, play a crucial role in achieving environmental objectives by investing in training and rewarding environmentally-conscious employees (Malik *et al.*, 2020b). Green Human Resource Management (GHRM) is increasingly relevant in Vietnam's agricultural sector amid the shift toward sustainable and climate-resilient farming. Green hiring should prioritize candidates with experience in organic cultivation, water-saving irrigation (AWD), and integrated pest management (IPM), aligning with standards like the Sustainable Rice Platform (SRP). Green training must focus on practical techniques and environmental awareness, especially in rural areas where experiential learning is key. Performance assessment should incorporate environmental indicators such as reduced agrochemical use, waste sorting, and compliance with green production protocols. These practices strengthen workforce capacity and support Vietnam's agricultural sustainability goals. Based on this, the study proposes the hypothesis:

H₁: GHRM practices have a positive impact on sustainable performance in the agricultural sector.

1.3.2. Green Innovation

Green innovation involves developing and applying new products, services, processes, or management models to minimize environmental impacts, utilize resources efficiently, and promote sustainable development within organizations. It helps businesses comply with environmental regulations while enhancing ecological performance and social responsibility (Chen, 2008; Kraus *et al.*, 2020). Numerous studies have explored the impact of Green Human Resource Management (GHRM) practices on green innovation and its influence on sustainable performance in the agricultural sector.

Firstly, green innovation is recognized as a foundational approach for implementing GHRM practices, improving ecological performance, and promoting sustainability in agriculture (Ren *et al.*, 2018). Research indicates that GHRM practices enhance employees' knowledge and competencies, facilitating innovation in products and processes (Syafri *et al.*, 2021). Green recruitment improves organizations' ecological management profiles and encourages employee participation in environmental activities, leading to new ideas in environmental management (Renwick *et al.*, 2013). Additionally, green training helps employees identify environmental issues and engage in green activities to stimulate innovation (Ahmeda *et al.*, 2020). Green performance appraisal practices also align employee attitudes with the organization's environmental objectives (Guerci *et al.*, 2016). Studies show that human resource management systems significantly impact organizational innovation and process improvement (Liu *et al.*, 2022).

Secondly, successful green innovation enables agricultural organizations to enhance productivity, strengthen core competencies, and improve economic efficiency (Khurshid *et al.*, 2019). Organizations pursuing green innovation tend to achieve high efficiency by utilizing green processes and tools, creating practical value (Sun *et al.*, 2023). Zailani (2015) assert that green innovation benefits organizations while reducing environmental harm. It supports the use of eco-friendly materials and processes and implements sustainable industrial practices. Key features of green innovation include environmentally friendly technologies and practices that mitigate ecological impacts in agriculture, such as new agricultural equipment design and sustainable supply chains (Awan *et al.*, 2023). These advancements enhance environmental performance, operational efficiency, and cost savings.

Research by Asadi (2020) demonstrates that GHRM practices positively influence organizational sustainable performance through green innovation (Asadi *et al.*, 2020). Additionally, Kanan *et al.* (2023) confirm that green innovation mediates the relationship between GHRM practices and sustainable performance improvements (Kanan *et al.*, 2023). Green innovation in Vietnam's agricultural sector focuses on climate-adaptive crop

varieties, biological pesticides, precision farming technologies, and circular economy models. Farmers and agribusinesses are increasingly adopting drought- and salinity-resistant seeds, using bio-based inputs to reduce chemical dependency, and applying tools like soil sensors and drip irrigation to optimize resource use. Circular practices such as recycling agricultural waste into organic fertilizer or converting livestock waste into biogas are also gaining traction. These innovations help reduce environmental impact, improve productivity, and support the country's transition toward sustainable agriculture. Based on these findings, the study proposes the following hypotheses:

H₂: GHRM practices positively affect Green innovation.

H₃: Green Innovation positively affects Sustainable Performance in the agricultural sector.

H₄: Green innovation positively mediates the relationship between GHRM practices and sustainable performance.

1.3.3. Green Culture

Green Culture comprises a set of environmentally oriented values, beliefs, norms, and practices shared within an organization or community to foster pro-environmental behavior and sustainable development. It is reflected in organizations prioritizing environmental protection in decision-making, encouraging employee participation in green practices, and integrating sustainability principles into daily management (Yong *et al.*, 2020). Numerous studies have explored the impact of Green Human Resource Management (GHRM) practices on Green Culture and its role in enhancing sustainable performance in the agricultural sector.

Firstly, GHRM practices are vital for developing Green Culture within organizations. By embedding green criteria in recruitment, training, appraisal, and rewards, GHRM practices spread environmental values and norms among employees, fostering a shared commitment to sustainability. Renwick *et al.* (2016) showed that GHRM policies enhance environmental awareness and stimulate employee involvement in initiatives essential for establishing Green Culture. Pham *et al.* (2019) demonstrated that GHRM practices positively influence green behaviors and employee engagement with environmental goals, contributing to the development of Green Culture in Vietnamese manufacturing. Mousa and Othman (2020) noted that GHRM not only strengthens individual commitment to green values but also influences how organizations maintain Green Culture over time.

Secondly, Green Culture is recognized as a crucial driver of sustainable performance in modern organizations. When environmental values are

integrated into an organization's culture, businesses improve operational efficiency and promote sustainability across economic, social, and environmental dimensions. Hooi (2021) noted that Green Culture encourages the implementation of environmental initiatives, enhancing overall green performance and competitive advantages (Hooi *et al.*, 2021). Ren (2021) confirmed that cultivating Green Culture enables companies to engage employees in environmental protection, leading to resource savings and emission reductions that directly support sustainable performance; fosters green innovation, allowing organizations to develop eco-friendly products and services for sustainable growth (Ren *et al.*, 2022).

Green Culture also plays a crucial mediating role between GHRM practices and organizational sustainable performance. According to Ren (2021), it mediates the effect of GHRM practices on measurable outcomes like improved green performance and resource efficiency (Ren *et al.*, 2022). Shahzad (2023) confirmed that GHRM practices positively impact sustainable performance only when a strong Green Culture is established (Shahzad *et al.*, 2023) or more precisely, green HRM, has significantly transformed in recent years. Human resources are an important and valuable asset of a firm. In this research, green HRM is concentrated on the areas where HRM is held accountable for the company's sustainability initiatives. The research examines the effects of green HRM on organizational performance in China while considering the mediating roles of green innovation (GI). Additionally, Gazi (2024) emphasized that Green Culture enhances the effectiveness of GHRM practices on sustainable performance through increased value sharing and commitment to environmental goals (Gazi *et al.*, 2024).

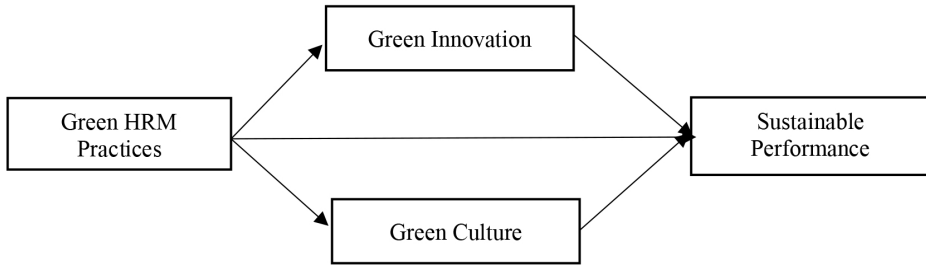
Green culture in Vietnam's agricultural sector is shaped by collective values, informal environmental norms, and community-based leadership. In rural areas, sustainable practices such as waste recycling, reduced chemical use, and ecological conservation are reinforced through social pressure and traditional customs. Informal regulations – rooted in local beliefs and peer influence – play a critical role in guiding environmentally responsible behavior. Cooperative leaders, farmer group heads, and village elders act as cultural facilitators, translating national sustainability goals into locally accepted actions. This bottom-up approach makes green culture a socially embedded force driving sustainable agriculture across Vietnam. Based on these arguments, this study proposes the following hypotheses:

H₅: GHRM practices positively affect Green Culture.

H₆: Green Culture positively affects Sustainable performance in the agricultural sector.

H₇: Green Culture positively mediates the relationship between GHRM practices and Sustainable Performance.

Figure 1 - The model of research



2. Materials and methods

This study utilizes a quantitative research method by employing questionnaires to survey managers and staff in the agricultural sector of Vietnam. The research follows a cross-sectional design to investigate the relationships between Green Human Resource Management Practices, Green Innovation, Green Culture, and Sustainable Performance.

2.1. Sampling method and sample description

To test the research hypotheses, this study employs the stratified random sampling method to ensure that the sample adequately represents different hierarchical levels and functional groups within agricultural enterprises in Vietnam (Neyman, 1992). The application of this method enhances external validity by collecting information from different subgroups within the population, while also ensuring the inclusion of participants who possess relevant knowledge and roles associated with the research topic.

A total of 400 questionnaires were distributed, of which 389 valid responses were received, resulting in a response rate of 97.25%. Among the 389 participants, 235 (60.4%) were male and 154 (39.6%) were female. Regarding age distribution, 42.7% of participants were between 25 and 34 years old, 38.3% were between 35 and 44 years old, and 19% were over 45 years old. In terms of work experience, 28.5% had 1 to 5 years of experience, 45.2% had 6 to 10 years of experience, and 26.3% had more than 10 years of experience in the agricultural sector. The breakdown of work positions reveals that 45% were managers and 55% were staff members. In terms of business types, the participation rates were as follows: cooperatives accounted for 29.3%, one-member limited liability companies accounted for 24.9%, two-or-more-member limited liability companies accounted for 19.0%, joint-stock companies accounted for 21.9%, and private enterprises accounted for 4.9%.

Table 1 - Descriptive Statistics of the Sample

Sample Information	Frequency	Percentage (%)
Gender		
Male	235	60.4
Female	154	39.6
Age		
25-34 years old	166	42.7
35-44 years old	149	38.3
Over 45 years old	74	19.0
Work Experience		
1-5 years	111	28.5
6-10 years	176	45.2
Over 10 years	102	26.3
Job Position		
Manager	175	45.0
Staff	214	55.0
Type of Business		
Cooperative	114	29.3
One-member Limited Company	97	24.9
Two-or-more-member Limited Company	74	19.0
Joint-stock Company	85	21.9
Private Enterprise	19	4.9

Source: Authors' data analysis results (2025).

2.2. Data collection procedure

Data were collected through direct distribution of questionnaires at agricultural enterprises. The data collection process took place over a period of 2 months (from March to April 2025). Each participant was provided with a questionnaire and had approximately 20-30 minutes to complete it. The questionnaires were then collected directly by the research team to ensure a high response rate and data quality.

2.3. Measurement scales

The study uses a 5-point Likert scale (from 1 = “Strongly disagree” to 5 = “Strongly agree”) for all variables in the model. The measurement scales were developed based on previous studies and adapted to fit the research context (Appendix A).

2.4. Data analysis

Data were entered into Smart PLS 3.0 software for processing. The study employed Cronbach’s alpha, Composite Reliability (CR), and outer loading coefficients to assess the reliability of the measurement scales. Subsequently, the authors used outer loading and Average Variance Extracted (AVE) to evaluate the convergent validity of the scales. To assess discriminant validity, the authors used the Fornell-Lacker criterion and the Heterotrait-Monotrait Ratio (HTMT).

To evaluate the structural model, the authors conducted the following steps: assessment of multicollinearity, evaluation of the fit of relationships, assessment of the coefficient of determination R^2 , evaluation of effect size f^2 , and assessment of the mediating role of variables. This comprehensive analytical approach ensures the robustness of the findings and the validity of the conclusions drawn from the data.

3. Results

3.1. Research results

3.1.1. Results of reliability and convergent validity testing of the measurement scales

The reliability of the measurement scales was assessed using Cronbach’s Alpha, Composite Reliability (CR), and outer loading (J. F. Hair *et al.*, 2019). Composite Reliability must be greater than 0.7 for the scale to be considered reliable (Diamantopoulos *et al.*, 2012). The results in Table 2 show that all scales have Cronbach’s Alpha coefficients greater than 0.8, composite reliability values greater than 0.7, and outer loading values for all observed variables greater than 0.4 (J. F. Hair, 2014). Therefore, the measurement scales in the model are highly reliable.

Table 2 - Results of reliability and convergent validity measurement

Constructs/ Items	Outer Loadings	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)	VIF
Green HRM Practices		0.902	0.920	0.561	
GHP1	0.761				1.892
GHP2	0.719				2.088
GHP3	0.725				1.948
GHP4	0.738				1.946
GHP5	0.813				2.869
GHP6	0.752				2.306
GHP7	0.749				2.062
GHP8	0.745				2.041
GHP9	0.735				2.355
Green Innovation		0.894	0.922	0.702	
GI1	0.804				2.047
GI2	0.874				2.758
GI3	0.845				2.359
GI4	0.834				2.391
GI5	0.831				2.174
Green Culture		0.889	0.915	0.644	
GC1	0.777				2.082
GC2	0.835				2.344
GC3	0.822				2.402
GC4	0.761				1.954
GC5	0.825				2.291
GC6	0.792				2.261
Sustainable Performance		0.923	0.934	0.543	
SP1	0.709				2.457
SP2	0.722				2.463
SP3	0.706				2.450
SP4	0.714				2.076
SP5	0.808				2.783
SP6	0.764				2.295

SP7	0.790	3.010
SP8	0.736	2.133
SP9	0.714	2.544
SP10	0.719	2.551
SP11	0.707	2.202
SP12	0.747	2.786

Source: Authors' data analysis results (2025).

To assess convergent validity, outer loading and Average Variance Extracted (AVE) were used. Outer loading values should generally be at least 0.7 for observed variables to be considered of good quality (J. Hair & Alamer, 2022) followed by a discussion of situations in which PLS-SEM should be the method of choice for structural equation modeling. It is argued that PLS-SEM is appropriate when complex models are analyzed, when prediction is the focus of the research – particularly out-of-sample prediction to support external validity, when data do not meet normal distribution assumptions, when formative constructs are included, and when higher-order constructs facilitate better understanding of theoretical models. The most up-to-date guidelines for applying PLS-SEM are provided, and step-by-step guidance is offered on how to apply the method using an R statistical package (i.e., SEMinR. Based on the results in Table 2, all observed variables have outer loading values greater than 0.7, and all AVE values in the model are greater than 0.5 (Subhaktiyasa, 2024). Therefore, the proposed measurement scales meet the requirements for convergent validity.

3.1.2. Discriminant validity

To assess discriminant validity, the authors used the Fornell–Lacker criterion and the Heterotrait-Monotrait Ratio (HTMT) (Henseler *et al.*, 2015). The Fornell-Lacker criterion is shown in Table 3. Table 3 shows that the square roots of AVE for each construct range from 0.661 to 0.838 and are all greater than the highest correlation value of that construct with any other construct in the model. In addition, the HTMT values in Table 4 range from 0.739 to 0.876 and are all less than 0.9. This demonstrates that the proposed measurement scales meet the requirements for discriminant validity.

Table 3 - Fornell-Larcker Criterion

	GC	GHP	GI	SP
GC	0.802			
GHP	0.757	0.749		
GI	0.661	0.788	0.838	
SP	0.765	0.777	0.755	0.737

Source: Authors’ data analysis results (2025).

Table 4 - Heterotrait-Monotrait Ratio (HTMT)

	GC	GHP	GI	SP
GC				
GHP	0.841			
GI	0.739	0.876		
SP	0.841	0.849	0.830	

Source: Authors’ data analysis results (2025).

3.1.3. Structural model and hypothesis testing

3.1.3.1. Assessment of multicollinearity

The structural model in this study includes multiple paths, necessitating the calculation of the variance inflation factor (VIF) for each sub-model. According to J. F. Hair *et al.* (2019), multicollinearity is not present when the VIF is less than or equal to 5. As indicated by the results in Table 2, all exogenous variables have VIF values below 5, which suggests that the research model’s multicollinearity is within an acceptable range. Furthermore, if all VIFs in the inner model, resulting from a comprehensive collinearity test, are equal to or less than 3.3, the model can be deemed free of common method bias (Kock, 2015).

3.1.3.2. Assessment of the coefficient of determination R²

R² analysis evaluates the coefficient of determination using total variance on independent constructs of the dependent constructs (J. F. Hair *et al.*, 2019). The R² values of this study’s model are: Green Innovation = 0.621, Green Culture = 0.574, and Sustainable Performance = 0.713. These values indicate

that the model explains 62.1% of the variance in Green Innovation, 57.4% of the variance in Green Culture, and 71.3% of the variance in Sustainable Performance, suggesting a substantial explanatory power of the model.

Table 5 - R Square and R Square Adjusted

	R Square	R Square Adjusted
GC	0.574	0.573
GI	0.621	0.620
SP	0.713	0.711

Source: Authors' data analysis results (2025).

3.1.3.3. Assessment of effect size f^2

Hair *et al.* (2019) used the f^2 coefficient to evaluate how important an independent variable is to a dependent variable when removed. Table 6 summarizes the f^2 effect size results when the authors split the structural model into sub-models with one dependent variable (SP, GC, GI) and several independent variables (J. F. Hair *et al.*, 2019).

Table 6 - Effect size f^2 results

Relationship	f^2 Value	Effect size
GHP → GC	1.346	Large
GHP → GI	1.641	Large
GHP → SP	0.062	Small
GC → SP	0.194	Medium
GI → SP	0.127	Small

Source: Authors' data analysis results (2025).

3.1.3.4. Assessment of the fit of relationships

Table 7 - Direct effect relationship results

	Path coefficient	T Statistics	P value
GC → SP	0.366	7.582	0.000
GHP → GC	0.757	28.590	0.000
GHP → GI	0.788	35.965	0.000
GHP → SP	0.253	4.732	0.000
GI → SP	0.314	6.150	0.000

Source: Authors’ data analysis results (2025).

The summary results in Table 7 show that, at a 5% significance level corresponding to $t > 4.732$, all relationships in the model are significant ($p < 0.05$). This confirms that all the proposed direct relationships in the research model are statistically supported.

3.1.3.5. Assessment of the mediating role of variables (Assessment of indirect relationships)

To assess the mediating role of Green Innovation and Green Culture, the authors used the procedure of Hair *et al.* (2016), as shown in Table 8:

Table 8 - Indirect effect relationship results

	Path coefficient	Confidence Interval of the Indirect Effect		Result
		2.5%	97.5%	
GHP → GC → SP	0.277	0.208	0.356	Partial mediation (complementary)
GHP → GI → SP	0.247	0.172	0.339	Partial mediation (complementary)

Source: Authors’ data analysis results (2025).

The results in Table 8 indicate that both Green Culture and Green Innovation serve as partial mediators (complementary) in the relationship between GHRM practices and Sustainable Performance. This means that

GHRM practices influence Sustainable Performance both directly and indirectly through these mediating variables.

3.1.3.6. Conclusion on research hypotheses

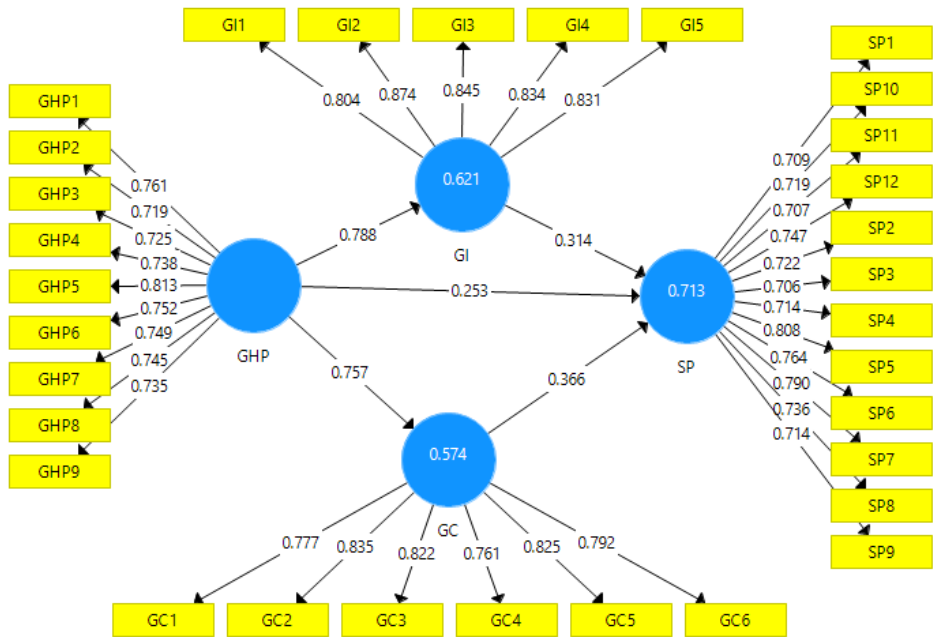
Based on the results of direct and indirect relationship assessments through path coefficients and the evaluation of the mediating roles of variables in the model above, the authors draw conclusions for the research hypotheses as shown in Table 9.

Table 9 - Conclusion on research hypotheses

Hypothesis	Statement	Conclusion
Direct relationships		
H1	GHRM practices have a positive impact on Sustainable Performance in the agricultural sector	Accepted
H2	GHRM practices positively affect Green Innovation	Accepted
H3	Green Innovation positively affects Sustainable Performance in the agricultural sector	Accepted
H5	GHRM practices positively affect Green Culture	Accepted
H6	Green Culture positively affects Sustainable Performance in the agricultural sector	Accepted
Mediating relationships		
H4	Green Innovation positively mediates the relationship between GHRM practices and Sustainable Performance	Accepted
H7	Green Culture positively mediates the relationship between GHRM practices and Sustainable Performance	Accepted

Source: Synthesized from research results.

Figure 2 - Model Evaluation Results



3.2. Discussion

Research results show that Green Human Resource Management practices are important factors influencing the Sustainable Performance of organizations in the agricultural sector. This demonstrates that integrating environmental factors into human resource management policies and practices not only raises awareness, attitudes, and behaviors of employees towards environmental protection but also directly contributes to improving the long-term performance of the organization across three aspects: economic, social, and environmental. This result is fully consistent with the findings of Shahzad (2023), showing that Green Human Resource Management plays an important role in promoting green work behavior and improving the sustainable performance of organizations in the modern context (Shahzad *et al.*, 2023).

Notably, the research also highlights the important mediating role of Green Innovation in the relationship between GHRM practices and Sustainable Performance. Green Innovation serves as a bridge, transforming green resources and awareness into environmentally friendly solutions, processes, and new products, helping organizations respond more effectively to

environmental challenges and modern market needs. This result is consistent with the findings of Shahzad (2023), Syafri (2021) and Liu (2022), all of which point out that GHRM practices not only have a direct positive impact but also indirectly promote Sustainable Performance through the spread of Green Innovation in organizations (Syafri *et al.*, 2021; Liu *et al.*, 2022). Domestic and international markets are increasingly demanding clean agricultural products that are traceable and environmentally friendly. At the same time, the Vietnamese government is actively promoting policies for green agricultural development – for example, the Strategy for Sustainable Agriculture Development to 2030. These factors create strong incentives for organizations to adopt Green Human Resource Management (GHRM) practices and green innovation in order to meet both market expectations and policy requirements.

In addition, green culture plays a key role in strengthening and enhancing the effectiveness of GHRM practices on the sustainable performance of organizations (Ren *et al.*, 2022). When green culture is disseminated and deeply rooted in the organization, it shapes values, norms, attitudes, and behaviors related to environmental issues, encouraging all employees to actively participate in environmental protection and sustainable development initiatives. This factor adds a new perspective to the research, enriching the contribution by illustrating how a strong green culture can amplify the positive impact of GHRM practices on sustainable outcomes (Kanan *et al.*, 2023). Green culture plays an extremely important role in the context of Vietnam, particularly in enhancing the effectiveness of Green Human Resource Management (GHRM) practices in the sustainable performance of organizations. In a country where agriculture accounts for a significant portion of the economy, developing a green culture not only contributes to the sustainable development of the agricultural sector but also protects the livelihoods of millions of farmers. This culture integrates traditional values that respect nature, encouraging communities to participate in environmental protection and sustainable development initiatives. Moreover, green culture promotes innovation in adopting sustainable farming methods, helping agricultural organizations adapt better to current environmental challenges. The Vietnamese government is also striving to implement supportive policies for sustainable development; therefore, a strong green culture within organizations will facilitate the achievement of these goals. Furthermore, optimizing production processes through green practices will improve organizational performance while minimizing waste and negative environmental impacts (Tuyết, n.d.). In summary, developing a green culture not only benefits individual organizations but also contributes to society as a whole, moving towards a more sustainable future for Vietnam.

Organizations can focus on integrating green criteria throughout HR processes-such as incorporating environmental objectives into recruitment, training, and evaluation systems. In Vietnam's agricultural context, implementing employee training programs on sustainable farming techniques, efficient water resource use, or reducing agricultural chemical use can bring significant benefits. For example, agricultural companies could develop training modules on organic farming methods or establish mentoring programs where experienced sustainable farmers guide newer employees. Similarly, performance evaluation systems can be designed to reward employees who propose and implement resource-saving solutions or waste reduction in agricultural production processes. One effective practice could be establishing "green performance metrics" that track specific environmental contributions alongside traditional productivity measures.

Promoting an organizational culture that values sustainability through training, recognition, and incentives for green initiatives can further reinforce these practices. In the agricultural sector, recognition and reward programs can focus on initiatives such as improving water-saving irrigation systems, processes for converting waste into organic fertilizer, or applying technology to reduce carbon emissions in agricultural supply chains. Agricultural businesses could implement monthly "Green Champion" awards for employees who develop innovative sustainable solutions, or create dedicated innovation funds that financially support employee-led environmental projects.

This study presents several important theoretical contributions. First, it extends the application of the Resource-Based View (RBV) to the agricultural sector, demonstrating that "green human capital" and organizational capabilities such as "green innovation" are strategic resources that can generate competitive advantages even within a traditional field. Second, by confirming the roles of mediating variables, the research clarifies the "black box" in the GHRM-performance relationship, providing evidence for the operational mechanisms of Social Exchange Theory (SET), where the organization's investment is "reciprocated" by employees through innovative behaviors and adherence to culture.

4. Conclusions

4.1. Recommendations

Based on the research findings, the author proposes several recommendations to enhance sustainability in the agricultural sector through green human resource management practices.

4.1.1. Policy Recommendations

First, it is necessary to build a strong and comprehensive legal framework to promote green human resource management practices in the agricultural sector. State management agencies need to issue policies and regulations that encourage agricultural businesses to apply green practices in human resource management, such as providing tax incentives, financial support, and other assistance for businesses implementing green human resource management initiatives.

Second, awareness and education about the importance of Green Human Resource Management in the agricultural sector need to be enhanced. Functional agencies need to organize communication campaigns, seminars, and training programs to raise awareness of businesses and employees about the importance of green human resource management for sustainable development in agriculture.

Third, promote research and development on Green Human Resource Management in the agricultural sector. Management agencies need to invest in research and development of effective green human resource management models and practices, suitable for the specific characteristics of the agricultural sector, while promoting knowledge and technology transfer between research organizations, universities, and businesses.

4.1.2. Recommendations for Businesses

For businesses, the author proposes three main recommendations:

First, integrate environmental factors into all aspects of human resource management. Agricultural businesses need to incorporate green criteria into recruitment, training, performance evaluation, and reward policies. Specifically, in the recruitment process, businesses can prioritize candidates with knowledge, skills, and positive attitudes towards environmental issues. In training, businesses need to organize training courses on environmental protection, sustainable use of resources, and green production techniques. For performance evaluation, businesses should develop evaluation criteria related to compliance with environmental regulations and contribution to the organization's sustainable goals.

Second, build and develop a green culture in the organization. Business leaders need to demonstrate a strong commitment to environmental issues, creating favorable conditions for the formation and spread of green culture in the organization. Businesses can organize activities to raise awareness about environmental protection, encourage employees to participate in green

initiatives, and recognize and reward outstanding contributions of employees to the organization's sustainable goals.

Third, invest in green innovation and application of technology in agricultural production. Businesses should encourage and support employees to propose and implement green innovation initiatives, invest in research and development of environmentally friendly solutions, processes, and products. Businesses can establish working groups specializing in green innovation, organize competitions to propose green initiatives, and provide necessary resources to realize innovative ideas.

4.1.3. Limitations and future research directions

Although the research objectives have been achieved, the study still has certain limitations. First, the study uses data from a single point in time, so it is difficult to assess the impact of green human resource management practices on sustainable performance over time. Second, the study focuses only on the agricultural sector in Vietnam, so the results may not be entirely suitable for other sectors or countries.

Based on the above limitations, the author proposes some future research directions as follows: (1) Conduct longitudinal research to assess the long-term impact of Green Human Resource Management practices on Sustainable Performance, (2) Expand the scope of research to other sectors beyond agriculture to compare and evaluate differences, (3) Research more deeply on cultural and organizational factors affecting the effectiveness of green human resource management practices.

4.2. Conclusion

The study confirms that Green Human Resource Management practices have a significant positive impact on Sustainable Performance in the agricultural sector, both directly and indirectly through the mediating roles of green innovation and green culture. Integrating environmental protection into HR policies not only enhances employees' awareness and behaviors but also contributes to improving the long-term effectiveness of organizations in economic, social, and environmental aspects. The findings provide important theoretical and practical implications for managers and policymakers in promoting sustainable agricultural development in Vietnam. In the context of increasing environmental challenges and global integration, the application of GHRM, Green Innovation, and Green Culture will be key factors helping the agricultural sector achieve sustainable growth and create lasting value for society.

Conflict of interest statement

The authors commit to declaring that there are no conflicts of interest related to the publication of this article.

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Appendix A

Table A - Measurement of variables

Items	Statements	Sources
Green HRM Practices (GHRM)		
GHP1	Green issues specified in job descriptions at companies and cooperatives	Renwick <i>et al.</i> , 2013; Correia <i>et al.</i> , 2024
GHP2	Green employer branding at companies and cooperatives (Green employer of choice)	
GHP3	Companies and cooperatives recruit employees who are green-aware	
GHP4	Training for green jobs and integrated training will create emotional involvement in HRM	
GHP5	Green knowledge management using the tacit knowledge of human resources in GHRM	
GHP6	Training workshops on green orientation for managers and employees at companies and cooperatives	
GHP7	Green performance indicators are included in green performance systems and appraisals	
GHP8	Managers set green targets, goals, and responsibilities	
GHP9	Managers set objectives for achieving green outcomes included in appraisals	
Green innovation (GI)		
GI1	Our companies/cooperatives competes in the market and always uses new technology	Asadi <i>et al.</i> , 2020; Correia <i>et al.</i> , 2024
GI2	Our companies/cooperatives uses materials that are easy to recycle, reuse, and decompose	
GI3	Our companies/cooperatives recovers the company’s end-of-life products and recycling.	
GI4	Our companies/cooperatives uses cleaner or renewable technology to make savings (such as energy, water, and waste)	
GI5	Our companies/cooperatives redesigned production and operation processes to improve environmental efficiency	
Green culture (GC)		
GC1	Our companies/cooperatives makes a concerted effort to make every employee understand the importance of environmental preservation	Banerjee, 2002; Fraj <i>et al.</i> , 2011; Wang, 2019.

GC2	Our companies/cooperatives has a clear policy statement urging environmental awareness in every area
GC3	Environmental preservation is a high priority activity in our companies/cooperatives
GC4	Preserving the environment is a central corporate value in our companies/cooperatives
GC5	Our companies/cooperatives links environmental objectives with our other corporate goals
GC6	Our companies/cooperatives develops products and processes that minimize environment impact

Sustainable Performance (SP)

SP1	We have improved overall stakeholder welfare	Yusliza <i>et al.</i> , 2020; Correia <i>et al.</i> , 2024
SP2	Improvement in community health and safety	
SP3	It improved the occupational health and safety of employees	
SP4	Improved awareness and protection of the claims and rights of customers in the community served	
SP5	Improved compliance with environmental standards	
SP6	Reduction in energy consumption	
SP7	Reduction in material usage	
SP8	Reduction in the consumption of hazardous materials.	
SP9	Decrease in costs for materials purchasing	
SP10	Decrease in costs for energy consumption	
SP11	Decrease in fees for waste discharge	
SP12	Decrease in fines for environmental accidents	

Nguyen Nhung

Faculty of Business Administration, University of Finance and Accountancy
University of Finance and Accountancy, 02 Le Quy Don Street, Tu Nghia Commune,
Quang Ngai Province, Vietnam

E-mail: nguyenthihongnhung@tckt.edu.vn

Phone number: 0906465689

ORCID: <https://orcid.org/0009-0008-9662-3881>

She holds a Master's degree in Business Administration. Her research interests include agricultural economics, quality management, brand management, and innovative entrepreneurship.

Mai Thuy

Faculty of Business Administration, University of Finance and Accountancy
University of Finance and Accountancy, 02 Le Quy Don Street, Tu Nghia Commune,
Quang Ngai Province, Vietnam

E-mail: maithithanhthuy@tckt.edu.vn

Phone number: 0905264679

ORCID: <https://orcid.org/0009-0007-4935-0924>

She holds a Master's degree in Business Administration. Her research interests include agricultural economics, supply chain management, and risk management.

Nguyen Phung

Faculty of Business Administration, University of Finance and Accountancy
University of Finance and Accountancy, 02 Le Quy Don Street, Tu Nghia Commune,
Quang Ngai Province, Vietnam

E-mail: nguyenthiphung@tckt.edu.vn

Phone number: 0939575445

ORCID: <https://orcid.org/0009-0001-1830-119X>

She holds a Master's degree in Business Administration. Her research interests include Innovative Startup, Consumer behavior.

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Agricultural Development versus Environmental Sustainability: FDI, Carbon Emissions, and Global Warming in Vietnam's Economy

Doan Ba Toai^{a,b}, Jianzhou Yang^b, Trieu Thi My An^{*,b}

^a Fujian Agriculture and Forestry University, China

^b Thanh Dong University, Hai Phong City, Vietnam

Abstract

This study provides a comprehensive examination of the environmental consequences of foreign direct investment (FDI) within Vietnam's agri-food sector, focusing on the tension between agricultural expansion and carbon emission control. In the context of rising global climate concerns, the analysis examines how FDI inflows affect CO₂ emissions, while considering agricultural structural transformation, economic development, and trade openness. The results indicate that FDI significantly increases CO₂ emissions, primarily through scale expansion and structural shifts toward emission-intensive agricultural activities. The findings underscore agricultural industrial restructuring as a crucial transmission channel. The study contributes both theoretically and practically by offering policy recommendations aimed at steering FDI toward cleaner agricultural development pathways and supporting Vietnam's transition toward a low-carbon and climate-resilient agri-food system.

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* *Corresponding author:* Trieu Thi My An - Thanh Dong University, Vietnam. E-mail: trieumyan@gmail.com.

Introduction

In recent years, increasing concern over the environmental consequences of economic expansion has placed the agri-food sector at the forefront of global policy debates, as it is both highly exposed to climate risks and a major contributor to greenhouse gas (GHG) emissions. In this context, foreign direct investment (FDI), a key engine of growth in emerging economies, has gained increasing relevance in discussions on sustainable development. This issue is particularly critical for Vietnam, where rapid economic transformation and agricultural modernisation have contributed to rising CO₂ emissions. According to a UNFCCC report released in December 2023, the rapid expansion of Vietnam's agri-food value chains – partly fueled by rising FDI inflows – has increasingly shaped the nation's carbon footprint, raising important questions about the environmental implications of its development trajectory.

Since the early 1990s, Vietnam's economic liberalisation and integration into global markets have enabled it to attract substantial FDI inflows, supporting sustained GDP growth of over 6% annually during the past decade (General Statistics Office of Vietnam). The economy has advanced, it has also witnessed notable industrial upgrading and deeper integration of the agricultural sector into global supply chains. However, these gains have also led to rising energy demand and mounting environmental pressures. Data from the International Energy Agency (IEA) show that Vietnam's CO₂ emissions have tripled since 1990, largely driven by fossil fuel consumption in manufacturing, urban expansion, and increasingly energy-intensive agri-food processing. This suggests that FDI-led development, while enhancing productivity, may simultaneously reinforce carbon-intensive production structures, intensifying environmental stress.

The Vietnamese government has recognised these challenges and adopted national strategies to promote low carbon development. However, balancing economic competitiveness with agricultural transformation and environmental sustainability continues to be a highly complex challenge. As noted by Tran and Le (2023), understanding the role of FDI in shaping Vietnam's emission trajectory is essential for designing targeted policy

interventions that encourage green-oriented investment and sustainable agricultural transformation. Policy instruments such as Resolution No. 569 (2022), which emphasises technological upgrading and environmentally responsible growth, indicate a growing commitment to aligning investment promotion strategies with climate objectives. In this context, rigorous empirical evidence is needed to clarify how FDI affects CO₂ emissions within the agri-food system.

Although previous studies have examined the FDI-environment relationship in various emerging economies, substantial gaps persist when it comes to Vietnam. First, most studies assess emissions at the aggregate or industrial level without focusing on the agri-food sector, despite its substantial contributions to energy use, land use change, and resource intensive production. Second, the mechanisms through which FDI influences emissions, such as structural upgrading or scale expansion, have not been sufficiently analysed using sector-specific evidence. Third, limited attention has been paid to competing theoretical explanations, including the Pollution Haven and Pollution Halo hypotheses, which carry important implications for sustainability-oriented investment policy.

This study contributes to literature in three main ways. First, it provides sector-specific empirical evidence on the environmental impact of FDI within Vietnam's agri-food system. Second, it examines the mediating role of agricultural structural transformation and economic expansion in shaping the FDI emissions relationship. Third, it incorporates dual theoretical perspectives, namely the Pollution Haven and Pollution Halo hypotheses alongside insights from the Environmental Kuznets Curve (EKC), offering a more nuanced interpretation of whether FDI reinforces carbon-intensive development patterns or promotes cleaner production practices.

The remainder of this paper is structured as follows. Section 2 synthesises previous evidence on the FDI emissions nexus and identifies key policy gaps. Section 3 outlines the empirical framework, variable selection, and data sources. Section 4 presents the empirical findings and interprets them in relation to transmission mechanisms and policy implications. Section 5 concludes with recommendations for restructuring FDI attraction policies, strengthening environmental governance in agriculture, and promoting climate-smart development pathways for Vietnam and similar emerging economies.

Pollution Haven Hypothesis

The Pollution Haven Hypothesis (PHH) posits that multinational corporations may relocate pollution-intensive industries to developing

countries where environmental regulations are relatively weak. Under such conditions, host countries risk becoming “pollution havens” as the inflow of FDI can exacerbate environmental degradation through increased emissions and resource-intensive production. This hypothesis was first formalised by Grossman and Krueger (1991) in their seminal analysis of the environmental implications of NAFTA, highlighting the potential for regulatory arbitrage in global production networks.

Subsequent studies offer substantial empirical support for this mechanism. Xing and Kolstad (2002), for example, report a positive relationship between FDI and pollution levels in China, suggesting that multinational firms favour locations with lower regulatory stringency. Sapkota (2017) further finds that across 14 Latin American countries, strengthened environmental regulations in developed countries accelerate the relocation of energy-intensive and high-emission industries to developing economies, especially under conditions of trade liberalisation. These patterns imply that economic incentives, coupled with weak domestic environmental governance, may encourage developing countries to attract foreign investment at the expense of environmental quality.

Evidence from China also supports the PHH, particularly in the context of rapid industrialisation. Dong and Zhang (2018) demonstrate that FDI inflows have significantly increased industrial pollution, while Hu and Shao (2022) find that in the early stages of development, FDI tends to raise CO₂ emissions. Only at more advanced stages of industrial restructuring do cleaner technologies begin to mitigate environmental impacts. Similar conclusions are drawn by Cheng Qinliang *et al.* (2022) and Zhu Yuke *et al.* (2022), who observe that FDI’s environmental effects are strongly conditioned by regional development levels, regulatory enforcement, and industrial composition.

Taken together, these findings indicate that developing countries, especially those prioritising growth and export-oriented industrialisation, may be particularly susceptible to pollution-intensive foreign investment. In Vietnam, its rapid structural transformation and expanding agri-food processing sector represent a context where PHH dynamics could be particularly pronounced.

Pollution halo hypothesis

In contrast, the Pollution Halo Hypothesis argues that FDI can improve environmental quality by introducing advanced technologies, cleaner production processes, and superior environmental management practices. Multinational corporations typically adhere to global environmental standards and can generate knowledge spillovers to domestic firms, thereby fostering greener production practices.

Empirical research provides several examples of this effect. Demena and Afesorgbor (2020), using meta-analytic evidence, find that FDI can reduce the intensity of local carbon emissions under certain institutional conditions. Nadeem *et al.* (2020), analysing Pakistan from 1971–2014, report a long-run negative correlation between FDI and CO₂ emissions, indicating that technology transfer can offset pollution associated with scale expansion.

Studies from China further support this perspective. Li and Li (2021), Lu and Luo (2021) show that coordinated development between FDI and economic growth can weaken emission intensity by facilitating technology upgrading. Zou and Chen (2022) highlight that when FDI enters high-tech industries, the resulting technology spillovers impose a strong inhibitory effect on CO₂ emissions. Additionally, Xiang Yu and Dai (2022) demonstrated that two-way FDI between neighbouring cities generates synergistic effects with local economic growth, thereby reducing carbon emission intensity through technology diffusion.

While the Pollution Halo framework offers an optimistic interpretation of FDI's environmental role, its applicability depends heavily on absorptive capacity, regulatory enforcement, and technological composition of inward investment factors that remain uneven across developing countries such as Vietnam.

Environmental Kuznets Curve

The Environmental Kuznets Curve (EKC) describes an inverted U-shaped relationship between economic development and environmental degradation. At early stages of growth, pollution rises as economies industrialise; after reaching an income threshold, cleaner technologies and stronger regulations lead to declining emissions. This dynamic was first empirically demonstrated by Grossman and Krueger (1995) using panel data from 42 countries.

FDI plays a complex role within the EKC framework. Wang and Huang (2017) find that FDI tends to raise CO₂ emissions in the early stages, but later exhibits a moderating effect as economies advance technologically. Wang *et al.* (2019) studied the Beijing-Tianjin-Hebei region and revealed that the environmental impact of FDI varies significantly with geographical location and industrial structure. Jia and Yang (2020) also provide evidence of heterogeneous FDI effects on emissions across China, using Generalised Method of Moments (GMM) estimation.

Overall, the EKC, Pollution Haven, and Pollution Halo hypotheses together offer a multi-dimensional theoretical foundation for analysing the FDI CO₂ emissions nexus. However, current studies still reveal significant limitations: much of it focuses on static or short-term effects; long-term dynamics remain

insufficiently explored; and few studies incorporate cyclical shocks such as the COVID-19 pandemic. To address these gaps, this study integrates the pandemic period into its empirical analysis to better capture structural changes and dynamic variations in FDI's environmental effects.

1. Theoretical analysis and research hypotheses

Vietnam's strategic role in regional production networks and policies favoring foreign capital have led to a spatially concentrated influx of FDI, particularly in coastal economic zones (Tran & Le, 2023). The environmental impact of FDI can be interpreted through the scale composition technique framework (Grossman & Krueger, 1995). At early development stages, scale effects dominate as FDI-driven production expansion increases energy consumption and emissions. The composition effect emerges when FDI encourages shifts toward emission-intensive agri-industrial activities such as processing and fertilizer production. While FDI may introduce cleaner technologies (technique effect), limited absorptive capacity, weak regulations, and early-stage industrialization often constrain such benefits in developing economies like Vietnam.

Previous studies highlight multiple determinants of emissions, including economic growth, industrial structure, energy consumption, foreign capital, and trade openness (Wang *et al.*, 2024; Li, 2014; Cheng, 2019; Cole & Elliott, 2005). Li *et al.* (2011) showed that both pollution haven and pollution halo effects may coexist, following an inverted U-shaped Environmental Kuznets Curve (EKC) trajectory. In addition, trade openness may amplify environmental pressures when production expansion is resource-intensive (Luan *et al.*, 2019). These findings imply that FDI influences CO₂ emissions through different mechanisms that depend on structural conditions and development stages.

Based on these theoretical insights, this study proposes the following hypotheses:

H1: FDI inflows are positively associated with CO₂ emissions in Vietnam.

H2: Industrial structure mediates the FDI-emissions relationship, with structural upgrading mitigating environmental impact.

H3: Economic development moderates the FDI-emissions nexus in a nonlinear (inverted U-shaped) manner.

H4: Trade openness strengthens the positive effect of FDI on CO₂ emissions.

2. Data description and model construction

Data sources

The dataset used in this study is compiled from internationally recognised sources to ensure consistency and comparability. CO₂ emissions data are obtained from the World Bank's World Development Indicators (WDI), using indicator EN.ATM.CO2E.KT, which reports total national emissions in kilotons (kt). This unit of measurement aligns with international reporting standards and previous empirical studies.

FDI inflows are drawn primarily from the World Bank (2023) and supplemented, where necessary, with data from Vietnam's General Statistics Office (GSO) to ensure accurate representation of investment trends. Data on agricultural value added, gross domestic product (GDP) per capita, and trade openness (measured as the ratio of total trade to GDP) are likewise obtained from WDI. Industrial structure indicators, representing the share of industrial output in GDP, are collected from both WDI and GSO to maintain alignment with domestic classification systems.

The study covers the period 2010-2022, corresponding to the years for which complete and consistent data are available for all variables. This period captures Vietnam's accelerated agricultural modernisation, deepening global integration, and shifts in FDI liberalisation, making it suitable for examining the FDI-CO₂ emissions nexus.

Variable selection

A. Dependent Variable

Following Hu and Shao (2022), CO₂ emissions serve as the dependent variable, representing Vietnam's environmental pressure.

B. Core Explanatory Variable

Consistent with findings by Wu and Liu (2021), FDI inflows are included as the core explanatory variable to evaluate the environmental implications of inward investment.

C. Control Variables

Three control variables are incorporated to strengthen model robustness:

Industrial structure (IS): measured as the ratio of industrial output to GDP, following Yuan and Cheng (2011).

Economic development (PGDP): GDP per capita as a proxy for income level (Liao, 2020).

Trade openness (TRD): the ratio of total imports and exports to GDP (Liao, 2020).

Together, these variables capture key structural and economic determinants of emissions.

Overall, these variables are selected to capture key economic, structural, and external factors influencing Vietnam's carbon emissions, thereby forming an integrated analytical framework for subsequent empirical estimation. The model is subsequently developed in the next subsection to analyse both the direct and marginal effects of FDI on CO₂ emissions.

Table 1 - Description of variables

Variant	Variable Symbol	Variable Name	Variable Meaning
Explanatory Variable	CO ₂	CO ₂ Emissions	Total CO ₂ emissions in Vietnam (thousands of tons)
Core Explanatory Variables	FDI	Foreign Direct Investment	Amount of FDI inflows to Vietnam (USD billion)
Control Variable	IS	Industrial Structure	Gross industrial sector product/GDP (%)
	PGDP	Level of Economic Development	GDP/total population at the end of the year (USD/person)
	TRD	Level of Foreign Trade	Total exports and imports of Vietnam/GDP

Model construction

In many early-stage developing countries, environmental regulations are relatively relaxed or intentionally kept loose to prioritise economic growth. Under such conditions, inward FDI can increase CO₂ emissions through scale effects, particularly when foreign capital flows into emission-intensive sectors. This may lead the host country to function as a “pollution haven”. Building on this theoretical foundation, the empirical model for this study is specified as follows:

$$CO_2 = \beta_0 + \beta_1 * FDI_t + \beta_2 * IS_t + \beta_3 * PGDP_t + \beta_4 * TRD_t + \varepsilon_t$$

where:

- CO_{2t} = total CO₂ emissions (kilotons)
- FDI_t = foreign direct investment inflows (billion USD)

- IS_t = industrial structure (% of GDP)
- $PGDP_t$ = GDP per capita (USD/person)
- TRD_t = trade openness (% of GDP)
- ε_t = error term

All coefficients (α_1 – α_4) are expected to be positive, reflecting the potential for scale effects, structural dependence, expanding economic activity, and increased trade to raise emissions.

3. Empirical findings

Descriptive statistical analysis

This paper performs descriptive statistics on the acquired data, and the statistical results are presented in Table 2.

Table 2 - Descriptive statistics

Variable	Observations	Minimum	Maximum	Mean	Std. dev.	Variances
CO ₂	13	1.5	3.6	2.379	0.7805	0.609
FDI	13	71.47	236.87	145.9677	57.9602	3359.395
IS	13	0.2130	0.6370	0.3756	0.1178	0.014
PGDP	13	1684	4164	2874.46	745.879	556334.936
TRD	13	0.8760	1.8260	1.3533	0.3228	0.104

Table 2 provides descriptive statistics for Vietnam from 2010 to 2022, including indicators related to CO₂ emissions, FDI, industrial structure, economic development, and trade openness. Vietnam's annual CO₂ emissions range from a minimum of 150 million tons to a maximum of 355 million tons, indicating that emissions have more than doubled over nine years.

With respect to FDI, the maximum inflow is USD 23.687 billion, and the minimum is USD 7.147 billion, suggesting that FDI inflows have more than doubled over the study period and confirming Vietnam's continued success in attracting foreign investment.

For the industrial structure, the share of industry in GDP ranges from 0.2130 to 0.6370, reflecting substantial structural variation during the study period. GDP per capita increases from USD 1,684 to USD 4,164, illustrating

Vietnam's rapid economic expansion. Trade openness varies between 0.8760 and 1.8260, with higher values indicating strong reliance on international trade.

This descriptive evidence suggests that Vietnam's economic transformation during 2010-2022 has been associated with rising emissions, deepening integration into global markets, and a growing role for FDI.

Correlation analysis

An ideal model is characterised by the absence of correlation among independent variables, with each variable providing unique information about the dependent variable that is not present in the other independent variables. In this case, the regression coefficient of each independent variable on the dependent variable is unique under the condition that the other independent variables remain constant.

Table 3 - Results of correlation analysis between variables

Variant	CO₂	FDI	IS	PGDP	TRD
CO ₂	1				
FDI	.826** (0.001)	1			
IS	.512** (0.001)	.809** (0.001)	1		
PGDP	.939** (0.000)	.804** (0.001)	.502 (0.080)	1	
TRD	.892** (0.000)	.819** (0.001)	.605* (0.028)	.961** (0.000)	1

* At the 0.05 level (two-tailed), the correlation was significant.

** At the 0.01 level (two-tailed), the correlation was significant.

Table 3 shows the correlation analysis of each variable, in which the core explanatory variable, FDI, is significantly positively correlated with CO₂. The results suggest that Vietnam's economic development is expanding with the continuous inflow of FDI, which requires the consumption of large amounts of energy and other resources. High-intensity energy consumption will increase the total amount of CO₂ emissions; therefore, FDI is significantly and positively related to CO₂ emissions in Vietnam.

From the perspective of industrial structure, Vietnam is in the stage of rapid industrialization, and the expansion of the industrial sector has increased the demand for energy, especially high-carbon energy sources such as coal and oil. The industrial structure is dominated by manufacturing and export processing industries, which typically have higher energy consumption, especially if fossil fuels are used, leading to higher CO₂ emissions. The agricultural sector, which still accounts for a large share of Vietnam's economy, has relatively low direct CO₂ emissions compared to the industrial sector, but agricultural expansion may lead to deforestation and land-use change, indirectly increasing CO₂ emissions. At the same time, technological underdevelopment in industry and inefficient energy consumption lead to increased CO₂ emissions per unit of output.

From the perspective of the level of economic development, as Vietnam's level of economic development increases and industrialization accelerates, the expansion of the industrial sector has led to an increase in the demand for energy, especially the use of fossil fuels. At the same time, to develop infrastructure work, such as roads, buildings, and power facilities, these increase CO₂ emissions. In addition, the shift in consumption patterns is also a manifestation of the increased level of economic development. As people's income increases, the demand for energy-intensive goods such as automobiles and electronics rises, further pushing up CO₂ emissions.

From the perspective of the level of foreign trade, Vietnam mainly plays the role of manufacturing and assembly in the global value chain. Vietnam's export-oriented economic model has led to the expansion of production scale, especially in the export processing industry, and these activities are usually energy-intensive, which directly increases energy consumption and CO₂ emissions; on the import side, Vietnam imports a substantial amount of raw materials and energy products, particularly fossil fuels, to sustain its industrial production, which in turn contributes to higher CO₂ emissions.

To summarize, FDI shows a clear impact on CO₂ emissions in Vietnam. On the one hand, the FDI inflow exerts a significant impact on Vietnam's CO₂ emissions while promoting its economic growth and industrial upgrading; on the other hand, with the rise in per capita income and the change in consumption patterns, foreign-funded enterprises have expanded their production scale to meet the domestic and international market demands, which may lead to an increase in energy consumption and CO₂ emissions. Meanwhile, the increase in the level of foreign trade, especially the expansion of export-oriented industries, intensifies production activities, which in turn increases CO₂ emissions. Therefore, in the process of attracting FDI, Vietnam needs to pay due attention to the comprehensive impact of industrial restructuring, per capita income growth, and foreign trade

expansion on CO₂ emissions to realize a win-win situation for both economic development and environmental protection.

Regression analysis

Table 4 reports the regression estimates for Vietnam's CO₂ emissions from 2010 to 2022. All coefficients are statistically significant at the 1% or 5% levels, and their signs are consistent with theoretical expectations:

Table 4 - Coefficients and significance results for each variable

Variables	Coefficients	t-statistics	p-values
Constant	0.976	1.611	0.001
FDI	0.897	4.893	0.000
IS	0.680	2.283	0.043
PGDP	0.942	8.874	0.000
TRD	0.953	6.738	0.000

FDI: The results of the core explanatory variable FDI are significantly positive, and the impact of FDI on Vietnam's CO₂ emissions is mainly in terms of capital deepening and technological advancement. FDI brings investment in capital-intensive industries, which tend to be more energy-intensive, leading to an increase in CO₂ emissions (Nadeem *et al.*, 2020; Demena & Afesorgbor, 2020). However, the introduction of more advanced production technologies and clean energy technologies in the future will help to improve energy utilization efficiency, thus curbing the growth of CO₂ emissions to a certain extent. Overall, the impact of FDI on CO₂ emissions in Vietnam depends on the relative intensity of capital increasing and technological progress (Grossman & Krueger, 1995).

IS: The impact of FDI on Vietnam's industrial structure acts on CO₂ emissions. If FDI is mainly concentrated in energy-intensive industries, the entry of foreign direct investment may exacerbate CO₂ emissions; when FDI is mainly concentrated in high-tech clean energy industries, the entry of foreign direct investment will inhibit CO₂ emissions (Cheng, 2019). This study finds that Vietnam is currently in a period of rapid economic development and is mostly dominated by traditional manufacturing industries and other industries in terms of industrial layout, so its CO₂ emissions have increased significantly (Li, 2014).

PGDP: As Vietnam's level of economic development increases, the impact of FDI on CO₂ emissions shows a growing trend. Increased income and upgraded consumption brought about by economic development have prompted FDI firms to expand production to meet market demand, which may lead to an increase in energy consumption and CO₂ emissions. However, economic development also provides Vietnam with more resources and capacity to adopt eco-friendly technologies and implement emission reduction measures, which may offset some of the growth in emissions (Grossman & Krueger, 1991; Sarkodie & Strezov, 2019).

TRD: Increasing levels of foreign trade exacerbate the impact of FDI on Vietnam's CO₂ emissions. Export-oriented FDI is often associated with energy-intensive and emission-intensive activities, and as the level of foreign trade increases, the production activities of foreign-owned firms increase, leading to a rise in CO₂ emissions (Luan & Bowen, 2019). The expansion of foreign trade is likely to bring more international pressure and market demand, which will prompt the Vietnamese government and enterprises to take more active measures in reducing emissions.

Therefore, although changes in the level of foreign direct investment have supported Vietnam's economic development and enhanced living standards, they have also generated growing environmental concerns. However, Vietnam's ecological environment has also seen a significant increase in CO₂ emissions due to the imbalance in the industrial structure. During the current stage of Vietnam's development, there is still much room for adjusting the industrial structure, especially in the introduction of future industries, attention needs to be paid to improving the development of clean industries.

To provide a deeper interpretation of the empirical results, it is necessary to clarify the transmission mechanisms through which FDI influences CO₂ emissions. The significant and positive coefficient of FDI suggests that the scale effect currently dominates in Vietnam's agri-food sector (Grossman & Krueger, 1995). In particular, foreign capital inflows tend to expand production capacity in energy-intensive segments such as agricultural processing, fertilizer production, and mechanized farming, leading to an increase in aggregate energy consumption and associated emissions. By contrast, the technique effect, which implies the transfer of cleaner technologies and more efficient production methods through FDI, appears limited under current conditions due to relatively low domestic absorptive capacity, weak environmental enforcement, and the predominance of cost-driven investment strategies pursued by foreign enterprises (Li *et al.*, 2011).

This pattern of influence is more aligned with the Pollution Haven Hypothesis (PHH), which posits that foreign firms may relocate pollution-intensive activities to developing countries with relatively lenient environmental regulations (Zarsky, 1999). Conversely, the Pollution Halo

Hypothesis, which argues that FDI can contribute to environmental improvements through technological spillovers and higher management standards, is not strongly supported by the present evidence (Li *et al.*, 2011). Hence, while FDI contributes to economic expansion and agricultural modernization, its environmental implications reflect an early-stage development context in which productivity-driven growth outweighs technological upgrading with low-carbon orientations.

Robustness Test

A. Shortening the sample period

Considering the outbreak of the COVID-19 pandemic from 2020 to the end of 2022, followed by the relaxation of control measures in 2023, foreign direct investment has become active again in Vietnam. In this paper, the sample period is adjusted to 2010-2019 to exclude the impact of pandemic-related factors, and regression calculations are carried out. The results in Table 5 show that FDI in Vietnam before the pandemic increased significantly with a high value of coefficient and the p-value of the F-test is less than 0.05, which indicates that the estimated coefficients in the model are significant at the 1% level, and the significance is also better than the previous one. It indicates that the empirical results are robust. FDI significantly increases CO₂ emissions in Vietnam.

Table 5 - Coefficients and significance results for each variable

Variables	Coefficients	t-statistics	p-values
Constant	0.988	3.906	0.005
FDI	0.938	6.576	0.000
IS	0.977	3.310	0.011
RGDP	0.954	7.112	0.000
TRD	0.939	4.949	0.001

B. Carbon emissions per capita

To further test the impact of FDI on CO₂ emissions in Vietnam, the regression test is conducted again with carbon emissions per capita as the explanatory variable, and the core explanatory variables and control variables remain unchanged, and the results are shown in Table 6.

Table 6 - Coefficients and significance results for each variable

Variables	Coefficients	t-statistics	p-values
Constant	0.946	2.599	0.025
FDI	0.890	5.021	0.000
IS	0.690	2.317	0.041
PGDP	0.912	7.288	0.000
TRD	0.927	5.729	0.000

The results show that the significant level of the core explanatory variables and CO₂ is in line with the test results, thus further validating the previous conclusions.

Therefore, after the empirical analysis and robustness analysis, hypothesis 1, hypothesis 2, and hypothesis 4 are in line with the performance of the findings of this paper, and hypothesis 3 is still showing a positive impact due to the current industrial structure of Vietnam.

Conclusions and implications

Vietnam, as a rapidly industrialising and structurally transforming emerging economy, is experiencing a marked increase in CO₂ emissions driven by economic growth, rising energy demand, and expansion of agro-industrial activities. Based on empirical evidence from 2010 to 2022, this study offers several key conclusions regarding the environmental implications of FDI in Vietnam.

First, FDI has a statistically significant and positive effect on CO₂ emissions. Capital inflows, particularly those allocated to energy-intensive agribusiness operations, fertiliser production, and large-scale food-processing sectors, have been shown to amplify emission levels. These activities expand production capacity, increase reliance on fossil fuels, and intensify pressure on the environment. The findings therefore reflect the structural trade-off inherent in export-oriented agricultural development, where productivity gains are achieved at the cost of greater carbon intensity.

Second, Vietnam's economic structure, especially the ongoing expansion of agro-industrial activities, plays a critical role in shaping emission outcomes. The current production system remains heavily dependent on carbon-intensive processes in both manufacturing and modernised agri-food value chains. Without a shift toward cleaner and more technologically advanced production structures, achieving substantial decarbonisation will remain

challenging. This underscores the need to align agricultural modernisation with environmental sustainability goals.

Third, the process of economic development has consistently coincided with rising levels of emissions. As income levels grow, infrastructure construction expands, consumer demand for energy-intensive goods increases, and agricultural production scales up; together, these factors contribute to higher CO₂ emissions. While economic growth has improved productivity and competitiveness, it has also intensified environmental pressures, highlighting the urgency of transitioning to low-carbon growth pathways.

Fourth, trade openness is positively associated with CO₂ emissions. Vietnam's export-oriented economic model continues to rely on resource-intensive and energy-demanding production activities. To mitigate emission intensity while maintaining competitiveness, Vietnam must move toward higher-value and lower-carbon export products, such as certified sustainable agricultural goods.

Taken together, these findings provide stronger empirical support for the Pollution Haven Hypothesis than for the Pollution Halo Hypothesis, indicating that scale effects of FDI currently outweigh potential technology-induced environmental improvements in Vietnam. Weak regulatory enforcement limited absorptive capacity, and the dominance of cost-driven FDI all constrain the realisation of cleaner production benefits.

Based on the findings, several policy implications emerge: (i) Promote green-oriented FDI and strengthen screening mechanisms: Vietnam should refine its investment promotion strategies to privilege environmentally responsible projects, especially those involving clean technologies, renewable energy, and sustainable agri-food processing. Strengthened FDI screening and environmental impact assessments are essential to prevent the relocation of pollution-intensive industries; (ii) Accelerate industrial restructuring within the agri-food sector: Policies encouraging technological upgrading, digitalisation, and efficient resource use in agricultural processing can reduce emission intensity. Incentives should support shifts from low-value, energy-intensive production to higher-value and low-carbon agri-food activities; (iii) Enhance environmental regulations and enforcement capacity: Stricter enforcement of emission standards paired with transparent monitoring can reduce the pollution-haven risk. Expanding the use of carbon pricing, green certification, and emission-reporting requirements can further align domestic practices with international environmental commitments; (iv) Strengthen absorptive capacity for green technologies: Promoting human capital development, strengthening university–industry linkages, and expanding technology-transfer programmes will enhance the capacity of domestic firms to absorb and apply the cleaner technologies introduced through FDI; (v) Advance sustainable and low-carbon trade strategies: Vietnam should

gradually shift toward exporting products with lower carbon footprints, supported by certification schemes and traceability systems. This is especially crucial given that global markets, with the EU at the forefront, are raising the stringency of environmental regulations on imported products.

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Doan Ba Toai

Ph.D Candidate

College of Economics and Management, Fujian Agriculture and Forestry University, Fuzhou, China

No. 15 Shangxiadian road Cangshan district, Fuzhou city, Fujian Province, China

Faculty of Foreign Languages, Thanh Dong University, Haiduong, Vietnam

No. 3 Vu Cong Dan, Tu Minh district, Haiduong city, Haiduong province, Vietnam

E-mail: doanbatoai@thanhdong.edu.vn

Phone number: +84 845071622.

Jianzhou Yang

Professor

College of Economics and Management, Fujian Agriculture and Forestry University, Fuzhou, China

No. 15 Shangxiadian road Cangshan district, Fuzhou city, Fujian Province, China

E-mail: yiz300@fafu.edu.cn

Jianzhou Yang, male, born in September 1965, is from Quanzhou, Fujian Province. He graduated from the College of Resources and Environment, Beijing Forestry University in June 2000 with a doctoral degree. He joined the Jiusan Society in January 1999. He is currently a professor and doctoral supervisor at the College of Economics and Management, Fujian Agriculture and Forestry University, a provincial-level high-level talent, director of the Forestry Economics Research Institute, leader of the Fujian Provincial Humanities and Social Sciences Basic Theory Research Innovation Team, and leader of the Fujian Provincial Undergraduate Teaching Team.

Trieu Thi My An

Ph.D

Faculty of Foreign Languages, Thanh Dong University, Hai Duong Province 34000, Socialist Republic of Vietnam

No. 03 Vu Cong Dan, Tu Minh, Hai Duong, 171967, Vietnam

No. 24, Section 1, South 1st Ring Road, Wuhou District, Chengdu, Sichuan Province, China

E-mail: anttml@thanhdong.edu.vn; trieumyan@gmail.com

Phone number: +84-8134-77777

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Understanding the Value of Health: Insights into Extra Virgin Olive Oil Consumer Behaviour in Southern Italy

Antonio Tulone^{*,a}, Maria Lia Riccobono^a, Claudio Mirabella^a,
Antonino Galati^a, Maria Crescimanno^a

^a University of Palermo, Italy

Abstract

The paper investigates the determinants of consumers' intention to pay a price premium for extra virgin olive oil with health claims on its label. Drawing on a multidimensional framework, the research explores the role of subjective and objective knowledge of the product, the importance attributed to the sensory attributes, the attention given to the health information, and the impact of socio-demographic variables on consumers' intention to pay. Data were collected via an online questionnaire administered to 405 consumers in Sicily (Italy), a region with a strong olive oil tradition. Using a logistic regression model, the results show that subjective knowledge, the importance attributed to health information, average expenditure for extra virgin olive oil, and household size significantly affect the willingness to pay. Conversely, flavour profile and objective knowledge do not have a statistically significant impact. These findings offer practical implications for extra virgin olive oil producers and marketers, highlighting the need for clear health-related labelling and targeted educational strategies to enhance consumer engagement and perceived value of the product with health claims on the label.

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* *Corresponding author:* Claudio Mirabella - University of Palermo, Italy. E-mail: claudio.mirabella01@unipa.it.

Introduction

Extra virgin olive oil (EVOO) is a functional food known for its nutritional and health benefits, whose composition contributes to improving quality of life by reducing the risk of cardiovascular, neurological, and metabolic diseases (Rabail *et al.*, 2025; Serreli *et al.*, 2024). Its content of monounsaturated fatty acids, such as oleic acid, and polyunsaturated fatty acids, including omega-3 and omega-6, gives EVOO antioxidant and anti-inflammatory properties, which make it an essential food within the Mediterranean diet (Scoditti *et al.*, 2014). When these nutritional and functional properties are disclosed on packaging through “health claims”, they aim to inform consumers about the scientifically recognised health benefits of EVOO, establishing a link between olive oil consumption and its beneficial effects on health (Lombardi *et al.*, 2021). Despite the recognised importance of health claims, their diffusion in the EVOO market is still limited (Pichierri *et al.*, 2020). So far, very few empirical studies have investigated the influence of health claims on labels among EVOO consumers (Bou Fakhreddine *et al.*, 2023; Bou Fakhreddine & Sánchez, 2023; Lombardi *et al.*, 2021; Pichierri *et al.*, 2021). A study conducted in Italy showed that consumers often struggle to understand this information, with negative consequences for the perception of product quality and propensity to purchase (Lombardi *et al.*, 2021). Pichierri and co-authors (2021) investigated the influence of the clarity of health claims on the perceived healthiness of food products. They concluded that clearly presented health claims positively affect the intention to purchase olive oil, as well as influence the consumers’ propensity to share positive word-of-mouth about the product. In line with this perspective, Bou Fakhreddine and Sánchez (2023) investigated how health claims combined with the sensory attributes of extra virgin olive oil (EVOO) influence consumers’ purchase intentions. They demonstrated that perceptions of product quality and health benefits are the result of interactions between health claim text and sensory experience. This suggests that the purchase and consumption frequency of EVOO is associated with several factors, particularly subjective and objective knowledge of the product, consumer interest in health-related issues, and socio-demographic variables such as age, education level and marital status of the individual (Gámbaro *et al.*, 2013). In this regard, subjective knowledge refers to individuals’ self-perceived understanding and familiarity with EVOO, while objective knowledge indicates their actual level of accurate information about the product, typically assessed through factual questions (Flynn & Goldsmith, 1999). For example, Gámbaro and colleagues (2013) show that the consumer’s subjective knowledge about the product is the factor that most influences the frequency of olive oil consumption. Although prior research

has highlighted the role of health claims (Perito *et al.*, 2019; Pichierri *et al.*, 2021; Zanchini *et al.*, 2022), product knowledge (Donoghue *et al.*, 2021; Gámbaro *et al.*, 2013; Shaalan *et al.*, 2024), and sensory attributes in shaping consumer perceptions and intentions (Bou Fakhreddine & Sánchez, 2023; Vázquez-Araújo *et al.*, 2015), there is still a lack of comprehensive understanding of how these elements jointly affect consumers' intention and actual willingness to pay (WTP) a premium for EVOO with health claims.

With the aim of filling this gap, the research aims to understand how subjective and objective knowledge, organoleptic attributes, health information on the label, and socio-demographic characteristics influence the consumers' intention to pay a premium price for EVOO. The EVOO market is an ideal context to investigate purchasing dynamics and the role of health information in influencing consumer choice, given the growing market interest in the health benefits associated with the consumption of the product (Bou Fakhreddine & Sánchez, 2023; Lombardi *et al.*, 2021). Furthermore, the research focuses on the Italian market, where EVOO is a pillar of the agricultural economy. Italy is one of the world's leading producers of EVOO, with a production for the year 2023 exceeding 328 thousand tons and generating a turnover of more than €4 billion, with a market characterised by high quality, a strong presence of appellations of origin (PDO and PGI) and a rich varietal heritage that confers uniqueness to regional products (ISMEA, 2024). The study focuses on Sicily, a region with a long-standing olive oil tradition, where EVOO plays a central role in both the local economy and dietary culture (Hilton, 2023). In particular, Sicily was selected as the research context due to its strong olive oil heritage, the high number of PDO and PGI designations, and the presence of distinctive local cultivars that contribute to the perceived quality and cultural relevance of Sicilian EVOO in both the regional economy and dietary practices. In general, EVOO is not only important economically, but also holds a central place in Italian food culture and traditions. It is an essential element of the Mediterranean diet and is deeply rooted in Italian families' consumption habits (Lanfranchi & Giannetto, 2012).

To the best of our knowledge, this is the first study to examine in depth the factors that influence consumers' willingness to pay a premium price for EVOO with health claims. The study takes a multidimensional approach, considering cognitive factors, sensory characteristics and socio-demographic dimensions. From a managerial point of view, the findings offer practical implications for EVOO producers and retailers, supporting the development of more effective communication strategies, the design of clearer health-related labelling, and the creation of targeted promotional campaigns for specific consumer segments.

1. Background

The growing consumer focus on food products with health claims has encouraged research into the factors affecting consumers' purchasing decisions. Among these, particular attention has been paid to the role of consumer knowledge, both objective and subjective, of EVOO, as well as to the importance attributed to its sensory characteristics and the influence of health information provided on the label. Understanding how these elements interact provides key insights into what drives consumers' intention to pay a premium price for EVOO with health claims on the label.

1.1. Consumer knowledge about olive oil

One of the crucial factors influencing the choice of agri-food products is the consumer's level of knowledge about the product (Galati *et al.*, 2019; Rai *et al.*, 2024), which can be distinguished into objective and subjective knowledge (Donoghue *et al.*, 2021; Mustapa *et al.*, 2025; Pieniak *et al.*, 2010). Objective knowledge refers to accurate information stored in memory that enables consumers to recognize and evaluate product attributes (Gámbaro *et al.*, 2013), whereas subjective knowledge reflects consumers' perception of how much they believe they know about the product (Gámbaro *et al.*, 2013). Several studies have shown that when consumers know more about the product, they place a higher value on the product's characteristics, increasing their intention to buy (Donoghue *et al.*, 2021; Mustapa *et al.*, 2025). In particular, subjective knowledge appears to exert a greater effect, as it directly influences perceived product quality (Donoghue *et al.*, 2021; Mustapa *et al.*, 2025). Similarly, a recent research confirms that greater subjective knowledge improves consumers' ability to distinguish between different commercial EVOO qualities using accurate sensory descriptors (Hodos *et al.*, 2025). This knowledge thus translates into a more informed assessment of product quality (Hodos *et al.*, 2025). Consistently, Lombardi *et al.* (2021), analysing the factors affecting the understanding of health claims in EVOO among Italian consumers, argue that subjective knowledge, concerning nutritional aspects, significantly influences the understanding of health claims. This suggests that consumers who perceive themselves to have a high level of knowledge about nutrition and health issues demonstrate a better understanding of such claims (Lombardi *et al.*, 2021). Similarly, Zanchini *et al.* (2022) found that subjective knowledge is positively correlated with health awareness and WTP for polyphenol-enriched EVOO, indicating that perceived understanding of the product enhances the perceived value by consume. The role of knowledge is also investigated by Gámbaro and

co-authors (2013) in relation to olive oil consumption among consumers in Uruguay. The authors show that individuals with higher subjective knowledge about olive oil and its health benefits tend to consume it more frequently. It also demonstrates that an increase in subjective knowledge could lead to an increase in consumption frequency, both among those who already habitually consume olive oil and among less frequent or new consumers. Nevertheless, Recchia and co-authors (2012), examining the role of consumers' subjective knowledge and perception of EVOOs in Finland, show that consumers' perception and subjective knowledge do not always necessarily guarantee greater acceptance of high-quality oils, suggesting that subjective knowledge does not always translate into more sophisticated sensory evaluation.

In relation to consumers' objective knowledge of olive oil, it is frequently observed that this is lower than the level of self-reported knowledge (Shaalan *et al.*, 2024). For example, Shaalan *et al.* (2024), studying the knowledge of olive oil and its benefits among Lebanese consumers, found low knowledge of the product and the need for educational campaigns that could influence their purchasing decisions. This aligns with Guedes de Melo *et al.* (2021), who demonstrated that consumers often do not understand key technical aspects of EVOO quality, such as the definition of "extra virgin" or the meaning of acidity levels, limiting their ability to make informed decisions based on labels. Not surprisingly, Garrido-Castro *et al.* (2021), after analysing the link between objective knowledge and consumer involvement in oil purchase, find that more objective knowledge could increase interest and propensity to purchase. Polenzani *et al.* (2020) highlight that consumers' perception of EVOO sustainability is positively shaped by their objective knowledge and direct exchanges with producers, underscoring the influence of knowledge on environmentally and socially responsible purchasing behaviour. Furthermore, dos Santos *et al.* (2023) demonstrate that after brief sensory training, consumers were able to discern EVOO's sensory attributes comparably to trained panelists, indicating that objective knowledge is not only learnable but also essential for enhancing product evaluation and appreciation.

In light of the above, this study explores the following hypothesis:

- H1a. Increased subjective consumer knowledge about EVOO significantly influences the intention to pay a premium price for an EVOO with health claims.
- H1b. Increased objective consumer knowledge about EVOO significantly influences the intention to pay a premium price for an EVOO with health claims.

1.2. The role of intrinsic attributes in consumer choice

Knowledge of agri-food products and their quality attributes is a factor that influences consumers' evaluation of products, as well as their attitude, which is reflected in both purchase intentions and consumption. The olive oil consumer today manifests ever-increasing expectations and is increasingly attentive to product quality, basing his or her purchase intentions on the evaluation of product attributes (Cicerale *et al.*, 2016). In particular, this study focuses on the intrinsic attributes of EVOO that refer to the physical characteristics possessed by the product (Grunert, 2002). Some studies show that consumers attach more importance to the intrinsic attributes of EVOO (such as flavour, colour, and aroma) than to extrinsic attributes such as packaging or brand (Ben Ali *et al.*, 2022; Del Giudice *et al.*, 2015). This is particularly true in countries where EVOO is part of the food tradition, such as Italy and Tunisia, where purchase preferences are mainly driven by the sensory characteristics of the product (Pieniak *et al.*, 2010; Recchia *et al.*, 2012). Although the IOC (International Olive Council) considers the colour of olive oil as having no influence on the quality of the oil (IOC, 2005), several studies show that this attribute exerts a significant influence on consumer intention to buy EVOO. Di Vita *et al.* (2013) point out that Italian consumers attach great importance to colour, showing a preference for green over yellow shades, a tendency that is particularly marked in the South of the country. Similarly, Mtimet *et al.* (2013) and Ben Ali *et al.* (2022) note similar results among Tunisian consumers. Perito and colleagues (2019) further confirm the role of colour as a determining attribute in the qualitative assessment of oil by Italian consumers. Similarly, Ilak Peršurić (2020), analysing the consumption preferences of individuals in England and Germany, identifies colour as one of the main factors associated with perceived quality and product originality. Besides colour, flavour also plays a decisive role in the purchasing choices of EVOO consumers. In particular, it is defined as “the sum of all sensory properties (stimuli) of a food product perceived by the senses of taste and smell and by the tactile receptors in the mouth” (Carlucci, 2001). It encompasses taste, aroma, and aftertaste and it is an important determinant of EVOO consumer behaviour. Sensory attributes such as fruitiness, bitterness, and pungency directly impact consumer preferences and willingness to purchase. Studies show that consumers rate EVOO more highly and are more likely to buy it when they perceive the flavour as pleasant and harmonious (Ben-Hassine *et al.*, 2022; Bou Fakhreddine & Sánchez, 2023). Other studies have found that consumers from major producing countries, such as Spain, Italy and Tunisia, show preferences towards oils with a green fruitiness, spiciness and a more intense flavour (Di Vita *et al.*, 2013; Mtimet *et al.*, 2013; Ben Ali *et al.*, 2022), while US consumers are more likely to purchase sweeter, “rounder”

and less savoury oils (Vázquez-Araújo *et al.*, 2015). The differences noted between the several consumer categories can be partially attributed to their different degree of exposure to olive oil and its quality. The first category of consumers is characterised by a daily consumption of olive oil produced in their country of origin, while the second consumes mainly imported oils that may have a reduced quality (hence less bitterness and spiciness) due to multiple factors that would lead to a series of defects in the product to which the consumers themselves are accustomed (Cicerale *et al.*, 2016; Delgado & Guinard, 2011). Furthermore, flavour appreciation seems to strengthen the overall perception of value of the product and may contribute to amplifying the positive effect of health information on the label. When the organoleptic profile is considered satisfactory, in fact, the health message conveyed by health claims may be more credible and effective, positively influencing consumers' propensity to purchase (Bou Fakhreddine & Sánchez, 2023).

In light of the above, therefore, the following hypothesis was formulated:

- H2. Consumers who attach more importance to the aromatic profile and flavour of EVOO are more likely to pay a premium price for an EVOO with health claims.

1.3. *Impact of health information on the label*

Health claims represent key communication tools to influence the consumers' purchasing behaviour of olive oil (Pichierri *et al.*, 2020). Several studies highlight how labels with clear health claims positively affect olive oil consumers' perception and purchase intention (Perito *et al.*, 2019; Pichierri *et al.*, 2020, 2021). On the contrary, Boncinelli *et al.* (2017), in a research conducted among Italian EVOO consumers, find that respondents attribute a marginal role to the presence of health claims on the label in their purchase choices compared to attributes related to the product's origin and organic certification. Consistent with this, De Gennaro and colleagues (2021), exploring the importance of health claims in Italian consumers' choice of EVOO, found that consumer interest in health claims in EVOO plays a secondary role and this result could be related to consumers' lack of understanding and familiarity with health claims on olive oil labels (De Gennaro *et al.*, 2021). A recent study, in fact, shows that not all consumers fully understand the health claims on the label, finding that only 36% of Italian consumers are able to correctly interpret health claims on EVOO (Lombardi *et al.*, 2021). More specifically, Lombardi *et al.* (2021) point out that in Italy, consumers who are older, have children in their families and perceive themselves to have a lower health status better understand health information and health messages on labels. Similarly, Perito and co-authors (2019), addressing the issue of health claims in the context of Italian

consumer preferences for EVOO, point out that the presence of health claims on the label positively influences consumer preferences, especially for those who are more attentive to product quality. Furthermore, Bou Fakhreddine *et al.* (2023) highlight that interest and WTP for health claims in EVOO increases when there is a high perception of health risk among consumers. In addition, Bou Fakhreddine & Sánchez (2023) find that, in the presence of health claims on the label, consumers also evaluate the sensory attributes of EVOO more positively and this contributes to improving the intention to purchase the product. The effectiveness of the information on the label would also depend on how it is presented. In line with this, the study by Pichierri and colleagues (2021) analyses how clarity in the wording of health claims positively influences the perception of the healthiness of EVOO, with a positive impact on purchase intention and the propensity to share positive word-of-mouth about the product. Zanchini and co-authors (2022) show that the value assigned by consumers to health-related nutrition claims on the label positively affects the premium price of olive oil with functional properties, highlighting the potential role of health claims on the label. Furthermore, Casini *et al.* (2014), investigating the WTP for higher prices for Italian consumers sensitive to health claims in EVOO, find that respondents exhibit high WTP. More precisely, consumers would be willing to pay €6.02 more for the presence of functional product claims on the label, €4.89 for the presence of disease risk reduction claims, €2.41 for nutritional claims related to EVOO. Furthermore, the authors identify two consumer segments that are most interested in the presence of health claims on EVOO labels. The first group is made up of young, male consumers who are interested in buying affordable products that show detailed information on the positive effects of the product on the label. The second group, on the other hand, is made up of elderly people who prefer products in a high price range and who present health information on the label that emphasises the product's ability to reduce disease (Casini *et al.*, 2014).

In view of the above, this study explores the following hypothesis:

- H3. Consumers who attach more importance to the presence of health information on the label are more likely to pay a premium price for EVOO with health claims.

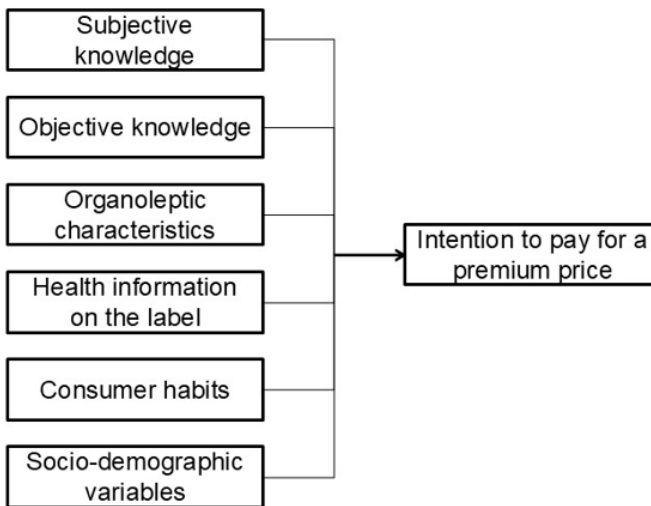
1.4. Conceptual model

The proposed conceptual model is based on the assumption that the intention to pay a premium price for EVOO bearing health claims on the label is the result of the interaction between different cognitive, sensory, informational and socio-demographic factors. Specifically, the aim of the research is to explore how subjective and objective knowledge of the product,

the perception of organoleptic characteristics such as aroma and flavour profile, the presence of health information on the label, consumption habits and some socio-demographic variables contribute to shaping the consumer's propensity to recognise an additional economic value in the product.

The model is configured as a multidimensional framework, aimed at integrating the main determinants of consumer behaviour with respect to EVOO with health claims. As depicted in Figure 1, the proposed framework allows for the empirical verification of the effect of the single independent variables on the intention to pay a premium price for health claims on EVOO's labels, thus offering a contribution to the understanding of the dynamics that drive health claim-oriented purchasing decisions in the EVOO market.

Figure 1 - Conceptual model. The model illustrates the hypothesized relationships between subjective and objective knowledge, the importance attributed to sensory attributes, health information on the label, socio-demographic characteristics, and consumers' intention to pay a premium price for EVOO with health claims



Source: Authors' elaboration.

2. Materials and methods

2.1. Data collection and questionnaire

The empirical investigation was conducted by distributing an online questionnaire to a sample of Italian consumers residing in Sicily. This is an

Italian region with a strong tradition linked to olive oil culture (Hilton, 2023). This makes it possible to obtain particularly relevant data on preferences and consumption habits in a context where olive oil plays a central role in the local diet and economy. Prior to distribution, the questionnaire was pre-tested to check the degree of comprehension of the questions and to identify any potential errors in the wording of the questions. This modification enabled the questionnaire to be revised in its initial form and subsequently finalized. The questionnaire was distributed through the main social networks (Facebook, Instagram and WhatsApp) between December 2023 and February 2024, using the snowball sampling method. This chain sampling method, in which initial participants share the questionnaire with their contacts, allows for rapid data collection but may introduce selection bias and limit sample representativeness (Atkinson & Flint, 2001; Noy, 2008). Indeed, this approach has been demonstrated to facilitate the recruitment of larger sample sizes, which has the potential to increase statistical power in specific contexts (Emerson, 2015).

The survey yielded 410 responses. After careful analysis, five questionnaires were excluded from the analysis due to incomplete or clearly illogical responses. Therefore, the analysis is based on data from 405 respondents residing in Sicily, who are aged 18 and over. The socio-demographic characteristics are presented in Table 1.

The data collected show that the study sample is not statistically representative of the target population. Respondents have a higher level of education and income, and larger household sizes compared to regional and national averages (IISicilia, 2022; Macchi, 2024, 2025). These deviations are likely influenced by the sampling method adopted, which may have attracted digitally literate, higher-income, and health-conscious individuals. While this limits the generalisability of the results, the findings offer strategic guidance for firms operating in premium markets, where consumers are typically more educated, health-conscious, and willing to pay a premium for added value products such as EVOO with health claims. Furthermore, while the sample is geographically limited to Sicily, the results may also be relevant to broader Southern Italian contexts, as Sicily shares many socio-economic indicators with other regions in the South of Italy. These include lower average income levels, higher household sizes, and a strong cultural attachment to olive oil consumption. Therefore, the insights gained from this study may support the development of targeted marketing strategies and health communication efforts in Southern Italian markets, where regional identity and product authenticity play a central role in consumer choices.

Table 1 - Socio-demographic profile of respondents

Variables	Categories	Frequency	Percent (%)
Age	18-34 years	171	42.2
	35-54 years	113	27.9
	55-74 years	118	29.1
	≥ 75 years	3	0.8
Gender	Male	191	47.2
	Female	213	52.8
	Other	1	0.3
Education	High school	7	1.7
	Secondary school	102	25.2
	University	249	61.5
	Post university	47	11.6
Average monthly income	1500 €	56	13.8
	1501-2000 €	101	24.9
	2001-3000 €	89	22.0
	3001-4000 €	68	16.8
	>4000 €	91	22.5
Number of household members	1	57	14.1
	2	80	19.8
	3	84	20.7
	4	184	45.4
Distribution of the 405 consumers surveyed in Sicily by age, gender, education, income, and household size.			

The questionnaire is structured in four sections and consists of a total of 25 questions.

The first section includes a series of questions aimed at understanding olive oil purchasing and consumption habits. Seven questions were used to investigate the importance that consumers assign to product quality attributes that influence their purchases, based on extant literature (Chrysochou *et al.*, 2022; Cicerale *et al.*, 2016). Four questions were about the aspect of the olive oil, such as its green or yellow colour, clarity, and opacity. The remaining three questions focused on its taste, specifically its fruity, bitter, and spicy qualities. These items were evaluated using a Likert scale, ranging from 1 (not at all important) to 5 (very important). Subsequently, a composite

variable was generated to represent the overall importance attributed to the three taste-related items (fruity, bitter, and spicy qualities). Internal consistency of these items was assessed through Cronbach's α reliability (Cronbach, 1951). According to literature, the scale reliability is generally considered satisfactory when Cronbach's $\alpha > 0.70$, although values between 0.60 and 0.70 may still be regarded as acceptable for exploratory research (Kline, 2023).

The second section includes questions aimed at understanding the level of objective and subjective knowledge of olive oil. Objective knowledge was measured using a scale with six items related to some beneficial properties of olive oil for human health. The proposed scale included answers of the type "True", "False", "I don't know". Furthermore, the inclusion of the response option "I don't know" for each statement was aimed to obtain greater precision regarding an individual's actual knowledge about the product, avoiding the random component associated with forcing an answer from the respondent. The number of correct answers (0-6) provided by each respondent was used as an indicator of objective knowledge (Gámbaro *et al.*, 2013). Subjective knowledge of the characteristics of olive oil was measured using a Likert scale from 1 (not at all agree) to 5 (fully agree) by administering five statements obtained from the adaptation of the work conducted by Gámbaro *et al.* (2013) and Salazar-Ordóñez *et al.* (2018). Furthermore, consumers' attentiveness to the importance of the health aspects of food products for consumption habits was analysed. For this purpose, a Likert scale from 1 (Not at all agree) to 5 (Fully agree) was used, which we adapted from the general health interest dimension from the validated scale developed by Roininen and colleagues (1999). Both objective's and subjective' knowledge items were used to generate composite variables to be assessed through Cronbach α 's reliability. In doing so, the "I don't know" option was coded as "0", equal to the incorrect answers, in order to maximize the variable reliability. While this option may be useful for providing greater detail in the sample, for the purposes of the econometric model, this difference is deemed irrelevant, because the variable is intended to capture the actual level of knowledge.

The third section of the questionnaire includes two questions. The first was aimed at assessing consumers' intention to pay a premium price for EVOO with health information on the label. The second question invited respondents to specify the exact amount they were willing to pay above the standard price, providing a quantitative measure of their valuation of these health attributes.

The fourth and final section gathers information to profile the respondent, focusing on socio-economic characteristics such as gender, age, education

level, income, and household size. These variables are essential both for describing the sample and for inclusion in the econometric analysis, allowing the study to examine how socio-demographic factors influence the purchase intentions.

2.2. Empirical approach

In order to investigate the main factors affecting the intention of consumers to pay a premium price for a bottle of EVOO bearing a label with health claims, we performed a logistic regression. Logistic regression, or the logit model, belongs to a class of statistical models used when the dependent variable is discrete and dichotomous, i.e. it can only take on values of 0 or 1. The objective of logistic regression is to determine the extent to which an independent variable, or regressor, has an effect on the probability of the dichotomous dependent variable taking on a value of 1 (Gujarati & Porter, 2009). To assess consumers' intention, the questionnaire included a question with a dichotomous answer option in which respondents were asked whether in a hypothetical purchase scenario, given the average price of € 9.00 for 0.75-litre bottle of EVOO, they would be willing to pay an additional price if health claims were present on the label. The answers were coded by assigning a value of 1 if the answer given was "Yes" and 0 in the opposite case. Subsequently, with the help of the statistical software Stata/IC 15.1, a logit model was developed using the above-mentioned intention to pay as the dependent variable.

The logit model was built using nine regressors, selected based on relevant scientific literature on consumer behaviour and WTP for EVOO with health information on the label.

All variables were subjected to data quality verification and coding consistent with the requirements of the logit model. The combination of cognitive and socio-demographic factors has allowed us to build a multidimensional interpretative framework, useful for understanding the mechanisms underlying the WTP for EVOO with health claims.

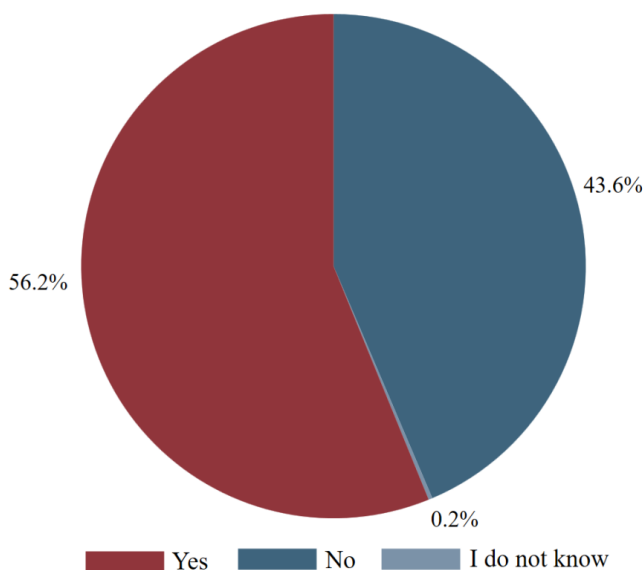
To assess potential multicollinearity among the explanatory variables, the Variance Inflation Factor (VIF) was computed. Although the VIF is formally defined within the framework of linear regression, it is commonly used in logistic models as an approximate diagnostic tool (Senaviratna & Cooray, 2019). In logistic models, values of VIF exceeding 2.5 generally indicate moderate correlation, while values above 5 or 10 are cause for concern.

3. Results and discussion

3.1. Consumers' purchase intention and WTP for EVOO with health claims

Figure 2 shows that 43.6% of the sample ruled out the intention to purchase EVOO with health-related information on the label, while 56.2% of the respondents indicated their intention to purchase in the future EVOO marketed with health claims. Only one individual was hesitant about this possibility. The results thus confirm the attention on the part of consumers towards health attributes in agri-food products, specifically in the case of EVOO (Bou Fakhreddine & Sánchez, 2023; Casini *et al.*, 2014). Furthermore, it would seem that consumers, who are increasingly informed and aware of their health, tend to prefer foods that can contribute to physical well-being. This evidence reflects an important shift in consumer behaviour, particularly among those who are increasingly health-conscious and attentive to the functional role of food in disease prevention. It supports previous findings that health-related attributes are becoming a key decision factor in the food sector (Bou Fakhreddine *et al.*, 2023; Bou Fakhreddine & Sánchez, 2023; Casini *et al.*, 2014). The fact that over half of the sample positively evaluates the inclusion of health claims on EVOO labelling reinforces the idea that

Figure 2 - Consumers' intention to pay a premium price for EVOO with health claims



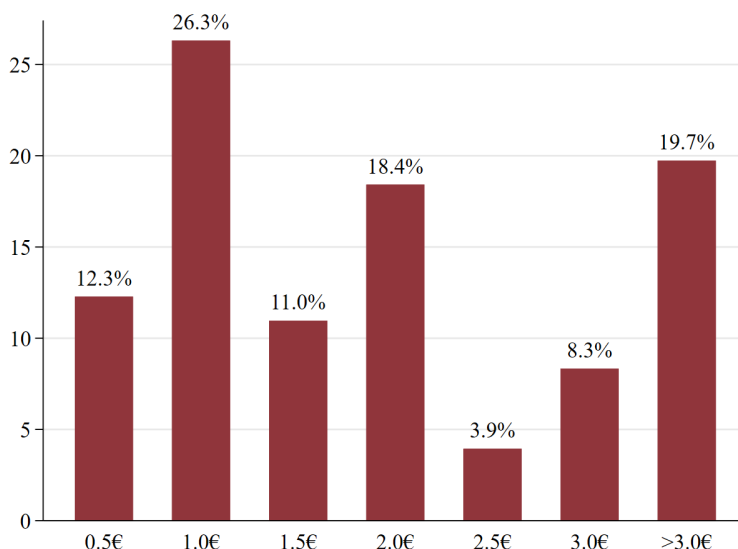
consumers are not only receptive to such information, but actively use it to guide their choices. In this respect, Casini and colleagues (2014) highlight that those who are interested in purchasing EVOO for its positive effects on health and its ability to reduce diseases show a greater propensity to purchase EVOO with health claims on the label. In this context, transparency and clarity of information on product labelling become essential to enable consumers to make informed choices, as suggested by Lombardi *et al.* (2021).

Within the framework of the intention to purchase for EVOO with health claims on the label, an attempt was made to quantify the premium price that consumers are willing to pay, assuming an average sale price, in Sicily, of €9.00 for a 0.75-litre bottle of EVOO. In particular, the WTP was determined on the basis of the answers given by the respondents who had not excluded the possibility of purchasing EVOO with health claims on the label in the future, i.e. 228 individuals, representing 56.2% of the total number of consumers interviewed. The most relevant results, presented in Figure 3, show that the largest share of the respondents, i.e. 26.3% of the respondents, declared that they would be willing to pay one euro more than the average expenditure, 19.7% of the respondents would be willing to pay more than €3, while 18.4% would pay a premium price of €2. These findings indicate a substantial segment of consumers who recognize the added value of health claims and are willing to reflect this appreciation in their purchasing behaviour. Notably, nearly one in five respondents intending to buy EVOO with health claims are willing to pay more than 30% above the market average, underscoring the strong market potential for value-based pricing strategies centered on health-related product attributes. These results align with previous studies, which have demonstrated that health claims on EVOO labels positively influence consumer preferences and WTP – especially among consumer groups that place greater emphasis on product quality (Perito *et al.*, 2019) and health considerations (Bou Fakhreddine *et al.*, 2023). In support of this, Casini *et al.* (2014) quantifies this effect, demonstrating that Italian consumers are willing to pay up to €6 more for EVOO with functional health claims. In light of this, these findings support the idea that the observed WTP in the present study is not an isolated phenomenon, but reflects a trend in health-driven purchasing behaviour for EVOO.

This WTP for a premium must be interpreted in light of the income levels reported in the sample, which, as previously observed, tend to be higher than the average of the Sicilian population. Therefore, the observed WTP values could reflect the purchasing attitudes of a segment of the Sicilian population with a higher income. Nonetheless, the results are significant if contextualized in the Southern Italian market, where EVOO is not only a fundamental element of the food tradition, but also a culturally rooted product. Despite the low income levels in Southern Italy, the strong cultural attachment to olive oil and the growing awareness of health issues could

encourage a segment of consumers, especially the more educated and economically stable ones, to purchase premium EVOO products. This implies that there are opportunities for health-oriented market segmentation even in low-income regions, provided that product positioning is aligned with both cultural expectations and perceived health benefits.

Figure 3 - Premium price to purchase EVOO with health claims



3.2. Econometric model

Findings show that Cronbach's α values indicate good reliability of the items included in the model. Indeed, the Cronbach's α for flavour importance is good, with a value of 0.792. Objective knowledge's reliability is discrete, with Cronbach α equal to 0.681. Finally, subjective knowledge's reliability is good, with Cronbach's α value of 0.924.

Table 2 shows the results of the logit model on consumers' intention to pay a premium price for an EVOO whose label carries health claims. The econometric analysis provides information on the effect of exogenous variables on consumers intention. The results show that there are four variables with a significant effect: subjective knowledge, health information, average usual expenditure and number of household members. The model's Pseudo R-squared (0.083) indicates a modest yet meaningful improvement over the null model, consistent with values typically observed in behavioural and consumer research. Table 3 shows the VIF values,

which indicate the absence of significant multicollinearity between the independent variables.

The positive and statistically significant coefficient of subjective knowledge suggests that consumers who on average feel they have more product knowledge than other individuals are more likely to pay an additional price for having health claims on the label. This confirms hypothesis H1a, according to which increased subjective knowledge about EVOO significantly increases the intention to pay a premium price for an EVOO with health claims. This result is consistent with several contributions from the literature. In particular, Lombardi *et al.* (2021) show that subjective knowledge about nutrition and health issues significantly improves consumers' understanding of health claims on EVOO labels. This implies that consumers who believe they are informed about nutrition and health are better equipped to interpret and trust the health benefits communicated on food labels, increasing in this way their purchasing choices towards such claims. Similarly, Zanchini *et al.* (2022) demonstrate that subjective knowledge is positively associated with health awareness and the purchase of polyphenol-enriched EVOO, suggesting that consumers' perceived understanding of a product enhances the value they attribute to it. In this context, subjective knowledge acts not only as a cognitive construct but also as a motivational factor that reinforces health-oriented behaviours and premium purchasing. This result coincides with the findings of Gámbaro and colleagues (2013), who found that individuals who consume more olive oil are generally those who perceive to have a high level of knowledge about the oil and its positive health effects. Consequently, such awareness would drive purchase and the intention to pay a premium price for having health claims on the label.

The coefficient associated with objective knowledge was not statistically significant, indicating that this variable does not influence the intention to buy EVOO with health claims. For this reason, hypothesis H1b is not supported by the model results. This evidence is consistent with findings that objective knowledge among consumers is generally low, limiting their ability to interpret technical or health-related information (Shaalan *et al.*, 2024; Guedes de Melo *et al.*, 2021). Nonetheless, other studies suggest that increasing objective knowledge can increase involvement, interest, and purchasing behaviours (Garrido-Castro *et al.*, 2021; Polenzani *et al.*, 2020). It is important to note that dos Santos *et al.* (2023) show that with even brief sensory training, consumers can meaningfully improve their evaluation skills, suggesting that objective knowledge can become impactful if supported by education.

Contrary to expectations, the variable related to the importance attributed to the flavour profile of EVOO was not statistically significant. Consequently, hypothesis H2, according to which consumers who attach greater importance to the flavour of EVOO show a higher intention to pay a premium price for an EVOO with health claims, was not confirmed by the results of the logit

model. This contrasts with previous empirical findings showing that flavour is an important sensory attribute influencing EVOO purchasing decisions, particularly in producing countries where consumers favour intense profiles like bitterness and pungency (Di Vita *et al.*, 2013; Ben Ali *et al.*, 2022; Vázquez-Araújo *et al.*, 2015). However, the result suggests a distinct cognitive separation between sensory appreciation and health value. More precisely, while flavour contributes to product satisfaction and preference, it may not directly affect the intention to pay for health claims. This could be due to consumers evaluating flavour and health as separate dimensions. The current findings imply that health-oriented value perception operates independently from flavour preferences.

Concerning the presence of health information on the label, the results demonstrate that the respondents who prefer the presence of health claims on the label are those who are most sensitive to the health benefits of the product and who would be willing to pay a premium price to purchase bottles of EVOO that have clear health benefit information. In this context, health claims would act as key communication tools influencing consumer choice (Pichierri *et al.*, 2020), especially when they are clearly formulated and easily understandable (Pichierri *et al.*, 2021). Zanchini and co-authors (2022) also point out that consumers who attach greater importance to health claims are precisely those who are willing to pay a premium price to buy an olive oil that has health benefits. Furthermore, Perito and colleagues (2019), addressing the issue of health claims in the context of Italian consumer preferences, show that those who are more attentive to product quality are more likely to choose olive oil characterised by the presence of health claims on the label. This result confirms hypothesis H3, according to which consumers who attach more importance to the presence of health information on the label show a more likely intention to pay a premium price for EVOO with health claims.

The coefficient of the variable “Usual expenditure” was positive and statistically significant. This suggests that consumers who spend a higher amount on average in their usual expenditure on olive oil have a more favourable intention to pay an additional price for health information on the label. This result indicates that those who already invest more in EVOO may perceive greater value in products that offer additional health benefits, likely due to a stronger orientation toward quality, well-being, and informed consumption. These consumers may also be more inclined towards premium products and therefore more responsive to added-value attributes such as health claims.

Finally, the variable associated with the number of individuals within the household was also found to be statistically significant and positive in sign. This evidence highlights that large households, in which children are likely to be present, would be the most sensitive to having health claims on the label and would therefore be willing to pay a premium price. Not surprisingly,

Lombardi and colleagues (2021) suggest that more adult consumers with children in the household and who perceive themselves to have a lower health status are those who are more attentive to health information in olive oil and are more able to understand the health messages on the label.

*Table 2 - Logit model for intention to pay a premium price for EVOO with health claims; Significance level .10, .05, .01 respectively indicated by *, **, ****

Independent variable	Coef.	St.Err.	p-value
Subjective knowledge	0.270	0.118	0.022**
Objective knowledge	-0.222	0.441	0.614
Importance flavour	0.067	0.119	0.573
Health information	0.289	0.093	0.002***
Usual expenditure	0.548	0.228	0.016**
Gender	0.244	0.226	0.279
Education level	0.155	0.104	0.139
No. of household members	0.223	0.101	0.026**
Age	0.000	0.008	0.977
Constant	-3.343	0.878	0.000***
Pseudo R-squared		0.083	

Coefficients, standard errors, and significance levels of the independent variables. Significant predictors include subjective knowledge, health information, expenditure, and household size.

Table 3 - Values of Variance Inflation Factor

Independent variable	VIF
Subjective knowledge	1.93
Objective knowledge	1.42
Importance flavour	1.60
Health information	1.19
Usual expenditure	1.08
Gender	1.10
Education level	1.05
No. of household members	1.08
Age	1.26
Mean VIF	1.30

Conclusions

This study analysed consumers' intention to pay a premium price to purchase EVOO with health claims on the label. The results showed that subjective knowledge of the product, perception of health information on the label, average expenditure for the purchase of EVOO, and household size are the variables that most influence consumers' intention. That is to say that consumers who perceive more of the health value of EVOO, who search for products with health claims, who spend more on purchasing olive oil, and who have large households are more inclined to purchase EVOO with information on the label.

A number of theoretical and practical implications can be drawn from the survey findings. Theoretically, this study addresses a notable gap in the literature by exploring the combined effect of health claims, product knowledge and sensory attributes on consumers' intentions to purchase EVOO with a clearly labelled description of its health benefits. While previous research has examined these factors individually, their interaction remains underexplored, particularly in the context of EVOO. From this perspective, the study advances the theoretical understanding of the processes involved in consumers' decisions, highlighting the complexity of how health-related information interacts with product familiarity and sensory experience.

From a managerial perspective, these findings are particularly relevant for EVOO producers, processors, and marketers. First, the evidence reveals significant opportunities for market differentiation in the EVOO sector through the strategic use of health claims. Companies can leverage this insight to invest in innovation and labelling. Particular attention should be paid to the wording, to ensure it is easily understood. For instance, companies could consider adding brief health-related information to accompany the health claim (i.e. how EVOO polyphenols contribute to cardiovascular health). Second, the positive effect of subjective knowledge and label comprehension on consumers' intention suggests the need for integrated communication campaigns that go beyond branding to include nutritional education, storytelling, and digital engagement tools. Alongside health claims, this educational marketing can raise consumer awareness, reinforce brand trust. Third, the influence of household size points to a strategic opportunity to target family-oriented market segments, especially those with health-conscious consumers and children. Therefore, targeted marketing initiatives aimed at highlighting the benefits of EVOO consumption according to the Mediterranean diet for a nutrient-rich and balanced diet could significantly improve families' response to increased consumption of EVOO with health claims.

Despite the clear contributions of this research, it has some limitations inherent to its methodological design. Firstly, the study is based on a relatively small sample size which calls for caution when interpreting the results and generalizing them to the broader population. From this perspective, the results must be interpreted in light of the sample's socio-demographic profile. In particular, 61.5% of respondents hold a university degree, an unusually high proportion for Sicily, where educational attainment is among the lowest in Europe (Il Sicilia, 2022). Similarly, the average household size and the income levels exceed regional averages (Macchi, 2024, 2025). The high proportion of highly educated respondents with high incomes may have inflated the WTP measure. These data indicate a clear selection bias, likely due to the online snowball sampling method. The sampling method used and the way the questionnaire was administered led to the exclusion of older individuals who have limited access to social media, as well as those who tend to pay greater attention to the quality and origin of olive oil. Therefore, as external validation for the broader Italian population is not guaranteed, results should be interpreted as representative of a specific consumer segment: informed, educated Southern Italian consumers with above-average income and interest in food quality and health.

Given these limitations related to sample representativeness, future research should aim to broaden the geographic and socio-economic scope of data collection. A nationally representative sample of the Italian population would allow for more robust and generalizable conclusions, reducing bias from overrepresentation of educated and affluent individuals. Therefore, a stratified sampling strategy covering multiple Italian regions, including both Northern and Southern areas, would ensure that the sample is more representative and reduce the risk of bias compared to random sampling. Furthermore, this would allow a more comprehensive understanding of how regional disparities influence attitudes toward health claims and intention to pay for premium EVOO.

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Antonio Tulone

Department of Agricultural, Food and Forest Sciences, University of Palermo
Viale delle Scienze, Building 4, 90128 Palermo, Italy
E-mail: antonio.tulone@unipa.it

He is a Research Fellow at the Department of Agricultural, Food and Forest Sciences of the University of Palermo, where he also obtained his PhD in Agricultural, Forestry, Environmental and Food Sciences. He has published research on topics such as climate-change mitigation policies, the impact of marine warming on fishing activities, land grabbing in developing countries, and the adoption of sustainable practices within agrifood supply chains.

Maria Lia Riccobono

No affiliation
90128 Palermo, Italy
E-mail: marialiariccobono04@gmail.com

She holds a Master's degree in Entrepreneurship and Quality for the Agri-food System from the Department of Agricultural, Food and Forest Sciences at the University of Palermo in Italy. As part of her studies, she conducted an empirical study for her master's thesis, examining the role of subjective knowledge in extra virgin olive oil consumption.

Claudio Mirabella

Department of Agricultural, Food and Forest Sciences, University of Palermo
Viale delle Scienze, Building 4, 90128 Palermo, Italy
E-mail: claudio.mirabella01@unipa.it

He is a PhD student at the Department of Agricultural, Food and Forest Sciences of the University of Palermo. His research focuses on social issues and decent work in rural economies, social sustainability, and the phenomena of undeclared labor, forced labor, and illegal hiring in agribusiness production systems. He has published studies on consumer behaviour and preferences, with a particular focus on ethical consumption, certification schemes, and value creation within agri-food supply chains.

Antonino Galati

Department of Agricultural, Food and Forest Sciences, University of Palermo
Viale delle Scienze, Building 4, 90128 Palermo, Italy
E-mail: antonino.galati@unipa.it

He is a Full Professor of Agricultural economics and valuation at the Department of Agricultural, Food and Forest Sciences. University of Palermo. obtained the National Scientific Qualification as Full Professor (Sector 07/A1 – Agricultural Economics and Valuation). He holds a Ph.D. in Agricultural Economic and Policy (2007) from the University of Palermo and a Postgraduate Specialization Diploma in “Politique et choix publique en agriculture et alimentation (2005) from Institut Agronomique Méditerranéen de Montpellier. He is the Italian country director and vicepresident of the EuroMed Academy of Business (EMRBI). fellow of the EMRBI and a Co-Chair of its Research Interest Committee in Agribusiness.

Maria Crescimanno

Department of Agricultural, Food and Forest Sciences, University of Palermo
Viale delle Scienze, Building 4, 90128 Palermo, Italy

E-mail: maria.crescimanno@unipa.it

She is a Full Professor at the Department of Agricultural, Food and Forest Sciences, University of Palermo (Italy). She is Coordinator of the graduate programs in agro-engineering and Forestry and environmental sciences. She was the delegate of the Chancellor of the University of Palermo for the planning and organization of the University's Masters and a Fellow of the EuroMed Academy of Business (EMRBI). Her research interests include international and European agricultural policy, foreign agri-food trade, agribusiness, market competitiveness, logistic, and fishery policy and market analysis. Her research has been published in many international peer-reviewed journals.

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Credit granting and rural producers' default in Rondônia, Brazil

Thaiane Cristino de Souza^{*,a}, Willian Carlos Barreto Luzini^a,
Haroldo de Sá Medeiros^a, Carlos André da Silva Muller^a,
Otacílio Moreira de Carvalho Costa^a, Mariluce Paes de Souza^a

^a Federal University of Rondonia, Brazil

Abstract

This article aims to examine the scenario of credit granting and default among rural producers in the state of Rondônia between the years 2020 and 2024. The research is quantitative and descriptive, based on secondary data and document analysis concerning the management and operations of Banco da Amazônia (Bank of the Amazon) related to the Constitutional Fund for Financing the North (FNO). The results show that approximately 4.5 billion reais and 16,689 loans were granted during the period under study, of which 9,239 were allocated for operating expenses and 5,116 for investment purposes. It was found that default rates are low, since only 282 contracts (1.69% of the total) had overdue installments. It is also noteworthy that 10 municipalities in Rondônia, out of a total of 52, concentrate 48.48% of the credit contracts and 62.75% of the total credit amount granted. The study concludes that rural credit provides producers with resources to finance their activities and invest in infrastructure, innovation, and technology, enabling them to increase production, productivity, employment, and income, as well as improve living conditions in rural areas. These findings contribute to the understanding of the dynamics of rural credit allocation and default, providing insights for future research and for policies aimed at improving the rural credit system in the state.

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* *Corresponding author:* Thaiane Cristino de Souza - Federal University of Rondonia, Brazil.
E-mail: thaiane764@gmail.com.

Introduction

Rural credit has been the main means of supporting rural producers since 1965, with the institutionalization of the National Rural Credit System through Law No. 4,829 (1965), regulated by Decree No. 58,380 (1966) and by the Rural Credit Manual (MCR) of the Central Bank of Brazil. The rural credit policy has undergone continuous revisions and improvements since its institutionalization, aiming to increase its effectiveness and simplify operational rules. Over time, more resources have been made available with more attractive market interest rates, focusing on small and medium-sized rural producers and on priority investment programs, promoting sustainable practices and technological innovation, while adapting to market conditions and other public policies (Araújo *et al.*, 2020).

Agribusiness financing in Brazil has historically offered interest rates lower than the country's basic interest rate, the SELIC. To illustrate this difference, the 2003/2004 crop season had R\$ 32.5 billion in credit, with an average interest rate of 8.75% for producers under the National Program for Support of Medium-Sized Rural Producers (PRONAMP) credit line. This represented almost half of the SELIC, which closed the year 2003 at 16.32%. The same incentive policy was maintained in the 2023/2024 crop season, when R\$ 364.22 billion was made available to support rural production. The interest rate applied was 8%, significantly lower than the SELIC, which ended 2023 at 11.65% (Brazil, 2003, 2024).

Rural financing is important to cover agricultural and livestock activities, invest in infrastructure, machinery, agricultural implements, and technologies, as well as to replenish working capital, acquire inputs necessary for cultivation and maintenance of rural establishments, commercialization, and industrialization of production.

In addition, the study by Borges and Parré (2022) sought to estimate the impact that rural credit has on Brazil's agricultural output between 1999 and 2018. To this end, the authors used Vector Autoregressions (VAR), Granger causality tests, and regressions by ordinary least squares (OLS) and generalized least squares (GLS). The research found that a 1% increase in the total volume of rural credit leads to an approximate 0.20% increase in agricultural GDP, meaning that rural credit stimulates agricultural GDP growth.

Since its creation in the 1960s to contemporary times, rural credit has been undergoing a process of structuring and evolution, expanding its reach and volume of resources and fulfilling its objectives of stimulating investment in rural activities, strengthening the economy of rural producers, among other positive results throughout its history.

Legislation itself emphasizes the importance of monetary authorities, especially the responsibilities assigned to the National Monetary Council

(CMN) and the Central Bank of Brazil (BCB) in regulating rural credit, establishing guidelines and instructions related to the application and control of this credit modality, providing technical and economic assistance services to producers, and overseeing the resources granted (Brazil, 1965). In addition, it aims at the proper use of invested resources, the fulfillment of its objectives, and avoiding negative results, such as delays in the payment of installments by producers and, mainly, default. Despite these institutional mechanisms of the National Rural Credit System, producers face challenges in meeting contractual obligations to repay loans, leading them into indebtedness and, in some cases, default.

Default occurs when credit installments are overdue or unpaid, resulting in the registration of debtors, whether individuals or legal entities, in credit protection databases maintained by organizations such as the Credit Protection Service (SPC) and SERASA, which may hinder future attempts to obtain credit from financial institutions. A survey conducted by Serasa Experian in July 2023 indicated that 28% of Brazilian rural producers were in default. In Rondônia, this percentage was even higher, reaching 31.7% (SERASA, 2023).

Rural producers are responsible for much of the food that reaches Brazilian households, such as grains, vegetables, fruits, meats, and dairy products. In this context, the agricultural sector is fundamental to the economy, generating jobs and contributing significantly to the country's Gross Domestic Product (GDP). It supplies both domestic and foreign markets with food and raw materials essential for industry, processed, and industrialized foods.

The economy of Rondônia is strongly influenced by agricultural and livestock production, which plays a significant socioeconomic role (Marcolan, Teixeira & Evangelista, 2018). Coffee, corn, soybeans, and rice stand out in agriculture, while beef and dairy cattle are key in livestock production (Embrapa, 2024). According to the 2017 Agricultural Census, the state has 91,438 rural establishments, of which 18,313 obtained some type of rural financing (IBGE, 2017). The state also stands out for its strategic geographic position in the Legal Amazon, with fertile soils and abundant water resources, which favor agricultural production.

The choice of Rondônia as the focus of this case study is justified by its characteristics within the Brazilian agricultural context. Located in the Northern region of Brazil, Rondônia has an estimated population of around 1.6 million inhabitants according to the 2022 demographic census (IBGE, 2022), with a strong presence of workers in the primary sector, especially in family farming and dairy cattle ranching (Silva, 2023). The composition of the workforce in the state reveals the importance of agribusiness and family farming, which account for a significant share of the state's Gross Domestic Product and employ a large portion of the economically active population (Santos, 2021).

However, Barros *et al.* (2015) reinforce that agricultural activity involves high risks for producers, due to the possibility of external factors such as adverse weather conditions, diseases, and pests, which can significantly affect both the quantity and quality of production. As a result, these factors may compromise the fulfillment of commitments established between stakeholders, including credit contracts. Furthermore, Lu *et al.* (2024) found a correlation between financial education and default. The results indicate that farmers who lack a good understanding of finance and who do not master essential money management skills are at greater risk of becoming defaulters.

Given this scenario, it becomes necessary to analyze credit granting and default among rural producers in Rondônia. To this end, the research focuses on the distribution of contracts and the ways in which producers use the resources obtained. In this context, the following research question arises: What is the extent of default among producers in the state of Rondônia?

The objective of this research is to describe the scenario of credit granting and default among rural producers in the state of Rondônia. In addition, it aims to analyze the distribution of contracts by economic scale and municipal location, based on data provided by Banco da Amazônia (BASA) for the years between 2020 and 2024, a period encompassing the pandemic and post-pandemic of Covid-19, which accentuated indebtedness and default in various sectors of the country.

1. Background

1.1. Regional Development Theory

Gunnar Myrdal's Theory of Regional Development argues that economic development tends to concentrate in already developed areas. This creates a virtuous cycle of growth, while less developed regions face a vicious cycle of underdevelopment. This dynamic is observed in underdeveloped rural areas, where the lack of investment is one of the main obstacles to progress (Myrdal, 1960).

In this context, rural credit is a fundamental strategy to break these vicious cycles. By providing financing to farmers, it not only stimulates agricultural production but also seeks to increase income and improve quality of life in rural areas. It is expected that access to credit will initiate a virtuous cycle, in which increased production generates more jobs and income, creating a favorable environment for new economic initiatives.

Myrdal (1960) notes that it is natural for a region to benefit from expanding agricultural markets and to be driven by technical progress. However, in order for these benefits to be maximized and regional

inequalities to be addressed, collaboration between public policies and the private sector is crucial.

Hirschman (1958) complements this theory by highlighting that countries face difficulties in reaching their full development potential due to the lack of strategic decision-making. He introduced the concept of linkages, which explains how investments in key sectors, such as agriculture, can catalyze regional development. For him, the State must be proactive in creating essential social infrastructure, including public services and adequate legislation, to foster production.

For this to occur, rural credit must be accompanied by a development strategy that prioritizes sectors with high linkage potential and that includes training for farmers and technological innovation (Lima & Simões, 2010).

According to Lima and Simões (2010), this infrastructure should not only meet immediate needs but also promote sustainable and inclusive economic growth. For this to happen, it is important that rural credit be accompanied by a development strategy that prioritizes sectors with high productive linkage potential and that encompasses farmer training and technological innovation.

Credit granting is fundamental for the rural sector, an important segment of the Brazilian economy. This sector drives foreign exchange generation and ensures food security in the country. Moreover, it contributes to the development of regions more distant from major financial and industrial centers (Cavinato & Capitani, 2023). Agricultural financing fosters the expansion of these areas, stimulating the development of regions where credit is made available.

Finally, foreign capital can act as a balancing mechanism in situations where the government faces limitations in taking action. External investments can provide the resources needed to initiate or expand projects that would otherwise not be viable. In this sense, rural credit, when well-structured and complemented by effective public policies, can become an important tool for the economic and financial development of rural activities (Farias *et al.*, 2018), breaking through the barriers of underdevelopment and fostering more equitable and sustainable growth.

1.2. Rural Credit and Default

The agricultural credit system is composed of formal financial institutions, such as government and private commercial banks, whose operations are supervised by the Central Bank of Brazil (BCB) and the National Monetary Council (CMN). Rural credit is an essential type of financing intended for producers, cooperatives, and agents in the agricultural

sector, with the purpose of covering crop expenses, investing in properties, commercialization, storage, logistics, and industrialization (BCB, 2024). The granting of this credit is conditioned on the presentation of documents proving financial capacity, the availability of guarantees, and the regularization of property ownership (CMN Resolution No. 4,883, 2020).

Rural credit is essential for the development of agricultural activity. It enables the introduction of technological innovations in the field, resulting in a significant increase in production in recent decades (Araújo & Silva, 2021). The studies of Silva & Ferreira (2016) and Gasques *et al.* (2017) investigated the connection between rural credit and total factor productivity (TFP), pointing out that there is a positive relationship between the two. According to them, credit allows improvements in the production process through access to technological innovations. To clarify, TFP is the increase in output that cannot be explained by greater use of inputs or resources such as labor, capital, and land. In addition, Barros *et al.* (2015) highlight the social importance of credit, which contributes to food supply, job and income creation, and the permanence of people in rural areas.

The Law No. 4,829/1965, which institutionalizes rural credit, establishes clear objectives for this system, such as stimulating rural investments, encouraging rational production systems, increasing productivity, and improving the standard of living of rural populations. The legislation also aims to protect soil and the environment, reduce production costs, facilitate commercialization, and strengthen rural producers, especially small and medium-sized ones. Furthermore, the BCB also points out that rural credit is intended to enable land purchase and regularization, as well as the development of agroforestry and fishing activities, strengthening producers, particularly small and medium-sized.

Access to formal agricultural credit, however, remains quite limited, highlighting the importance of finding ways to expand it (Benson & Faguet, 2022). This scenario is aggravated by the issue of default. Default occurs when an individual or organization fails to meet the payment obligation on the contractually established date (BCB, 2024). According to Lu *et al.* (2024), financial institutions do not have effective methods for analyzing credit risk, which increases the likelihood of default. This problem represents a major challenge for both borrowers and banks, with negative consequences for both sides, such as asset loss for borrowers and profit reduction for financial institutions (Zu *et al.*, 2024).

The behavioral and financial characteristics of borrowers are naturally considered as risk factors for default (Medina-Olivares *et al.*, 2022). Moreover, Kvitschal *et al.* (2015) highlight several causes of the problem, such as lack of producer training, adverse weather conditions, use of inadequate technology, difficulties in marketing production, use of credit for

other purposes, and deficiencies in technical assistance. The indebtedness process is further aggravated by the low level of training, especially among small-scale producers (Oliveira *et al.*, 2018).

Stiglitz and Weiss (1981) argue that the loan market is characterized by credit rationing. According to the authors, lenders tend to increase interest rates and collateral requirements, which ultimately attracts higher-risk borrowers. In such a situation, only projects with higher expected returns remain attractive, resulting in negative effects on default. Rocha *et al.* (2022) add that the growth of default reduces credit supply and increases financing rates.

The Banco da Amazônia (BASA) is a public bank that acts as an arm of the Federal Government in the implementation of public policies and the management of funds for sustainable development in the Amazon region. With a results-oriented management approach, BASA's strategic objectives are to promote sustainability and to be a reference in microbusinesses. Its role seeks to direct resources toward inclusive and equitable development, contributing to the agricultural sector and improving the quality of life of rural populations (BASA, 2023). Concern with default is particularly relevant, since loans from public sources, such as those it manages, are five times more likely to result in indebtedness compared to those from private sources (Barros *et al.*, 2015).

Public banks may facilitate the allocation of small credit operations to low-wealth farmers, following normative considerations such as their mission to promote rural development and regulations that favor these farmers. Moreover, aggregate access to credit for low-wealth farmers occurs mainly through the public sector (Benson & Faguet, 2022).

2. Materials and methods

This research can be classified as descriptive, with a quantitative approach. It used secondary data sources with the aim of obtaining a comprehensive understanding of the financing granted to rural producers in Rondônia. In addition, documents related to the management and operations of Banco da Amazônia linked to the Constitutional Fund of the North (FNO) were analyzed.

To obtain an overview of rural financing in the state of Rondônia, an analysis was carried out using the database of the Rural Credit Data Matrix of the Central Bank of Brazil (BCB). This consultation made it possible to identify the main financial institutions operating in this sector, revealing that Banco do Brasil and Banco da Amazônia S.A. (BASA) stand out as the institutions that granted the most loans to rural producers in the region between 2020 and 2024.

In this sense, to obtain a general view of the number of contracts in default, information requests were made based on Law No. 12.527/2011 (Access to Information Law) through the Fala.BR platform. These requests were directed to Banco do Brasil and Banco da Amazônia, financial institutions that operate with resources from public constitutional funds aimed at regional and social development.

To analyze the evolution of credit granting during and after the Covid-19 pandemic, a period of crisis and economic downturn, the analysis focused on the period from 2020 to 2024. Thus, the following data were requested: number of rural financing contracts signed with rural producers (individuals and legal entities) and cooperatives; number of contracts in default in the same period; classification of contracts according to the purpose of credit (working capital, investment, commercialization, industrialization); and sociodemographic data of the borrowers (age, gender, income, and city of contracting).

The requests were submitted through the Fala.BR channel, which, according to Article 11 of Law No. 12.527/2011, must be answered by the requested entity within 20 days, with a possible extension of 10 more days. Banco do Brasil denied access to default data on the grounds of commercial confidentiality and referred to the BCB as the source of the data. On the other hand, Banco da Amazônia granted access to most of the requested data.

Banco da Amazônia provided a data spreadsheet of loans granted with resources from the Constitutional Fund for Financing of the North (FNO), covering the period from January 2020 to May 2024, with the following information: number and value of contracts, year, type of activity (livestock, agriculture), size, purpose, program, bank product, municipality, and contracts in default with overdue amounts. It should be noted that the financial institution reported that it does not have gender, age, and income information in its database.

In the spreadsheet sent by BASA, the amounts granted for 132 contracts were not provided, which affected the analysis. It was decided not to apply data imputation techniques in order to avoid distorting the results. Furthermore, these contracts were not excluded from the analysis and were included in the contract quantity statements. Given the above, the analysis of this study was limited to credit borrowers – rural producers – served by BASA, making a comparison with open data from the Central Bank.

The choice of Banco da Amazônia (BASA) for this study is justified by two main reasons: first, because it is one of the institutions that most granted loans to rural producers in the analyzed period; and second, due to its strategic nature and development mission for the Amazon region, as established in Law No. 12.024/2009.

Unlike banks with a strictly commercial focus, BASA has a credit portfolio shaped by its social and economic role. This characteristic directs its financing toward specific types of producers and projects, such as small landowners, family farming, and beneficiaries of public programs (BASA, 2023). In addition, BASA, as a public financial institution, plays a fundamental role in supporting regional development by providing credit and financial services to small and medium-sized entrepreneurs, farmers, and local communities (De Lima, Da Cruz Bastos, Dos Santos Gastão, 2025).

The execution of BASA's resources is carried out through Financing Programs, developed by Banco da Amazônia, following the general guidelines of the Ministry of Integration and Regional Development and the sectoral and spatial priorities established by the Superintendence for the Development of the Amazon (SUDAM), in line with Regional Development Plans. Moreover, the resources primarily serve the smallest productive segments (mini/micro, small entrepreneurs, individual micro-entrepreneurs, and family-based agriculture) (BASA, 2023).

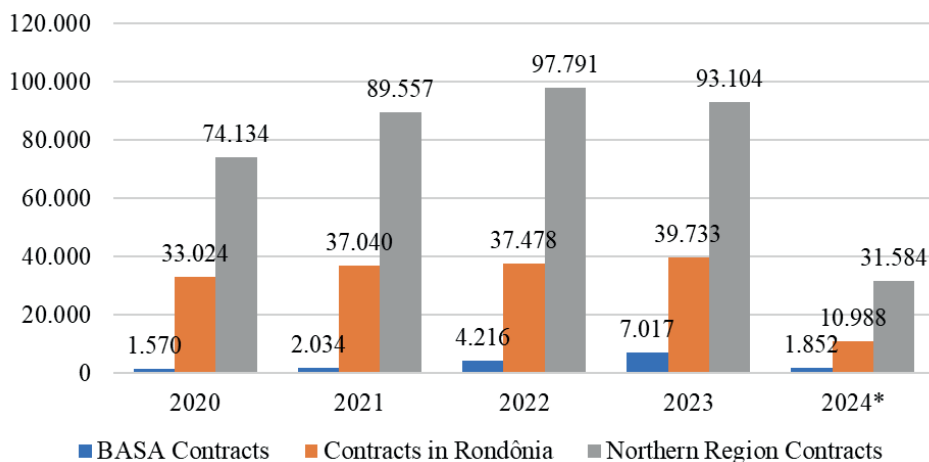
The data provided by Banco da Amazônia cover only the financing granted with resources from the Constitutional Fund for Financing of the North (FNO), an economic-financial instrument to stimulate economic activities developed on a sustainable basis in the North Region. In this regard, in the rural sector it is destined for the National Program for Strengthening Family Farming (Pronaf), the Oriented Productive Microcredit (MPO), and other credit lines of the sector. The interest rate applied depends on the sector, size, and purpose of the loan (BASA, 2024).

The data collected were tabulated using Microsoft Excel, allowing a detailed and organized analysis of the information. This stage included categorizing the data according to various criteria, such as sector of activity, value and number of contracts granted, purpose of loans, size of borrowers, default rate, and municipality of clients.

3. Results

When analyzing the time series from Banco da Amazônia and the BCB, it is noted that the granting of rural credit resources has increased in the state of Rondônia, demonstrating that there is significant financial support for the progress of agricultural activity. When compared to the Northern Region, it appears that Rondônia accounts for a large portion of the loans granted. The Figure 1 presents a comparison of the total number of rural credit contracts granted by financial institutions in the Northern Region, in the state of Rondônia, and specifically by Banco da Amazônia (BASA), in the period from 2020 to 2024.

Figure 1 - Number of rural credit contracts in the period from 2020 to 2024



Source: Elaborated by the authors based on data from Banco da Amazônia and the Central Bank of Brazil.

* 2024 data until 05/31/2024.

As can be observed in Figure 1, the credit granted by Banco da Amazônia to rural producers in Rondônia grew throughout the analyzed period, and 2023 was the year in which there were more concessions by the institution in the state. The data also reveals that BASA does not have a significant participation in the total financing signed in the state, since in the period from 2020 to 2024 it was responsible for only 10.55% of the total contracts in Rondônia.

Table 1 - Number of BASA contracts in Rondônia, by purpose

Purpose	Year					Total
	2020	2021	2022	2023	2024	
Operating Costs	7	104	2.268	5.399	1.461	9.239
Investment	1.024	1.240	1.320	1.218	314	5.116
Fixed Investment	157	136	140	90	22	545
Mixed Investment	19	21	10	5	11	66
Semi-Fixed Investment	363	533	478	305	44	1.723

Source: Elaborated by the authors based on data from Banco da Amazônia and the Central Bank of Brazil.

* 2024 data until 05/31/2024.

The analysis of contracts, segmented by purpose, as presented in Table 1, reveals the distribution of financing according to the specific needs of rural producers. It's observed that 9,239 contracts were allocated to operating costs, reflecting the high demand from producers for resources to cover operational expenses. For investment purposes, 5,116 contracts were accounted for. This type of financing is aimed at acquisitions that seek to expand the productive capacity of producers, such as the purchase of machinery and equipment.

A specific segment of investment, fixed investment, had 545 contracts signed in the analyzed period, standing out for financing aimed at permanent improvements in property infrastructure. Mixed investment (operating costs and/or commercialization associated with investment) corresponds to 66 contracts, and this type of transfer allows greater flexibility for producers to meet the needs of their enterprise. Finally, financing for semi-fixed investment totaled 1,723 contracts, and this resource should be used for acquisitions that do not fully qualify as fixed or variable, covering intermediate items.

This distribution by purpose of rural credit contracts highlights the diversity of financial needs of rural producers in Rondônia over the years and the importance of making different credit modalities available to adequately meet the demands of the agricultural sector. Furthermore, it allows producers to improve their operations to compete more equitably with producers from more developed regions.

Regarding the amounts released for each purpose, it was found that financing aimed at investments corresponds to the largest portion of the resources granted, as can be observed in Table 2.

Table 2 - Total amount released by BASA in Rondônia, by credit purpose (2020-2024)*

Purpose	Total amount
Operating Costs	R\$ 1.669.328.530,00
Investment	R\$ 469.384.376,60
Fixed Investment	R\$ 929.862.902,50
Mixed Investment	R\$ 106.895.842,00
Semi-Fixed Investment	R\$ 1.361.269.369,00

Source: Elaborated by the authors based on data from Banco da Amazônia.

* 2024 data until 05/31/2024.

The resources allocated to operating costs in the period from 2020 to May 2024 totaled R\$ 1,669,328,530.00, while the amount allocated to investment in general was R\$ 2,867,412,490.10. In this context, throughout the period under analysis, approximately 4.6 billion reais were made available to rural producers, allocated in the operating costs, investment, and commercialization segments.

In this sense, considering the possibilities of applying investment resources provided for in CMN Resolution No. 4,883 of 12/23/2020, it is found that producers needed to resort to BASA to finance services such as construction, renovation and improvements in permanent facilities, acquisition of machinery, irrigation and drainage works, formation of permanent crops, formation or recovery of pastures, soil correction and recovery, and acquisition of animals for reproduction.

The analysis of default by rural producers benefiting from credit in Rondônia presents data that help to understand the evolution of this problem over the years. The default scenario for Banco da Amazônia customers is represented in Table 3.

Table 3 - Default of BASA's rural financing portfolio in Rondônia

Year	Resource Granting	Default (%)	Defaulted contracts
2020	R\$ 598.004.823,33	0,16%	R\$ 964.326,02
2021	R\$ 803.533.813,67	2,35%	R\$ 18.921.602,24
2022	R\$ 1.115.484.596,03	0,83%	R\$ 9.298.550,55
2023	R\$ 1.498.709.658,87	0,99%	R\$ 14.853.716,79
2024*	R\$ 521.008.128,17	–	R\$ 0,00
Total	R\$ 4.536.741.020,07	0,97%	R\$ 44.038.195,60

Source: Elaborated by the authors based on data from Banco da Amazônia.

* 2024 data until 05/31/2024.

The agribusiness figures demonstrate that the portfolio's default level is low, with an average default rate of 1.09% in the period between 2020 and 2023, a period in which approximately 4.5 billion reais were released to producers.

Data relating to 2024 contracts with overdue installments had zeroed values and did not include the default percentage in the spreadsheet provided by BASA, which may indicate that all contracts for the current year are current due to the short period analyzed in the year (January

to May 2024) or that the bank had not yet registered debtors in credit protection registries.

It is observed that the default rate peaked in 2021 (2.35%), significantly above the average for the analyzed period (0.97%). This behavior may be associated with the context of the Covid-19 pandemic, especially in the year when its economic effects were most severe in Brazil. The pandemic brought significant impacts to the global economy, with direct repercussions on the agricultural sector (Oliveira, 2025). The slowdown of economic activity, mobility restrictions, and rising production costs directly affected the payment capacity of rural producers, contributing to the temporary increase in default.

The 2024 FNO Application Plan indicates the existence of green credit programs and lines of financing that encourage sustainable agricultural practices and the adoption of new technologies. These initiatives are fundamental for increasing productivity, reducing risks associated with external factors (such as climate change), and improving farmers' capacity to repay their debts, thereby decreasing default rates and promoting a virtuous cycle of development.

The combination of easy credit with relative price and trade policies has greatly influenced the use of inputs/factors and agricultural production. A vast number of rules, regulations, programs, and projects were established by the Central Bank. These programs and projects had specific objectives, interest rates, terms, and repayment schemes. Three general features of credit policy deserve emphasis. The first is the nominal interest rates set at levels lower than those practiced in other loans. The second consists of numerous incentives and controls to ensure that banks lend more resources to farmers, using both their own liabilities – mainly demand deposits – and National Treasury funds. Third, since the creation of the National Program for Strengthening Family Farming (*Programa Nacional de Fortalecimento da Agricultura Familiar* – Pronaf) in 1996, with its social and distributive purpose, the nominal interest rates on loans granted to family farming producer groups have been set well below the rates applied to loans directed to commercial farmers (Araújo, 2011).

When analyzing default based on the number of contracts with overdue installments, it is evident that default is considered very low, as shown in Table 4.

Table 4 - Defaulted BASA contracts in Rondônia by credit release year

Year	Defaulted contracts	Total contracts
2020	31	1.570
2021	54	2.034
2022	119	4.216
2023	78	7.017
2024*	–	1.852
Total	282	16.689

Source: Elaborated by the authors based on data from Banco da Amazônia.

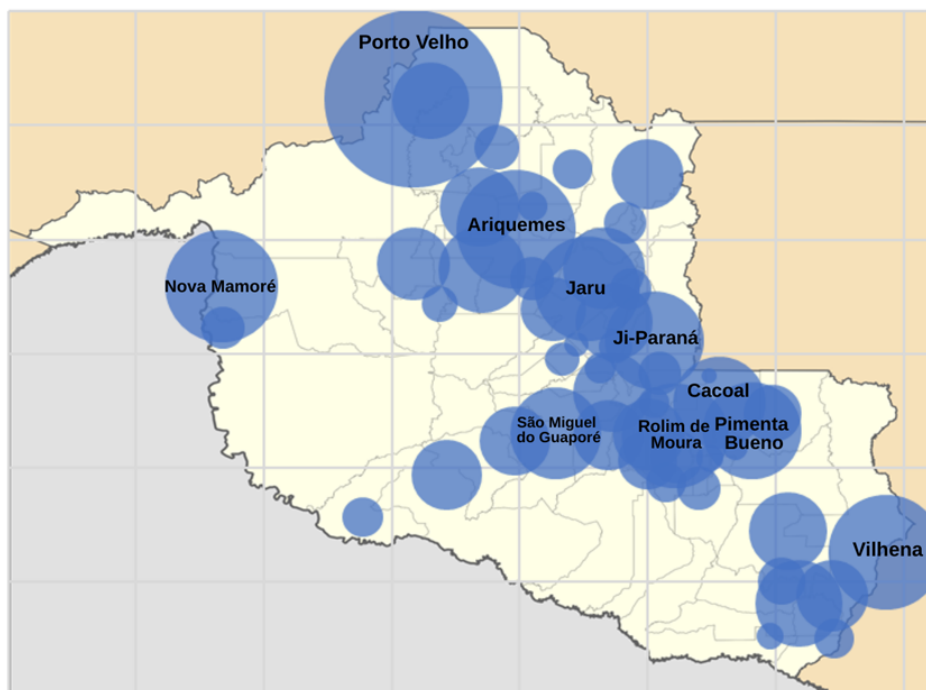
* 2024 data until 05/31/2024.

As shown in Table 4, of the 16,689 financing contracts granted between 2020 and May 2024, only 282 were in default. This figure corresponds to 1.69% of the contracts analyzed. This indicates that most producers are able to honor their commitments and remain current, even when facing challenges related to the climate, the agricultural market, and the challenges posed by the Covid-19 pandemic, which affected all sectors of the Brazilian economy.

Regarding the city of the clients, it was found that clients who obtained financing from BASA to subsidize agricultural activities in Rondônia reside in 117 municipalities, distributed across 17 Brazilian states.

The data reveals that 2.12% (384) contracts were signed with clients who maintain some activity related to agriculture or livestock in Rondônia, but who live outside the state. Contracts signed with residents of Rondônia correspond to 97.88% (16,335) of a total of 16,689 concessions. Figure 2 presents the concentration of contracts by municipality.

Figure 2 - Concentration of contracts granted in Rondônia, by municipality (2020 to 2024)



Source: Elaborated by the authors based on data from Banco da Amazônia.

As shown in Figure 2, most of the financing is concentrated in the capital Porto Velho, Ariquemes, Nova Mamoré, Vilhena, and in the municipalities located in the central portion of the state, along the BR-364 highway. On the map, the 10 municipalities most benefited by credit were identified. It is worth noting that the main cities of Rondônia developed along the BR-364 axis, and with agricultural activities it was no different. In this context, the entire surrounding region can benefit from the linkages of the agricultural sector, as postulated by Myrdal (1960).

The concentration of credit in a few municipalities observed in Rondônia, where 48.48% of credit contracts are concentrated in only 10 out of 52 municipalities, highlights strong regional inequalities in access to financing. This phenomenon can be interpreted in light of Myrdal's (1960) theory of cumulative causation. According to this theory, investments tend to cluster in already consolidated centers, such as those located along BR-364, reinforcing the development of these areas to the detriment of others. Thus, the already

developed regions continue to attract more resources, which widens the gap in relation to the less favored areas.

The Table 5 presents a ranking of the 20 municipalities with the most contracts.

Table 5 - Position of Rondônia municipalities in terms of number of contracts and amount granted (2020-2024)

Ranking	City	Contracts	Amount released
1	Porto Velho	1.962	R\$ 401.601.435,30
2	Ariquemes	883	R\$ 469.294.705,70
3	Vilhena	827	R\$ 406.020.198,00
4	Nova Mamoré	796	R\$ 524.148.172,30
5	Rolim de Moura	688	R\$ 214.374.163,10
6	Jaru	687	R\$ 218.533.173,00
7	Ji-Paraná	606	R\$ 134.556.423,50
8	Pimenta Bueno	595	R\$ 147.643.990,20
9	Cacoal	526	R\$ 259.923.768,90
10	São Miguel do Guaporé	521	R\$ 70.573.180,05
11	Monte Negro	484	R\$ 27.180.454,86
12	Cerejeiras	478	R\$ 259.199.083,10
13	Theobroma	412	R\$ 24.828.606,00
14	Alto Paraíso	392	R\$ 25.622.925,06
15	Alvorada D'Oeste	390	R\$ 38.169.286,70
16	Chupinguaia	386	R\$ 24.293.590,76
17	Ouro Preto do Oeste	369	R\$ 69.631.300,05
18	Candeias do Jamari	363	R\$ 9.730.030,80
19	Buritis	336	R\$ 45.489.142,66
20	Novo Horizonte do Oeste	328	R\$ 19.918.296,66

Source: Elaborated by the authors based on data from Banco da Amazônia.

As highlighted in Table 5, the top 10 municipalities together benefited from 8,091 loans out of a total of 16,689 contracts, equivalent to R\$ 2,846,669,210.05, an amount that represents 62.75% of the granted value from 2020 to May 2024, which was R\$ 4,536,741,020.07.

The area that benefited the most, in absolute values, from rural credit was livestock, both in the number of concessions and in the amount released, as it had 14,716 contracts and an injection of almost R\$ 3 billion in the period. On the other hand, in agriculture there were 1,973 contracts and R\$ 1,554,521,998.00 destined to producers in this segment.

In this context, according to BASA's FNO Financial Application Plan, beneficiaries (companies, individual micro-entrepreneurs, and rural producers) are classified by size based on their annual gross agricultural income or annual gross operating revenue, as shown in Table 6:

Table 6 - Classification of Credit Borrowers by Size and Contract Volume

Size	Annual Gross Agricultural Revenue⁽¹⁾ / Annual Gross Operating Revenue⁽²⁾ (R\$ 1,00)	Number of contracts
Mini/Micro	Up to R\$ 360.000,00	14.752
Small	Above R\$ 360.000,00 and up to R\$ 4.800.000,00	1.201
Small-Medium	Above R\$ 4.800.000,00 and up to R\$ 16.000.000,00	1
Medium I	Above R\$ 16.000.000,00 and up to R\$ 90.000.000,00	634
Medium II	Above R\$ 90.000.000,00 and up to R\$ 300.000.000,00	26
Large	Above R\$ 300.000.000,00	75

Source: Adapted from BASA data.

(1) For the rural sector.

(2) For non-rural sector.

Smaller-scale productive segments are classified as family farmers, mini, small, and small-to-medium rural producers, as well as their respective small and small-to-medium-sized cooperatives (Lima, 2016).

In Rondônia, during the period under analysis, it was identified that 88.39% (14,752) of the financing contracts were granted to mini/micro-sized beneficiaries, with an annual gross revenue of up to R\$ 360,000.00, among which 752 were subclassified as family farmers. In addition, small producers also stood out, as 1,201 loans were granted to them through various FNO credit lines. This result is positive, as it demonstrates that small rural enterprises are being financially supported and have the opportunity to improve their productive capacity. Furthermore, the fund allows small producers and entrepreneurs access to long-term financing under special conditions, promoting growth in employment and income and fostering the development of the Northern Region.

Conclusions

The data collected reveal a multifaceted reality of rural credit in Rondônia, highlighting both the economic vitality of the agricultural sector and the challenges faced by local producers. The analysis shows that rural credit has been important for the region's economic development, providing producers with the resources necessary for investment and working capital in their activities. The predominance of contracts aimed at covering operating costs reflects the ongoing need for support with operational expenses, while investments in infrastructure and technology indicate a movement toward modernization and increased production efficiency.

The low default rate observed suggests a capacity for financial management on the part of producers, despite market and climate adversities. This positive scenario, however, should not be interpreted as an absence of difficulties. The concentration of credit in certain regions of the state and in the livestock segment indicates that there are still areas and sectors that require greater attention and support in order to achieve balanced and sustainable development.

In addition, the analysis underscores the importance of public policies that continue to support rural credit, especially for small and medium-sized producers, who make up the majority of beneficiaries. The role of Banco da Amazônia and the use of funds such as FNO can help maintain the economic dynamism of the agricultural sector, promoting not only economic growth but also increases in productivity, the implementation of technology and innovation, food security, social inclusion, and the reduction of regional inequalities. The continuation of financial support, combined with risk management strategies and the diversification of credit modalities, helps ensure the resilience of the agricultural sector in Rondônia.

In this regard, this study contributes to the understanding of the dynamics of rural financing and default, providing inputs for future research and policies that may further improve the rural credit system in the state. The limitations of the analysis are related to the incomplete data provided by Banco da Amazônia, which affected the quality of the analysis. Furthermore, the reasons why borrowers are behind on their payments were not part of the scope of this study.

The main contribution of this study lies in revealing, based on official data, how rural credit policy has materialized in Rondônia during a period marked by crisis and economic recovery. By highlighting the low default rate, the regional concentration of contracts, and the distinctive role of Banco da Amazônia in financing with FNO resources, the article broadens the understanding of the dynamics of rural credit in the state and offers original insights for researchers, policymakers, and financial institutions. This

contribution is particularly relevant because the literature lacks recent and region-specific analyses on the subject, especially in the Amazonian context.

Thus, it is suggested that future studies conduct surveys with rural producers to analyze the reasons that led them to default. Despite its limitations, it is believed that this study provided relevant information for the discussion on the rural credit market.

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Thaiane Cristino de Souza

Federal University of Rondônia, Brazil

BR-364 Highway, km 9.5, 76801-059 - Porto Velho/RO

E-mail: thaiane764@gmail.com

She holds an MBA in Strategic Business Management from North Paraná University (2022), a degree in Economics from the Federal University of Rondônia (2021), and is currently a Master's student in Administration at the same institution. Her research interests include rural economics, sustainable development and financial education.

Willian Carlos Barreto Luzini

Federal University of Rondônia, Brazil

BR-364 Highway, km 9.5, 76801-059 - Porto Velho/RO

E-mail: willianbarretos80@gmail.com

He holds a Master's in Administration from the Federal University of Rondônia (2025), an MBA in Management of Public Institutions from the Federal Institute of Rondônia (2024), and a degree in Accounting Sciences from Rolim de Moura College (2012). He is currently a professor at Estácio University and an employee of the City Hall of Rolim de Moura, Rondônia. His research interests include circular economy, production systems, and supply chain management.

Haroldo de Sá Medeiros

Federal University of Rondônia, Brazil

BR-364 Highway, km 9.5, 76801-059 - Porto Velho/RO

E-mail: haroldo.medeiros@unir.br

He holds a Doctoral degree in Business Administration from the University of Fortaleza (2019), a Master's in Administration from the Federal University of Rondônia (2012) and a degree in Administration from the Federal University of Rio Grande do Norte (2009). Currently, he is Professor and Vice-coordinator of the Postgraduate Program in Administration at the Federal University of Rondônia. His research interests include sustainable management and tourism planning, stakeholder participation management, and public value.

Carlos André da Silva Muller

Federal University of Rondônia, Brazil

BR-364 Highway, km 9.5, 76801-059 - Porto Velho/RO

E-mail: carlosandre@unir.br

He holds a PhD in marketing area at the São Paulo School of Business Administration of the Getúlio Vargas Foundation, a Doctoral degree in Applied Economics from the Federal University of Viçosa (2007), a Master's in Applied Economics from the Federal University of Viçosa (2004) and a degree in Business Administration from the Federal University of Rondônia (2002). Currently, he is a Full Professor at the Federal University of Rondônia in the Business Administration course and the Master's in Administration. His research interests are entrepreneurship, technology, sustainability, the Amazon, and the role of public and private organizations in local development.

Otacílio Moreira de Carvalho Costa

Federal University of Rondônia, Brazil

BR-364 Highway, km 9.5, 76801-059 - Porto Velho/RO

E-mail: otaciliomc@unir.br

He holds a Doctoral degree in Information Science from the University of São Paulo (2021), a Master's degree in Administration from the Federal University of Rondônia (2008) and a degree in Economics from the Federal University of Rondônia (2002). Currently, he is a professor at the Federal University of Rondônia. He has experience in the field of Economics, with an emphasis on Economic Theory, working mainly on the following topics: New Institutional Economics, Agribusiness Economics, Industrial Economics, Economic Regulation, Competition Law, Governance Structure, and Information Quality.

Mariluce Paes de Souza

Federal University of Rondônia, Brazil

BR-364 Highway, km 9.5, 76801-059 - Porto Velho/RO

E-mail: mariluce@unir.br

She holds a Doctoral degree in Socio-environmental Sciences from the Federal University of Pará (2004), a Master's degree in Production Engineering from the Federal University of Santa Catarina (1998), a Specialist degree in Human Resources Management (UFSC - 1989) and a degree in Business Administration from the Federal University of Rondônia (1984). She is a full professor at the Federal University of Rondônia in the Administration course and postgraduate programs.

She has experience in the areas of Administration, Production, and Socio-environmental Sciences, working on the following themes: governance, sustainability, strategies and coordination, interorganizational relationships, chain-network, sustainable supply chains, circular economy, and public policies in the Amazon, with an emphasis on the organization of traditional communities, the water-energy-food nexus, food insecurity, social capital, and Amazonian resources.



Enhancing Food Security through Gender-Inclusive Empowerment: A Localized Model for Rural Farming Households

Lili Winarti^a, Rokhman Permadi^{*a}, Maswadi^b

^a Darwan Ali University, Indonesia

^b Tanjungpura University, Indonesia

Abstract

Food insecurity persists in rural Indonesia despite agricultural abundance, disproportionately affecting women in farming households. This study investigates the interplay of food security, gender inclusion, and women's empowerment among 296 pineapple farming households in East Kotawaringin Regency, Central Kalimantan. Employing a cross-sectional design, data were collected via structured questionnaires and analyzed using the Household Food Insecurity Access Scale (HFIAS), a Localized Women's Empowerment in Agriculture Index (LWEAI), and Partial Least Squares Structural Equation Modeling (PLS-SEM). Results reveal that access to credit and market information significantly reduces food insecurity, while larger household sizes increase vulnerability. Gender inclusion strongly predicts empowerment, enhancing women's autonomy and leadership, though food insecurity undermines both. The LWEAI, tailored to local contexts, and PLS-SEM's robust analysis offer novel frameworks for understanding these dynamics. Findings advocate for gender-responsive policies – such as women-targeted microcredit and extension services – to strengthen food security and equity, aligning with Indonesia's national development goals and Sustainable Development Goals (SDGs) 2 and 5.

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* *Corresponding author:* Rokhman Permadi - Agribusiness Department, Universitas Darwan Ali - Jl Batu Berlian Kotawaringin Timur, Central Kalimantan 74312, Indonesia. E-mail: rokhmanpermadi@gmail.com.

Introduction

Food insecurity remains a paradoxical and persistent challenge in many developing countries, where agricultural households despite being primary food producers are disproportionately vulnerable to hunger and malnutrition. This vulnerability stems from structural constraints such as limited access to land, credit, market infrastructure, and public services (FAO, 2022; Nour & Abdalla, 2021). In Indonesia, the COVID-19 pandemic further exposed these fragilities, with more than 50% of households reporting moderate to severe food insecurity (Akbar *et al.*, 2023; Amrullah *et al.*, 2023). The situation is particularly evident in East Kotawaringin Regency, Central Kalimantan, a major pineapple-producing region where agricultural productivity coexists with rising poverty, illustrating that food surplus does not necessarily translate into household food access (Statistics Office of East Kotawaringin Regency, 2023). This contradiction raises urgent questions about the structural and gendered dimensions of food security at the local level.

Rural women play a critical yet undervalued role in agricultural production and household food provisioning. In Indonesia, women account for up to 64% of agricultural labor, with around 25% formally classified as farmers or landowners (Ratnasari & Sugiyanto, 2023). Beyond production, they shoulder responsibilities for caregiving, resource management, and food preparation. Yet, their agency is routinely constrained by insecure land rights, gender-biased credit systems, weak access to extension services, and exclusion from decision-making platforms (Osanya *et al.*, 2020; Puspitawati *et al.*, 2019). These barriers suppress women's economic potential and undermine collective agricultural productivity. Addressing gender inequality in agriculture is therefore not only an ethical imperative but also a practical necessity for strengthening food security and rural resilience.

An expanding body of literature emphasizes women's empowerment as a pathway to improved nutrition, household welfare, and livelihood sustainability (Kehinde *et al.*, 2021; Shuai *et al.*, 2019). However, most existing frameworks, such as the Women's Empowerment in Agriculture Index (WEAI), rely on standardized indicators like control over income and access to resources, while neglecting localized dimensions such as group participation or access to market information (A. R. Quisumbing *et al.*, 2021). Few studies have examined how these localized forms of agency interact with food insecurity under systemic shocks such as pandemics. In remote and agriculturally active regions like East Kotawaringin, empirical evidence on the interplay between food insecurity, gender inclusion, and empowerment remains scarce.

To conceptualize empowerment, this study draws on Kabeer's Empowerment Framework (1999), which defines empowerment as the process

through which individuals gain the ability to make strategic life choices in contexts where this capacity was previously denied. The framework highlights three interrelated dimensions: resources (material, human, and social), agency (the ability to set and pursue goals), and achievements (the outcomes of agency). In rural agricultural systems, these dimensions manifest through land access, decision-making in farming, income control, time allocation, and leadership in community organizations. Adapting Kabeer's framework to a localized and gendered food system allows this study to capture how empowerment is shaped not only by institutional arrangements but also by cultural norms and lived experiences.

This study develops a localized, gender-inclusive empowerment model tailored to the socio-economic and cultural context of East Kotawaringin. Unlike standardized indices, the proposed model integrates community-grounded indicators such as group participation, access to agricultural information, credit availability, and household decision-making. It further examines how food insecurity, exacerbated by the COVID-19 crisis, influences empowerment pathways through gender inclusion and time poverty. By employing Partial Least Squares Structural Equation Modeling (PLS-SEM), the study explores multidirectional relationships among these variables, providing a more robust analysis of interactions under stress and scarcity.

The research is guided by three objectives: (1) to examine the direct relationship between household food insecurity and gender inclusion in agricultural decision-making; (2) to assess whether gender inclusion mediates the effect of food insecurity on women's empowerment; and (3) to evaluate how localized empowerment variables such as market information, group participation, and access to credit contribute to sustainable food security outcomes.

By situating women's empowerment within a multidimensional and localized framework, this study contributes to theoretical development while informing targeted interventions and policies. It provides critical insights for rural development planners, gender-focused practitioners, and policymakers seeking to address food insecurity and gender inequality through integrated, context-sensitive strategies. Ultimately, the findings aim to support adaptive policies that recognize rural women as co-creators of resilient and equitable food systems.

1. Literature Review

This study adopts Kabeer's Empowerment Framework (1999) as its primary theoretical lens. The framework conceptualizes empowerment through three interrelated dimensions: resources (such as access to land,

credit, and information), agency (the ability to participate in decision-making), and achievements (the realization of improved wellbeing). This multidimensional approach provides a robust foundation for analyzing how gender inclusion shapes food security, particularly in rural agricultural contexts such as East Kotawaringin, where structural and cultural barriers remain deeply embedded.

Women's contributions underpin agricultural production and household welfare in many developing economies. In Indonesia, women provide up to 64% of agricultural labor, yet face persistent marginalization in land ownership, access to credit, and leadership roles (Ratnasari & Sugiyanto, 2023; Puspitawati *et al.*, 2019). Such inequalities restrict women's agency, suppress productivity, and undermine broader rural development goals. Evidence shows that gender inequality hampers both empowerment and agricultural performance (Peterman *et al.*, 2021). The Women's Empowerment in Agriculture Index (WEAI) offers a useful benchmark, but its aggregated indicators often lack context-specific sensitivity. Shuai *et al.* (2019) demonstrate that when women participate in agricultural decision-making, productivity rises and nutrition outcomes improve. However, institutional biases in credit systems and extension services continue to limit equitable access, highlighting the need for structural transformation alongside individual inclusion.

Gender inclusion in agricultural policy functions not only as an ethical obligation but also as a strategic lever to enhance resilience and food security. Kehinde *et al.* (2021) show that women's control over resources and income directly benefits household investments in nutrition, education, and health. Yet barriers related to land tenure, labor division, and markets persist. In Nigeria, women supply more than half of farm labor but own less than 15% of land (Bello *et al.*, 2021). Comparable dynamics appear in Indonesia, including East Kotawaringin, where women's essential contributions remain undervalued (Colfer *et al.*, 2015; Puspitawati *et al.*, 2019). Addressing these inequities represents a precondition for long-term food system sustainability.

Food insecurity disproportionately affects women and children, intensifying vulnerabilities within rural households. Jemaneh and Shibeshi (2023) in Ethiopia confirm a strong correlation between women's empowerment and household food security, as empowered women prioritize nutritional diversity and child health. Similarly, Madzorera *et al.* (2023) associate women's agricultural decision-making with improved dietary diversity. In East Kotawaringin, where food insecurity persists despite agricultural abundance, these dynamics remain particularly relevant. Strengthening women's roles in agricultural leadership and planning could mitigate access issues and bolster resilience.

Access to credit strongly influences household capacity to stabilize consumption and absorb shocks. Millimet *et al.* (2018) demonstrate the role of financial inclusion in strengthening resilience, yet women often remain excluded due to collateral requirements and insecure land rights. Akbar *et al.* (2023) highlight that households with women in decision-making roles coped more effectively during the COVID-19 pandemic. Gender-sensitive financial services, such as microcredit or cooperative lending, therefore not only empower women but also enhance community-wide food security.

Market information likewise serves as a critical determinant of household resilience. Hlatshwayo *et al.* (2023) find that timely access to price and demand data reduces losses and improves income. Gendered restrictions on mobility and technology, however, often prevent women from benefiting fully. In Indonesia, initiatives to expand digital literacy and inclusive information channels have begun to address this gap (Budiwiranto *et al.*, 2025). Such interventions demonstrate how local institutions can mitigate structural inequities.

Intersectionality further conditions women's empowerment. Variables such as age, marital status, and ethnicity influence the degree of agency women exercise. Gualoto (2023) documents how Indigenous women in the Galápagos face multiple layers of exclusion, exacerbating time poverty and reducing access to services. Comparable patterns emerge in Indonesia, where younger women or those in polygamous households often experience less autonomy than their older or widowed counterparts. Interventions must therefore remain sensitive to these intersecting identities to achieve equitable outcomes.

Time poverty constitutes another critical barrier. Adeyeye *et al.* (2021) note that women in rural Nigeria devote significantly more time to unpaid care than men, constraining their participation in training, cooperatives, and decision-making. Labor-saving technologies, improved water access, and community childcare centers can release women's time for productive engagement. In East Kotawaringin, initiatives such as communal food processing or childcare services could support women's economic participation while maintaining household wellbeing.

Extension services, long oriented toward men, require redesign to reflect women's needs. Osanya *et al.* (2020) demonstrate that joint training for spouses enhances household productivity and decision-making, yet many programs continue to target male heads of households. Indonesian evidence shows that flexible schedules and female-led facilitation significantly improve women's participation (Anik & Rahman, 2021). Female extension agents and peer-learning models can strengthen women's confidence, leadership, and technical capacity, thereby contributing to long-term resilience.

Empirical models that combine food security and empowerment indicators remain limited. Quisumbing *et al.* (2021) call for integrated metrics that

capture both structural (access to land, income) and relational (decision-making, autonomy) dimensions. The Localized Women's Empowerment in Agriculture Index (LWEAI), developed in this study, addresses this gap by contextualizing indicators for East Kotawaringin. By incorporating household size, access to credit, and community participation, the LWEAI enhances explanatory power compared to standardized indices. Pre-testing with 20 respondents and validation by agricultural and gender experts confirmed cultural relevance, while Cronbach's alpha values above 0.80 indicated strong internal consistency.

The methodological design integrates PLS-SEM with empowerment indices to analyze complex multidirectional relationships. Hair *et al.* (2019) recommend PLS-SEM for exploratory research where distributional assumptions and large sample requirements cannot be met. This approach yields nuanced insights into how resource access shapes both food security and empowerment outcomes. Convergent and discriminant validity were established ($AVE > 0.50$, $CR > 0.70$), while bootstrapped path coefficients and VIF confirmed mediation effects and absence of multicollinearity. The model's explanatory and predictive capacity provides evidence for targeted interventions and contributes to a more equitable agricultural system that recognizes women as central actors.

2. Research Methodology

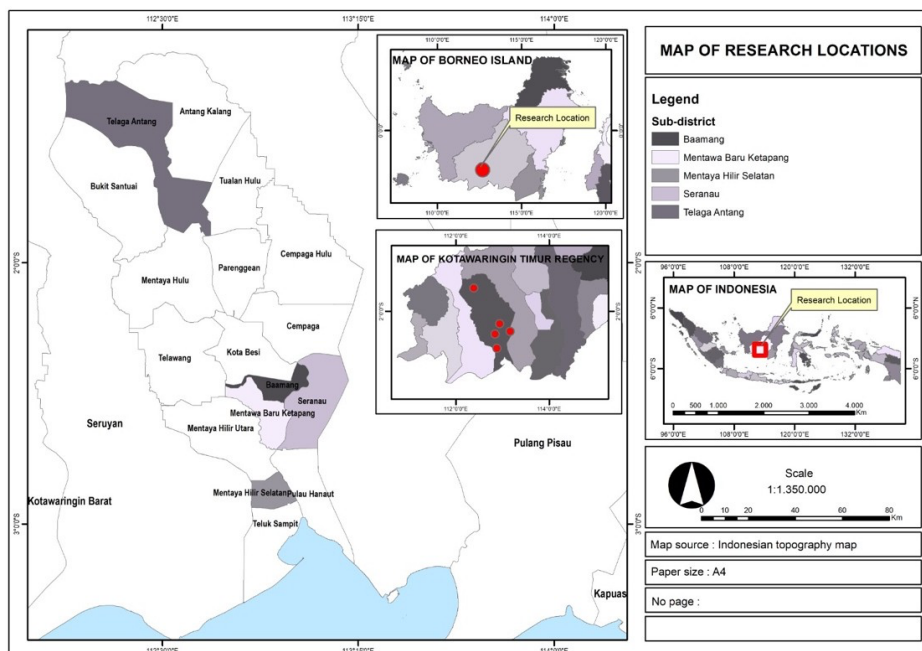
2.1. Study Area and Population

The study was conducted in East Kotawaringin Regency, located in Central Kalimantan Province, Indonesia. This regency ranks as the fourth-largest pineapple-producing area among the 14 regencies and municipalities in the province, with total production reaching 336.4 tons in 2022 (Statistics Office of East Kotawaringin Regency, 2023). The research focused on five sub-districts (Baamang, Mentawa Baru Ketapang, Mentaya Hilir Selatan, Seranau, and Telaga Antang) which were purposively selected based on their consistent levels of high pineapple output and the density of farming households (Figure 1).

These sub-districts were not only agriculturally significant, but also characterized by socio-economic vulnerabilities, including relatively high poverty rates and persistent food insecurity despite agricultural abundance (Agriculture and Food Security Office of East Kotawaringin Regency, 2024). This paradox provides a compelling context for analyzing the interactions between agricultural productivity, household food security, and women's empowerment in rural settings. Particular attention was given to women

actively engaged in agricultural work both as contributors to farm labor and as decision-makers within their households.

Figure 1 - Map of Kotawaringin Timur Regency Highlighting the Selected Sub-Districts



Source: Indonesian topography map.

2.2. Research Design and Sampling

A cross-sectional research design was adopted to capture data at a single point in time, providing a snapshot of prevailing conditions related to food security, gender inclusion, and women's empowerment among rural farming households. The target population comprised all wives of pineapple farmers residing in the five selected sub-districts of East Kotawaringin, totaling 1,132 individuals. Data collection was conducted through structured questionnaires administered via face-to-face interviews by trained enumerators.

A stratified random sampling technique was employed to ensure proportional representation across the selected sub-districts. Stratification was based on five purposively chosen sub-districts Baamang, Mentawa Baru

Ketapang, Mentaya Hilir Selatan, Seranau, and Telaga Antang identified as the region's primary pineapple-producing zones. Sample allocation within each stratum was conducted proportionally based on the number of active pineapple-farming households in each sub-district, as recorded by the East Kotawaringin Agriculture and Food Security Office (2023). This approach ensured both geographical and socio-economic representativeness of the sample.

The sample size was calculated using Yamane's formula (1973), with a 5% margin of error ($\alpha = 0.05$), yielding a required sample size of 296 respondents:

$$n = \frac{N}{1 + N(e)^2} = \frac{1,132}{1 + 1,132(0.05)^2} = 296$$

where n is the sample size, N is the total population (1,132), and e is the margin of error (Yamane, 1973). The proportional distribution of respondents per sub-district was determined using the formula:

$$n_i = \frac{N_i}{N} \times n$$

where n_i is the number of samples from sub-district i and N_i is the total pineapple-farming household population in sub-district i . This proportional allocation strategy enabled the research to capture contextual variations in agricultural engagement, demographic composition, and household-level vulnerability across locations.

To clarify the sampling unit, the study focused on married women who directly participated in pineapple farming, either as co-farmers or key decision-makers. This included spouses of land-owning farmers, tenant farmers, and smallholders managing less than 2 hectares. Women-headed farming households were also included. Selection was based on active engagement in agricultural production and management rather than legal land ownership, ensuring diverse representation across farming roles.

2.3. Data Collection Instrument

A structured questionnaire was developed to collect data on four major areas: (1) socio-demographic and economic characteristics, (2) household food insecurity, (3) gender inclusion, and (4) women's empowerment in agriculture. The Household Food Insecurity Access Scale (HFIAS) was

used to assess household-level food access over the previous 30 days. The instrument captured various dimensions of food insecurity, ranging from concerns about food availability to more severe experiences such as skipping meals or not eating for an entire day (Salarkia *et al.*, 2014). A composite score was calculated for each household, ranging from 0 to 27, where higher scores indicated greater levels of food insecurity.

To measure empowerment, this study developed a Localized Women's Empowerment in Agriculture Index (LWEAI), adapted from the original Women's Empowerment in Agriculture Index (WEAI) (Alkire *et al.*, 2013). The index retained the five core domains of empowerment: (1) decision-making in agricultural production, (2) access to and control over productive resources, (3) control over income use, (4) leadership in community activities, and (5) allocation of time for productive and domestic tasks. Items were scored using a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5). Domain-specific scores were aggregated into a composite empowerment index.

The gender inclusion index was adapted from indicators developed by (A. Quisumbing *et al.*, 2023), focusing on women's participation in agricultural decision-making, access to resources and training, involvement in group activities, and contribution to market-related agricultural activities. Responses were also collected using a 5-point Likert scale, allowing for both descriptive and multivariate analysis of inclusion levels (Joshi *et al.*, 2015).

Demographic and socio-economic variables collected included age (in years), level of education (total years of formal schooling completed), farming experience (in years), household income (in Indonesian Rupiah), landholding size (in hectares), and household size (number of family members living in the household). Descriptive statistical analyses including means, standard deviations, frequency distributions, and cross-tabulations will be used to profile the sample. These data serve to contextualize the empowerment and food security outcomes explored in subsequent analysis.

To ensure validity and cultural appropriateness, the localized instruments (LWEAI and the Gender Inclusion Index) underwent a two-stage validation process. First, the questionnaire was pre-tested with 20 respondents from a comparable demographic group to ensure clarity, relevance, and local comprehensibility. Second, internal reliability testing using Cronbach's alpha demonstrated strong consistency, with all major constructs exceeding a coefficient of 0.80. Expert judgment from academic and field practitioners was also used to refine item formulation and content validity.

To mitigate the risk of common method bias arising from face-to-face interviews and Likert-scale items, several procedural remedies were applied. The questionnaire incorporated both positively and negatively worded statements to reduce acquiescence bias. Furthermore, enumerators

emphasized respondent anonymity and confidentiality prior to each interview session, encouraging honest and unbiased responses. Survey instructions were standardized to avoid interviewer influence, and participants were assured that there were no right or wrong answers.

2.4. Data Analysis Techniques

The data analysis was conducted in two main stages: descriptive statistics and inferential analysis. In the first stage, descriptive statistics were applied to summarize the socio-demographic and economic characteristics of the respondents. Measures of central tendency (mean, median) and dispersion (standard deviation, range) were used for continuous variables, while frequencies and percentages were used for categorical variables. The demographic profile includes variables such as age, education level, farming experience, land size, farm income, and household size, along with access to credit, market information, and agricultural extension services. The summary of these characteristics is presented in Table 1.

Table 1 - Descriptive Statistics of Respondents' Demographic Characteristics

Variable	Mean	SD
Age (years)	40.82	9.53
Education (years)	7.87	2.33
Farming experience (years)	19.30	25.31
Farm size (hectares)	2.27	1.47
Farm income (IDR)	2,743,936	1,895,423
Household size (members)	2.71	1.266
Variable	Category	Frequency (%)
Credit Access	Have access	172 (58.11%)
	No access	124 (41.89%)
Market Information Access	Have access	246 (83.11%)
	No access	50 (16.89%)
Agricultural Extension Access	Have access	87 (29.39%)
	No access	209 (70.61%)

Source: Primary data (2024).

In the second stage, inferential analysis was conducted using Partial Least Squares- Structural Equation Modeling (PLS-SEM) via SmartPLS version 4.0 to test the hypothesized relationships (Hair *et al.*, 2019). PLS-SEM was chosen due to its robustness in handling complex models involving multiple constructs and indicators, especially under limited sample sizes and when normal distribution assumptions are not strictly met (Hair *et al.*, 2021). Compared to covariance-based SEM (CB-SEM), PLS-SEM emphasizes predictive accuracy and is appropriate for exploratory modeling.

To evaluate the measurement model, several validity and reliability tests were performed:

- Factor loadings (> 0.70) confirmed indicator reliability.
- Cronbach's Alpha and Composite Reliability (CR) values above 0.70 indicated good internal consistency.
- Average Variance Extracted (AVE) values above 0.50 were used to confirm convergent validity (Fornell & Larcker, 1981).

The structural model was then evaluated based on path coefficients, significance levels, and the explanatory power of endogenous constructs:

- R^2 values ($0.25 = \text{weak}$, $0.50 = \text{moderate}$, $0.75 = \text{substantial}$)
- Q^2 values (from Stone-Geisser test) greater than zero confirmed predictive relevance.
- Bootstrapping (5,000 subsamples) was applied to test the significance of direct and indirect effects at the 95% confidence level.

A summary of construct reliability and validity is presented in Table 2, followed by Table 3 showing the R^2 and Q^2 values for the main constructs.

Table 2 - Construct Reliability and Validity

Construct	Cronbach's Alpha	Composite Reliability	AVE
Food Security	0.846	0.890	0.577
Women's Empowerment	0.912	0.935	0.743
Gender Inclusion	0.883	0.914	0.680

Source: Primary data (2024).

Table 3 - Coefficient of Determination (R^2) and Predictive Relevance (Q^2)

Construct	Q^2	R^2	R^2	
			Adjusted	Criteria
Food Security	0.078	0.641	0.630	moderate
Gender Inclusion	0.097	0.176	0.173	weak
Women's Empowerment	0.463	0.472	0.469	moderate

Source: Primary data (2024).

While the R^2 values for gender inclusion and women's empowerment were modest, they remain within acceptable thresholds for exploratory PLS-SEM models (Hair *et al.*, 2021). Future research could incorporate additional predictors such as social capital or institutional trust.

To further understand each predictor's contribution, effect size (f^2) was calculated. This metric assesses how much an independent variable contributes to explaining the variance in each endogenous variable. The results are displayed in Table 4.

Table 4 - Summary of Effect Size (f^2)

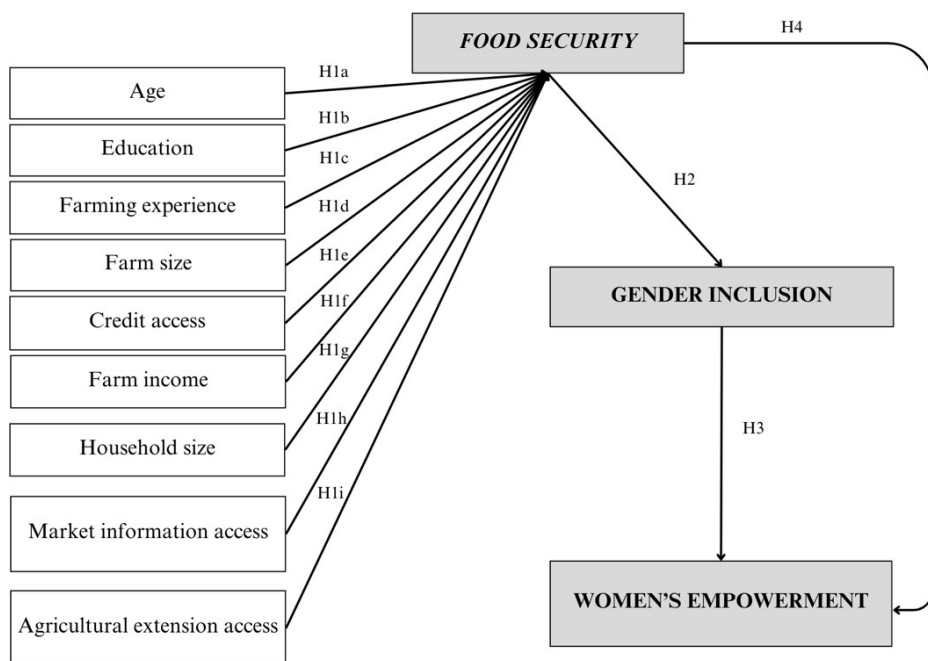
Construct	Food Security	Gender Inclusion	Women's Empowerment
Age	0.003		
Education	0.002		
Farming experience	0.000		
Farm size	0.001		
Farm income	0.004		
Household size	0.197		
Credit access	0.041		
Market information access	0.303		
Agricultural extension access	0.000		
Food security		0.214	0.149
Gender inclusion			0.387

Source: Primary data (2024).

The final structural model was developed to visualize the hypothesized relationships among constructs. Each latent construct was operationalized using 4 to 6 reflective indicators adapted from validated sources. Figure 2 presents the path model, illustrating both direct and indirect causal effects between demographic characteristics, resource access variables, food security, gender inclusion, and women's empowerment. Key relationships explored include how factors such as market information access and household size influence food security, and how gender inclusion functions as a mediating variable in the empowerment process of women in agricultural households. The figure includes standardized path coefficients and significance levels, obtained through bootstrapping with 5,000 iterations.

Specifically, hypotheses H1a-H1i examine the influence of socio-economic characteristics and access to agricultural resources on food security. H2 and H3 assess the mediating role of gender inclusion between food security and women's empowerment. Finally, H4 represents the direct effect of food security on women's empowerment. These pathways provide a comprehensive framework to analyze both structural and relational dimensions of empowerment in the context of rural food systems.

Figure 2 - Structural Model of Hypothesized Relationships



Source: Author's own work.

SmartPLS 4.0 was used to test the structural model, including direct and indirect paths among food insecurity, gender inclusion, and women's empowerment. To test for the mediating role of gender inclusion, a bootstrapping procedure with 5,000 resamples was employed. Mediation was confirmed using the Variance Accounted For (VAF) criterion, where partial mediation is established if VAF exceeds 20%.

All research procedures adhered to ethical standards for studies involving human participants. Prior to data collection, formal approval was obtained from the Agriculture and Food Security Office of East Kotawaringin Regency. Participation was voluntary, and verbal informed consent was secured after explaining the study's objectives, confidentiality, and the right to withdraw at any time. No personal identifiers were collected, and all data were treated anonymously and analyzed in aggregate. Enumerators were trained to conduct interviews respectfully and in accordance with local cultural and gender norms.

3. Results

The results of this study provide comprehensive insights into the factors influencing food security, gender inclusion, and women's empowerment within agricultural households in East Kotawaringin Regency, Indonesia. This section is structured into several subsections, including demographic characteristics, levels of food security, dimensions of gender inclusion and empowerment, as well as findings from structural equation modeling. The analysis integrates both descriptive and inferential statistical approaches, with the inferential component utilizing Partial Least Squares Structural Equation Modeling (PLS-SEM) to examine hypothesized relationships among variables.

3.1. *Demographic and socio-economic characteristics of the respondents*

The demographic and socio-economic profiles of respondents provide essential contextual information for interpreting the dynamics of food security, gender inclusion, and empowerment in the study area. As shown in Table 1, the mean age of respondents was 40.82 years (SD = 9.53), suggesting a mature group of women engaged in agricultural activities. On average, respondents had 7.87 years of formal education (SD = 2.33), indicating limited educational attainment, which may affect access to agricultural knowledge and services.

The average farming experience was 19.30 years (SD = 25.32), showing extensive engagement in agriculture, although the high standard deviation suggests wide variation in experience levels. The average household size was 2.71 members (SD = 1.27), which reflects a trend toward smaller family units in the region.

In terms of access to agricultural support systems, a majority of respondents (83.11%) reported having access to market information, and 58.11% had access to credit. However, only 29.39% had access to agricultural extension services, highlighting a significant institutional gap that may affect farmers' capacity to implement improved practices and enhance productivity. These characteristics are critical for understanding the determinants of food security and empowerment outcomes examined in subsequent sections.

3.2. Levels of Food Security, Gender Inclusion, and Empowerment

Household food security was assessed using the Household Food Insecurity Access Scale (HFIAS), which captures a household's access to adequate food over the past 30 days. As shown in Table 5, the majority of households (71.62%) were classified as food secure, indicating reliable access to sufficient and appropriate food throughout the year. Additionally, 23.99% of households experienced mild food insecurity, characterized by occasional difficulties in food access without major impacts on quantity or quality. A further 4.39% were found to be moderately food insecure, facing more frequent disruptions that compromised both the quality and quantity of food consumed. Notably, no respondents fell into the category of severe food insecurity.

Table 5 - Food Security Levels of Respondent Households

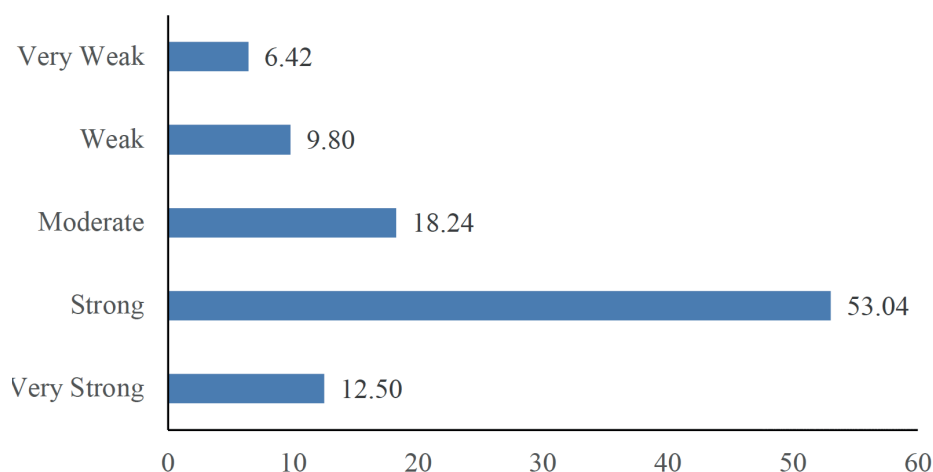
Food Security Level	Frequency	Percentage (%)
Food Secure	212	71.62
Mildly Food Insecure	71	23.99
Moderately Food Insecure	13	4.39
Severely Food Insecure	0	0.00
Total	296	100.00

Source: Primary data (2024).

Gender inclusion was measured using composite indicators reflecting women's participation in agricultural decision-making, access to productive resources, involvement in farming activities, and access to extension services

or training. As presented in Figure 3, 6.42% of respondents reported very weak inclusion, while 9.80% were categorized under weak inclusion. The largest group (53.04%) demonstrated strong gender inclusion, indicating partial but meaningful participation in agriculture-related decisions and moderate resource access. Additionally, 18.24% of respondents experienced moderate inclusion, and 12.50% were classified under very strong inclusion, characterized by full participation in decision-making, leadership, and access to diverse agricultural support services.

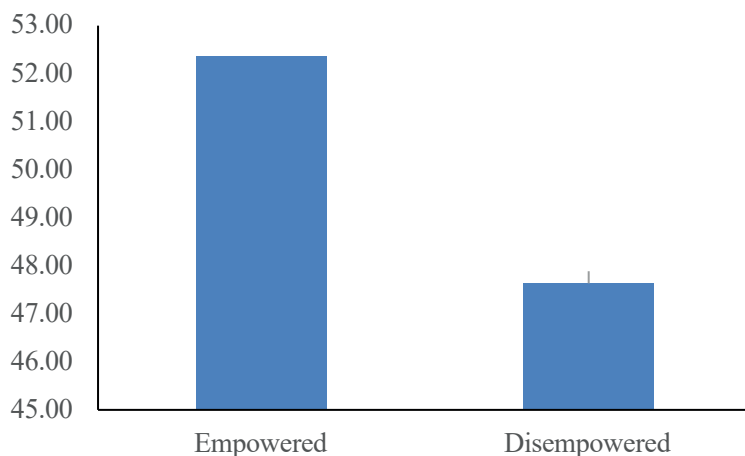
Figure 3 - Gender Inclusion Levels Among Respondent Households



Source: Author's own work.

Women's empowerment in agriculture was assessed using a localized version of the Women's Empowerment in Agriculture Index (WEAI), adapted to the study context. Based on a composite scoring system covering five domains, respondents were classified as empowered if they achieved adequacy in at least 80% of the indicators. Results in Figure 4 show that 52.36% of women were classified as empowered, while 47.64% were considered disempowered. Among the disempowered, constraints included limited access to land, credit, and training opportunities, as well as minimal participation in income-related and production decisions. In contrast, empowered women were more actively engaged in leadership roles, household income control, and agricultural decision-making. These findings indicate persistent gendered barriers in agricultural empowerment, despite some progress.

Figure 4 - Empowerment Levels of Farmers' Wives in the Study Area



author's own work.
Source: Author's own work.

3.3. Path Analysis and Hypothesis Testing

Path analysis using Partial Least Squares-Structural Equation Modeling (PLS-SEM) with 5,000 bootstrapped subsamples examined the hypothesized relationships between socio-economic factors, food security, gender inclusion, and women's empowerment. The explanatory power of the model was moderate for food security ($R^2 = 0.641$) and women's empowerment ($R^2 = 0.472$), while relatively weak for gender inclusion ($R^2 = 0.176$). Nevertheless, all Q^2 values exceeded zero, confirming predictive relevance across constructs.

Table 7 summarizes the standardized path coefficients, t-values, and significance levels. Results indicate that three factors significantly influenced food insecurity: household size ($\beta = 0.323$, $p < 0.001$), credit access ($\beta = -0.279$, $p < 0.01$), and market information access ($\beta = -0.915$, $p < 0.001$). These findings suggest that larger households are more vulnerable to food insecurity, while access to financial and informational resources reduces vulnerability. In contrast, age, education, farming experience, farm size, farm income, and access to extension services did not significantly affect food security.

Table 7 - Summary of Path Coefficients and Hypothesis Testing Results

Relationship	Path Coeffients (β value)	<i>t</i> -Value	<i>n</i> -Value	Significant Level
Age > Food Security	0.040 ^{ns}	0.914	0.361	Not significant
Education > Food Security	0.024 ^{ns}	0.701	0.483	Not significant
Farming Experience > Food	-0.010 ^{ns}	0.246	0.806	Not significant
Security Farm Size > Food Security	-0.058 ^{ns}	0.715	0.475	Not significant
Credit Access > Food Security	-0.279**	3.127	0.002	Significant
Farm Income > Food Security	-0.100 ^{ns}	1.282	0.200	Not significant
Household Size > Food Security	0.323**	6.296	0.000	Significant
Market Information Access > Food Security	-0.915**	7.696	0.000	Significant
Agricultural Extension Access > Food Security	0.015 ^{ns}	0.186	0.852	Not significant
Food Security > Gender Inclusion	-0.420**	6.438	0.000	Significant
Gender Inclusion > Women's Empowerment	-0.498**	9.599	0.000	Significant
Food Security > Women's Empowerment	0.309**	6.155	0.000	Significant

Source: Primary data (2024).

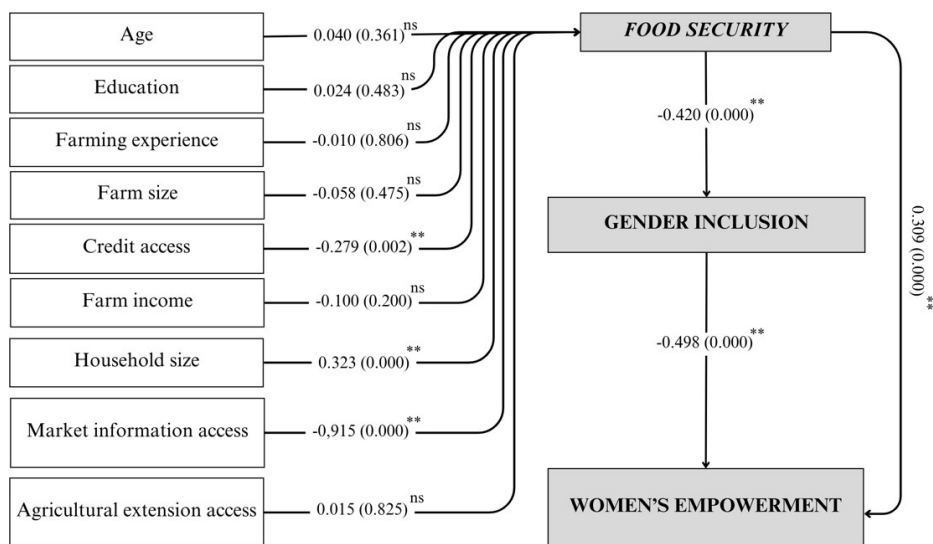
Food insecurity was found to negatively affect gender inclusion ($\beta = -0.420$, $p < 0.001$), indicating that when households face food stress, women's participation in agricultural decision-making and access to productive resources are diminished. Gender inclusion, in turn, exerted a strong positive influence on women's empowerment ($\beta = 0.498$, $p < 0.001$), reinforcing the notion that inclusion is a prerequisite for agency, autonomy, and leadership within rural households. Importantly, food insecurity also directly reduced women's empowerment ($\beta = -0.309$, $p < 0.001$), highlighting its dual role: not only undermining inclusion but also directly constraining women's capacity to exercise agency.

The results provide evidence of both direct and indirect pathways through which resource access and household dynamics shape women's empowerment.

The mediating effect of gender inclusion confirms that empowerment cannot be achieved solely through material resources but requires meaningful participation in agricultural and household decision-making. At the same time, the modest explanatory power for gender inclusion suggests the influence of additional unobserved factors, such as social norms, collective action, or institutional trust, which should be explored in future studies.

These relationships are visually summarized in Figure 5, which illustrates both the direct and indirect causal effects among food security, gender inclusion, and women's empowerment, including the standardized path coefficients and their significance levels. The figure reinforces the central role of gender inclusion as a mediating pathway, while also depicting how food insecurity exerts negative effects through multiple channels.

Figure 5 - Structural Model with Path Coefficients and Significance Levels



Note: * and ** indicate significance levels of 5% and 1%

Source: Author's own work.

4. Discussion

4.1. Key Findings on Food Security

This study provides nuanced insights into the determinants of household food security among pineapple farming communities in East Kotawaringin

Regency, Indonesia. Surprisingly, none of the sampled households reported severe food insecurity, despite regional statistics consistently identifying these areas as food-insecure zones. This divergence may reflect contextual factors, including the timing of data collection (post-harvest season), ongoing food assistance programs, and possible underreporting due to cultural norms or social desirability during face-to-face interviews. Such dynamics may have temporarily obscured structural vulnerabilities, underscoring the need for seasonally sensitive and multi-method assessments in future research (Li *et al.*, 2025).

Quantitative analysis confirms that access to credit and market information significantly reduces the likelihood of food insecurity. These findings align with broader literature on the importance of financial capital and informational access in improving household resilience (Hlatshwayo *et al.*, 2023; Millimet *et al.*, 2018). Credit enables investment in productivity-enhancing inputs, while market information improves production and sales decisions, both of which directly enhance food access. Similar evidence from rural Africa and Asia shows that access to formal credit strengthens food security, while reliance on informal credit may have adverse effects due to unfavorable repayment terms (Salima *et al.*, 2023).

In contrast, larger household size was positively associated with food insecurity, reflecting the strain of higher dependency ratios where children and elderly increase resource pressure in smallholder systems with limited land. This finding is consistent with recent studies reporting that greater dependency ratios reduce food security outcomes, especially in low-income farming households (Olumba *et al.*, 2023). The pattern also reflects gendered labor burdens, where women in large households balance caregiving and farm work, potentially constraining productivity. Given these results, a more detailed discussion of household size dynamics is presented in Section 4.2.

Socio-demographic variables such as age, education, farming experience, farm size, and access to extension services were not significantly related to food security. While earlier studies found these factors influential (Osanya *et al.*, 2020), their insignificance here may point to limitations in the relevance of local extension systems or barriers to women's participation. Comparable findings elsewhere show that extension services often underperform due to weak institutional support and limited gender responsiveness (Li *et al.*, 2025).

4.2. Household Size and Food Insecurity

The positive and statistically significant relationship between household size and food insecurity reinforces the notion that larger families face greater challenges in securing adequate food. This is consistent with Akello &

Mwesigwa (2023) and Olayemi (2012), who observed that increasing household size heightens consumption needs that are not always matched by income, thereby increasing vulnerability. Manyong *et al.* (2024) similarly report that larger family sizes in rural households are associated with lower food security due to trade-offs between food quantity and quality.

Households with more dependents, especially young children or school-age members, must distribute limited resources across more individuals, reducing per capita food availability and heightening poverty risks (Akello & Mwesigwa, 2023). Owoo (2021) likewise found that higher dependency ratios force households to adopt more coping strategies and reduce per capita food expenditures.

However, the relationship is not universally consistent. Olayemi (2012) reported that in Osun State, Nigeria, larger households contributed positively to food security where communal support systems and labor availability offset resource strain. Manyong *et al.* (2024) also note that in some rural settings, larger households with adequate access to credit, inputs, and markets can maintain or even improve food security. These findings indicate that the effect of household size depends on contextual factors such as livelihood structures and access to resources.

Policy interventions are therefore essential to support larger households in resource-constrained contexts. Recommended strategies include nutritional support for high-dependency households, income diversification schemes aligned with household labor capacity, and improved access to microcredit and productive inputs. As Eicher-Miller *et al.* (2020) and Atuoye *et al.* (2019) argue, strengthening economic resilience through market access, social protection, and women's income-generating opportunities can reduce vulnerability and promote equitable food access.

4.3. Gender Inclusion, Empowerment, and Food Insecurity

In this study, gender inclusion refers to women's participation in agricultural decision-making, access to productive resources, and involvement in collective or market-related activities, whereas empowerment reflects agency through control over income, time, and leadership within households and communities. While inclusion represents opportunity, empowerment embodies influence.

Findings reveal a significant negative association between food insecurity and gender inclusion, suggesting that women's roles in decision-making and resource access diminish under food stress. This supports Quinonez *et al.* (2019), who argue that scarcity reinforces patriarchal norms and excludes women from productive roles. Recent work confirms that structural

inequalities mediate resilience pathways, with food stress limiting women's engagement in decision-making and collective action (Slavchevska *et al.*, 2024).

These dynamics indicate that deteriorating food access drives women's withdrawal from public and productive spheres, a trend shaped by increased unpaid care burdens, reduced mobility, and prioritization of household survival. Prior studies show that during food scarcity, women's time and autonomy are reallocated toward survival tasks (Kabeer, 1999, 2016; A. R. Quisumbing *et al.*, 2024). Seasonal fluctuations can also obscure these dynamics, as the timing of measurement influences how women's roles are captured (Wubetie *et al.*, 2024).

Time poverty compounds these effects. Adeyeye *et al.* (2021) found that rural women consistently work longer hours than men due to dual productive and reproductive roles. In East Kotawaringin, women face similar constraints, balancing farming, caregiving, and household management, which limits opportunities for training and leadership. This aligns with O'Meara *et al.* (2025), who emphasize that overlapping constraints – mobility limits, caregiving responsibilities, and weak institutional recognition – shape women's agricultural inclusion.

In marginalized contexts, such overlapping burdens are rarely recognized in policy or statistics, perpetuating the invisibility of women's labor (Gualoto, 2023). Nonetheless, the structural equation model in this study confirms that gender inclusion significantly predicts empowerment, as women engaged in farming decisions and training report higher autonomy, income control, and leadership roles (Peterman *et al.*, 2021; Shuai *et al.*, 2019).

The inclusion-empowerment relationship, however, remains context-dependent. Rahmiyati & Rachmawati (2023) show that women's cooperatives can sustain empowerment even under food insecurity. Yet in East Kotawaringin, weak institutional and social capital limit such protective effects. Moreover, concurrent stresses, such as food and water insecurity, intensify gendered vulnerabilities and restrict empowerment opportunities (Charles *et al.*, 2023). Resource scarcity, as highlighted by Tanto *et al.* (2021), further narrows women's agency and reinforces traditional power structures.

Empowered women, through decision-making autonomy, leadership, and income control, enhance household resilience by improving dietary diversity, farm outcomes, and intergenerational wellbeing (Kehinde *et al.*, 2021; Madzorera *et al.*, 2023). However, without meaningful inclusion, empowerment efforts risk superficiality. Interventions that focus solely on individual capacity, without addressing gender norms and institutional barriers, remain inadequate. Advancing from individual-level initiatives to systemic frameworks that promote inclusion, redistribute household labor, and institutionalize recognition is therefore critical for sustainable change.

4.4. Implications of the Study

This study contributes to the theoretical discourse on food security and gender by empirically validating the mediating role of gender inclusion between food insecurity and women's empowerment. The results extend Kabeer's empowerment framework (1999) by showing that empowerment in agricultural households cannot be achieved solely through resource access but requires relational dimensions of inclusion in decision-making. Moreover, the development of the Localized Women's Empowerment in Agriculture Index (LWEAI) demonstrates how empowerment indices can be tailored to local socio-cultural contexts, thus addressing the limitations of universal measures such as the WEAI. This adaptation provides a more nuanced understanding of how household size, time poverty, and market information interact with empowerment outcomes, offering a theoretical lens that is both context-sensitive and globally relevant. Methodologically, the application of PLS-SEM illustrates the value of predictive modelling in exploring multidirectional relationships within rural development research.

Traditional approaches often treat food security and empowerment as separate constructs; however, this study demonstrates the utility of structural equation modelling for examining complex interactions simultaneously. This approach enhances the predictive power of empowerment research, especially under conditions of moderate sample sizes and non-normal data distributions common in rural fieldwork. Future studies can replicate and extend this methodological framework to integrate additional variables such as institutional trust, social capital, or collective action.

The findings underscore the need for integrated, gender-responsive policies to strengthen rural resilience. First, the significant role of market information in reducing food insecurity highlights the urgency of promoting inclusive communication platforms, such as mobile-based applications, farmer WhatsApp groups, or community radio programs that specifically target women. Second, the positive effect of credit access suggests that microfinance schemes tailored to women minimizing collateral requirements and coupled with financial literacy training can enhance both household food security and women's agency. Third, the dual burden of food insecurity and time poverty implies that interventions must go beyond resource provision to address structural inequalities. Community-based childcare, labor-saving technologies, and gender-sensitive extension services are critical to enabling women's participation in leadership and decision-making.

These implications resonate strongly with Indonesia's rural development priorities and the Sustainable Development Goals (SDGs) 2 (Zero Hunger) and 5 (Gender Equality). The evidence presented here advocates for the institutionalization of gender inclusion within agricultural extension systems, monitoring frameworks, and local governance structures. By

embedding gender-sensitive metrics such as the LWEAI into policy evaluation, governments and development agencies can design more adaptive interventions that reflect grassroots realities while advancing national and global development agendas.

4.6. Limitations and Future Research

While this study offers valuable contributions to the understanding of gender inclusion, food security, and women's empowerment in agricultural households, several limitations must be acknowledged, which also open opportunities for future research.

First, the study employed a cross-sectional design, collecting data at a single point in time. This limits the ability to infer causal relationships or to capture changes in empowerment, gender roles, or household food security over time. Future studies should consider adopting longitudinal or panel data approaches to examine how shifts in access to credit, household composition, or market dynamics affect gendered outcomes and food security across different seasons or over multiple years.

Second, the study was geographically limited to pineapple-producing communities in East Kotawaringin Regency, Central Kalimantan. While this localized focus allows for in-depth contextual analysis, it may limit the generalizability of findings to other agroecological zones or cultural settings. Future research should expand to diverse farming systems and regions (including rice-based, dryland, or coastal agriculture) to assess the robustness and adaptability of the gender-inclusive empowerment model proposed.

Additionally, the study relied on self-reported measures of empowerment and food security, which may be subject to social desirability bias or subjective interpretation. Complementary qualitative approaches (such as in-depth interviews or ethnographic methods) could enrich future analyses by uncovering the lived experiences and intra-household negotiations behind empowerment and inclusion dynamics.

Lastly, future work could explore the role of intersectional factors such as age, ethnicity, or marital status in shaping women's empowerment trajectories in agriculture. Doing so would help refine and tailor empowerment strategies to the specific needs of marginalized subgroups within farming communities.

Conclusion

This study underscores the critical interplay between food security, gender inclusion, and women's empowerment in rural agricultural households of East Kotawaringin Regency, Indonesia. The findings demonstrate that access to credit and market information significantly mitigate food insecurity,

while larger household sizes exacerbate vulnerability a pattern reflecting the structural inequities embedded in smallholder farming systems. Crucially, gender inclusion is significantly associated with food security dynamics: women's participation in agricultural decision-making correlates with greater empowerment outcomes. Conversely, households experiencing food insecurity tend to report lower levels of women's agency – potentially reflecting increased unpaid care responsibilities, reduced access to mobility, or heightened social stigma. While causality cannot be confirmed due to the cross-sectional design, these patterns suggest interdependent constraints that warrant further longitudinal investigation.

The primary contribution of this study lies in the development of the Localized Women's Empowerment in Agriculture Index (LWEAI), a context-sensitive adaptation of the Women's Empowerment in Agriculture Index (WEAI). Unlike conventional frameworks that prioritize aggregate metrics (e.g., income control, resource access), the LWEAI incorporates localized indicators such as household size, community participation, and time poverty to capture the socio-cultural and structural barriers unique to rural Indonesia. This model fills a critical gap in empowerment research by bridging macro-level policy tools (e.g., WEAI, Gender Equity Index) with grassroots realities, offering a nuanced lens to analyze how informal decision-making roles and intra-household dynamics shape women's agency. By linking food security indicators with gendered participation metrics, the LWEAI advances a holistic understanding of empowerment, one that acknowledges the interdependence of resource access, social norms, and systemic inequities.

These insights carry transformative implications for policy and practice. First, the LWEAI provides a replicable framework for designing gender-responsive interventions in agrarian Global South contexts, particularly where cultural norms and decentralized governance limit the applicability of universal empowerment indices. Second, the study advocates for integrated strategies that simultaneously address food security and gender inclusion, such as:

- Expanding microcredit programs tailored to women farmers' needs,
- Leveraging digital platforms to democratize market information access,
- Mainstreaming gender quotas in agricultural cooperatives and extension services.

These findings also resonate with Indonesia's national development agenda. The 2020-2024 National Medium-Term Development Plan (RPJMN) explicitly emphasizes improving rural food systems and strengthening women's participation in agricultural decision-making. By integrating empowerment and food security into one analytical framework, this study provides localized evidence to support these policy priorities. Such alignment reinforces the relevance of the LWEAI as both a diagnostic and strategic tool for achieving national food resilience targets.

Such measures align with Sustainable Development Goals (SDGs) on zero hunger (SDG 2) and gender equality (SDG 5), fostering resilient rural livelihoods. Future research should explore the longitudinal impacts of LWEAI-informed interventions and test its adaptability in diverse agroecological settings. By centering women's voices in food systems governance, this work charts a pathway toward equitable and sustainable rural development.

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Lili Winarti

Darwan Ali University, Indonesia

Jl Batu Berlian Kotawaringin Timur, Central Kalimantan 74312, Indonesia

E-mail: liliwinarti14@gmail.com

She holds a Bachelor's degree in Agriculture (Indonesia) and a Master's degree in Agricultural Economics (Indonesia). Her research focuses on women's empowerment and gender issues in rural and agricultural development. Her academic interests include community empowerment, gender equality in agribusiness, and the socio-economic dynamics of smallholder farmers. She has been actively involved in collaborative projects and community service programs promoting inclusive rural development and sustainable livelihoods.

Rokhman Permadi

Darwan Ali University, Indonesia

Jl Batu Berlian Kotawaringin Timur, Central Kalimantan 74312, Indonesia

E-mail: rokhmanpermadi@gmail.com

He holds a Master's degree in Agricultural Economics (Indonesia) and a Doctorate in Agricultural Science (Indonesia) with a research focus on agricultural product marketing. His current research interests include market access for smallholder farmers, collective action, managerial capacity, digital inclusion, gender empowerment, and household food security.

Maswadi

Tanjungpura University, Indonesia

Jl Prof Hadari Nawawi Pontianak, West Kalimantan 78124, Indonesia

Email: maswadi@faperta.untan.ac.id

He holds Bachelor's degree in Social Economic in Agriculture (Indonesia), a Master's degree in Agricultural Economic (Indonesia) and a Doctorate in Agricultural Economics (Indonesia) with a research focus on Supply chain and value chain management sustainable, green marketing, green agriculture, sustainable food economics. His current research interest include gender community empowerment and household food security, and sdgs village.



Empowering Agriculture: A Comprehensive Study of LGU Initiatives for Vegetable Farmers in Cebu, Philippines Amidst COVID-19

Rosalyn P. Alburo^a, Hemres M. Alburo^a, Lorelie Q. Escabal^b,
Roberto C. Cutillar^a, Tylo Junior L. van Steenhuyse^{*,a},
Anesito L. Cutillas^a

^a Cebu Technological University – Argao Campus, Philippines

^b Cebu Technological University – Barili Campus, Philippines

Abstract

This study explores the initiatives of Local Government Units (LGUs) in Cebu, Philippines, to support vegetable farmers during the COVID-19 pandemic. Through a mixed-methods approach, we assess the effectiveness of policies, financial aid, and capacity-building programs in enhancing agricultural resilience. Key findings highlight the role of LGU-driven innovations in mitigating economic disruptions and improving food security. Challenges such as resource limitations and policy gaps are also examined. The study underscores the need for sustainable, adaptive strategies to strengthen local agricultural systems against future crises.

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* *Corresponding author:* Tylo Junior L. van Steenhuyse - Biodiversity, Environment and Natural Resources Research Center (BENRC), Cebu Technological University - Argao Campus, Philippines. E-mail: benrc.argao@ctu.edu.ph.

Introduction

The COVID-19 pandemic has severely affected the global economy, and the agricultural sector is not exempted from its impact (Barichello, 2020; Nicola *et al.*, 2020; Kumar *et al.*, 2021). Farmers have encountered numerous challenges in marketing their products due to the restrictions and limitations imposed by the government to contain the spread of the virus (Workie *et al.*, 2020; Barman *et al.*, 2021). According to Brodeu *et al.* (2020), the pandemic triggered significant changes in economics, regional and global policies, social behavior, and citizens' mentalities.

Accordingly, the COVID-19 pandemic has been primarily triggered by population density (Kang *et al.*, 2020), the high degree of mobility of humans, mass socialization, and cultural, social, and tourism events (Praharaj *et al.*, 2020 and McCloskey *et al.*, 2020). The measures taken by most world states (governments) have addressed issues such as quarantine and isolation, more precisely, the enforced social isolation of the population along with the economic isolation between various states or regions as well as between different economic sectors (Diele-Viegas *et al.*, 2020). The lockdown has impeded the interactions among food systems incorporating every stage of food production and delivery (Butu *et al.*, 2020).

The agricultural sector is one of the most critical sectors of the Philippine economy, contributing significantly to the country's Gross Domestic Product (GDP) and providing livelihood to millions of Filipinos (Mopera, 2016). In 2020, the country's agriculture sector grew by 1.5 percent, despite the challenges posed by the pandemic (Rasul *et al.*, 2021). However, the sector's growth was not evenly distributed, with some sub-sectors experiencing declining production and marketing activities. One of the subsectors significantly affected by the pandemic is the vegetable industry, particularly those produced locally (Pan *et al.*, 2020; Apostolopoulos *et al.*, 2021). The strict implementation of quarantine protocols has resulted in the temporary closure of some markets, causing farmers to incur significant losses due to the inability to sell their produce (Weersink *et al.*, 2021; Rasul *et al.*, 2021). The pandemic has also limited the transportation of agricultural products, resulting in a lack of access to markets, and high transportation costs have further exacerbated the situation (Kumar *et al.*, 2021).

Local Government Units (LGUs) in the Philippines have three levels, namely Provincial LGU, City/Municipal LGU, and *Barangay* (village, smallest Filipino political unit) LGU, which are all under the supervision of the Department of Interior and Local Government (DILG). There are three main study sites for this study: Alcoy, Dalaguete, and Cebu City. The municipalities of Alcoy and Dalaguete are under the Cebu province; however, Cebu City is not because it is an independent city. Under the

Local Government Code of the Philippines also known as Republic Act 7160 of 1991, the Department of Agriculture (DA) together with some other government offices were devolved to the local governments. Hence, the provincial, city, and municipal LGUs have their own local agriculture office, which assists local officials in the delivery of services to the farmers.

In response to the pandemic's impact on the agricultural sector, various LGUs have implemented initiatives to assist farmers in marketing their products effectively. These initiatives include establishing direct links between farmers and consumers, facilitating the delivery of agricultural products, and providing financial assistance to farmers (Gregorioa & Ancog, 2020; Blay-Palmer *et al.*, 2021). For instance, the Department of Agriculture (DA) of the Philippines issued Memorandum Circular 9 on extending the imposition of unhampered movement of all cargoes, agriculture and fishery inputs, food products, and agribusiness personnel nationwide, especially those coming from Visayas and Mindanao to Luzon, and vice versa in response to President Rodrigo Duterte's declaration of a national state of calamity (DA-AFID, 2020; Kampman *et al.*, 2021). Consequently, the President of the Philippines signed a bill 23rd day of March 2020 on Bayanihan to Heal as One Act (RA11469) to allow local government units to access their calamity funds and purchase fresh rice directly from farmers (in some cases, at a higher price than would be found at the market).

The LGUs' response to the pandemic's impact on the agricultural sector is crucial. The industry employs a significant portion of the population and is an important food source for Filipinos (Dickella Gamaralalage *et al.*, 2020). In the province of Cebu, several LGUs have implemented strategies and practices to assist farmers in marketing their produce, ensuring their survival during the pandemic. Moreover, the Cebu Provincial Government initiated several programs to help farmers during the pandemic, such as the "Food Resiliency Program." This program aimed to provide food for residents during the pandemic while supporting local farmers. The program includes establishing "*KADIWA ni Ani at Kita*" outlets (literally "*KADIWA* of Harvest and Income"; *KADIWA* is an acronym of *Kabataang may Diwang Wagas* – literally "Youth with Noble Intent" – and is also a Filipino word for "fellow of the same purpose or thinking" or "one idea, one thought"), directly linking farmers to consumers by providing a venue to sell their produce (Quintana *et al.*, 2021). The Alcoy Municipal Government has also initiated the "Buy Local, Eat Local" program, which promotes the consumption of locally produced agricultural products. This program includes establishing an online platform where farmers can directly sell their products to consumers, eliminating the need for intermediaries.

While these initiatives have been successful in assisting farmers in marketing their produce during the pandemic, there is a need to assess

their effectiveness and identify best practices. This research aims to provide insights into the strategies and techniques LGUs use to assist farmers in marketing their produce during the pandemic. Specifically, this research seeks to identify the marketing strategies adopted and used by farmers and middlemen or resellers to sell their products during the pandemic, assess the effectiveness of the marketing strategies adopted and used by farmers and middlemen/resellers to market their products, and document and assess the best practices in terms of LGU assistance in agricultural marketing during the pandemic.

1. Background

Study Sites

The project was conducted in three selected areas: Nug-as, Alcoy, Mantalongon, Dalaguete, and Sudlon, Cebu City. Most cabbages, pechay, and spring onions are produced in these areas. Likewise, interviews of middlemen/resellers and consumers will be conducted in 15 randomly selected cities/municipalities of the province.

According to the Philippine Statistics Authority, the total production of major vegetables and root crops for the 2024 first semester in the province of Cebu was recorded at 18,426.75 metric tons. This is a 9.73% increase compared to the previous year, with vegetables such as cabbage experiencing a 150.67% increase from the previous year. Overall, vegetable and root crop production in the province of Cebu accounts for 23.08% of volume of production of other crops (PSA, 2024). The three aforementioned areas are among the largest vegetable producing areas in the province of Cebu, making these locations ideal study sites for this paper.

Nug-as, Alcoy

Nug-as is a *barangay* in the municipality of Alcoy, located approximately 105 km southeast of Cebu City. The *barangay* has a vegetable landing area with market days every Tuesday, Wednesday, Friday, and Saturday. While Nug-as hosts the largest patch of natural forest in Cebu, it also has farm areas planted with cabbage, pechay, and spring onions, among other vegetables. Similar crops are also grown in its surrounding *barangays*. Before the pandemic, middlemen from Dumaguete City and other places in Negros regularly came to Nug-as to buy in bulk vegetables since it became a little cheaper than if they buy their supplies in Cebu City plus, it is also more convenient for them to transport at a shorter distance via the ports of Bato

(Samboan, Cebu) to Tampi (Negros Oriental) and Tangil (Dumanjug, Cebu) to Guihulngan City (Negros Oriental).

Mantalongon, Dalaguete

Mantalongon (Dalaguete) is probably one of the most known places in the mountain *barangays* of Cebu. It is known as Cebu's summer capital and vegetable basket because of its cooler environment. The area is about 700 meters above sea level and is about 95 km southeast of Cebu City. Dalaguete and Alcoy are adjacent municipalities, and Mantalongon and Nug-as are less than 10 km away. For many years, truckloads of vegetables have been hauled from Mantalongon daily and brought to Cebu City's Carbon Market, where vegetables are redistributed to supermarkets, various municipalities, and even in the provinces of Leyte, Negros Oriental, Bohol, and other small islands. Lately, traders from Negros also directly come to the area to buy bulk volumes of vegetables, similar to what is happening in Nug-as. Cabbage, pechay, and spring onions are commonly produced in Mantalongon and neighboring *barangays*.

Sudlon, Cebu City

Sudlon is one of the many *barangays* in the mountains of Cebu City. It is also known for growing vegetables. Among the crops they grow are cabbage, pechay, and spring onions, although not as much as those produced in Nug-as and Mantalongon.

2. Materials and methods

Research Design & Participant Selection

This study employed a qualitative research design with a mixed-methods approach to document and assess the best practices of Local Government Units (LGUs) in supporting agricultural marketing during the COVID-19 pandemic. The primary data collection method was Key Informant Interviews (KIIs) conducted with people who were directly involved in the planning and execution of agricultural assistance programs. Primary respondents for KIIs included provincial, city/municipal, and *barangay* officials. Respondents at the provincial level include the governor or his/her representative, the provincial agriculturist (one from LGU and the other from the Department of Agriculture) and the chairman of the Agriculture Committee at the Provincial Board. Representatives from cities/municipalities

include the city/municipal mayor or his/her representative, the city/municipal agriculturist, committee chair on agriculture at the city/municipal council, market administrator and representative from the Philippine National Police. Lastly, the *barangay* captain, committee chair on agriculture at the *barangay* council and a *tanod* (*barangay*-level law enforcement officer) representative will also represent the *barangay*. In addition to KIIs, several Focus Group Discussions (FGDs) and supplementary interviews were conducted with other LGU personnel to validate and expand on the insights gathered from the primary informants. Notably, the responses from these additional participants were largely consistent with those provided by the key informants, further supporting the reliability of the information obtained.

The interviews were conducted without a formal, structured questionnaire. Instead, the conversations were guided by a single, central research objective: to document and assess the best practices implemented by LGUs to ensure effective agricultural marketing for farmers during the pandemic despite movement and market restrictions. Interviewers were instructed to focus discussions around actual LGU-led marketing interventions and their perceived effectiveness, allowing respondents to freely share relevant experiences and insights. This flexible approach enabled the collection of detailed, context-specific narratives that reflected the unique strategies and conditions of each locality.

FGD allow researchers to gain insights into the extent of agreement between participants (Barbour, 2018; Morgan & Krueger, 1993). This method helps understand not just individual views but also how those views converge or diverge within a group, providing a richer understanding of collective perspectives. It also compels participants to articulate and justify their perspectives to each other (Geampana *et al.*, 2024; Morgan, 1996, 2018). This interactive nature makes researchers characterize them as “active social experiments” where the dynamics of power become apparent through the participants’ interactions (Geampana *et al.*, 2024; Demant, 2012). On the other hand, KIIs are particularly strong at capturing the surrounding context and subtle details of a topic, as highlighted by GeoPoll (2024). They delve deeper into “why” and “how” trends emerge, moving beyond surface-level observations. Similarly, Brown (2021) notes that KIIs offer extra insight, either by building on survey data or by enriching existing literature on a subject.

FGDs and KIIs were employed to gather insights from Local Government Units (LGUs). Notably, a principle of voluntary participation was maintained, thereby refraining from coercion for respondents unwilling to participate in the study. The FGD method facilitated data collection at the *barangay* level, while the KII method was employed to gather insights from stakeholders at the municipal/city and provincial levels. Participants in the FGD sessions

included the *barangay* captain, councilors, and other key officials, collectively engaging in discussions that lasted approximately 45 minutes per session. Notably, a single session was conducted per *barangay* to ensure data quality.

In line with enhancing the robustness of the research, the triangulation method proposed by Carter *et al.* (2014) was implemented. This entailed conducting interviews with vegetable farmers and traders from Nugas, Mantalongon, and Sudlon, which served to validate and augment the data garnered from FGD and KII methodologies (Lambert *et al.*, 2008). Furthermore, all interactions adhered to the minimum health protocols stipulated by the Inter-Agency Task Force (IATF). In addition, the flexibility of online discussions was extended to respondents if deemed preferable.

Data Analysis

All interviews and focus group discussions were recorded then transcribed and reviewed to identify common themes and patterns. The research team used thematic analysis to interpret the qualitative data, focusing on the key areas outlined in the study's objective, specifically, the types of interventions provided by LGUs and their perceived effectiveness. Responses were grouped according to the level of LGU (provincial, municipal/city, and *barangay*), and recurring practices and strategies were identified. The team also took note of unique or innovative approaches mentioned by specific LGUs. These insights were then synthesized to form the narrative findings presented in the results and discussion sections.

Theoretical Framework

This study is anchored in the Developmental State perspective, a theory which posits that government institutions, when properly motivated and equipped, play a proactive role in shaping economic development and market outcomes (Woo-Cummings, 1999). Traditionally associated with East Asian economic growth models, this perspective highlights the importance of state-led coordination in mobilizing resources, guiding investment, and correcting market failures. Rather than leaving development solely to market forces or private actors, the developmental state actively intervenes to steer sectors of national interest, especially agriculture and industry, toward long-term transformation.

In the Philippine context, this perspective is applied at the subnational level by examining how Local Government Units (LGUs) function as decentralized instruments of the national government. Under the Local Government Code of 1991, LGUs are granted fiscal and administrative

autonomy to implement locally responsive programs. Within the framework of a developmental state, LGUs have the potential to act as agents of rural transformation, particularly during crises such as the COVID-19 pandemic, when national systems are strained, and localized innovation becomes necessary.

However, consistent with critiques of decentralization and adaptive governance (Turner *et al.*, 2013), this study also recognizes the institutional constraints that LGUs face. These include uneven capacity, limited coordination with national agencies, and short-term project funding, all of which may hinder their ability to consistently deliver developmental outcomes. The study uses this framework to assess not only the LGUs' interventions but also the structural and institutional enablers and barriers that affect their ability to fulfill a developmental role in agricultural marketing and support.

Analytical Framework

This study follows the analytical framework presented in Figure 1 below which focuses on evaluating LGU interventions in the context of local agriculture, specifically vegetable production and marketing. The framework analyzes interventions at different administrative levels, including provincial, municipal, and *barangay* levels, and assesses their effects on various aspects such as value chains and gender roles.

Figure 1 - Analytical Framework

LGU	Approach	Context/ Circumstances	Effect/Impact
Provincial Level Municipal Level Barangay Level	• Direct interventions (market day) • Indirect interventions • Characterization of the various approaches • Role of men and women in the production and marketing of vegetables	Examination of local conditions as well as dynamics which led to the choice of the approach	Value Chain • Production • Processing • Distribution • Marketing • Consumption Gender and Development Roles

Approaches and Context

LGU interventions can be categorized into direct interventions, such as organizing market days, and indirect interventions, which may involve policy changes or capacity building (Chandra *et al.*, 2017). These interventions are influenced by the local conditions and dynamics of each area, with the choice of approach often shaped by the challenges and opportunities present (Dayamba *et al.*, 2018). On the other hand, LGUs must build strong partnerships with Civil Society Organizations (CSOs) and Non-Governmental Organizations (NGOs) to effectively implement programs and services. Passing local ordinances is also essential to ensure the long-term sustainability of community development initiatives (Sanjorjo, 2025).

Effect and Impact

The impacts of LGU interventions are evaluated across the entire value chain of vegetable production and marketing, encompassing production, processing, distribution, marketing, and consumption (Maghirang *et al.*, 2011). By examining each stage of the value chain, the framework aims to assess the effectiveness of interventions in enhancing market access and improving overall efficiency.

Gender and Roles Development

The analytical framework places a significant emphasis on gender roles within the context of agriculture. It investigates how LGU interventions influence gender roles and whether they contribute to more equitable participation of men and women in various stages of the value chain (Behrman *et al.*, 2014). The framework recognizes the potential for interventions to impact on women's empowerment, decision-making, and access to resources, ultimately shaping the dynamics of gender roles.

Study Limitations

This study offers valuable insights into the best practices implemented by LGUs to support agricultural marketing during the COVID-19 pandemic. However, several methodological and design limitations must be acknowledged. The qualitative nature of the research means that findings are context-specific and cannot be generalized across all LGUs or agricultural settings in the Philippines. The absence of quantitative measures or standardized evaluation indicators may also limit the ability to compare results across different sites or with other studies. Additionally, the absence

of a structured interview protocol may have limited consistency in the depth and scope of data collected across different respondents and locations. While the unstructured approach allowed flexibility and responsiveness to local context, it may have introduced variation in how questions were interpreted or discussed. Despite these limitations, the study contributes to a deeper understanding of local governance strategies in times of crisis and offers a practical basis for future research and policy interventions.

3. Results

Issuance of Quarantine Pass

The travel restrictions implemented due to the coronavirus have paralyzed the movement of people including the goods from the point sources to the market. These restrictions resulted in disruptions in the transport of goods in the market, thereby resulting in a distorted marketing channel. The worst affected were perishable farm products like vegetables, which led to huge losses on the part of the farmers. The lack of a market discouraged farmers from harvesting their vegetables. Vegetables were often left to overmatured and eventually rot on the farm or not being taken care of as fertilizer and chemical applications will only add to their production costs and eventually losses. To alleviate the situation, local government units initiated actions to assist their farmers. The issuance of quarantine passes was done at all levels of the LGU. It was commonly practiced that in a household, only one member is allowed to go out to buy their needs. Moreover, in support of those involved in transporting commercial goods including the transport of vegetables, a quarantine pass is also issued. Provinces, highly urbanized cities, and independent component cities have their travel policies (Orozco *et al.*, 2023).

There was coordination between LGUs in the province where usually the municipalities along the route, usually from Mantalongon, Nug-as, and Sudlon vegetable dealers were allowed to pass entry in every town before reaching Cebu City to bring farm produce and on returning home. However, travel was not convenient because everyone had to adhere to the required protocols. Nevertheless, the issuance of travel passes helped greatly in the transport of vegetables from the farms to the market.

Moreover, in Cebu, Philippines, public behavior on traveling during the height of the pandemic changed into something that is driven to buy goods that are essential for the households (Mayo *et al.*, 2021). This behavior could be influenced by fears of contracting the virus. To help mitigate these problems, Local Government Unit (LGU) from the *barangay*, municipal, and regional levels have initiated various interventions.

A. Barangay Interventions

Mantalongon, Dalaguete

Proactive interventions were undertaken at the *barangay* (village, smallest Filipino political unit) level to address the challenges posed by the pandemic. Engr. Expeditas Lenares, head of the Municipal Agricultural and Natural Resources of Dalaguete Cebu, highlighted that innovative approaches were implemented to support both local farmers and residents. One notable initiative involved the creation of food delivery programs, mirroring those at the municipal level. This strategy aimed to avoid overcrowding in markets and facilitate convenient access to essential commodities for residents. Local farmers played a crucial role, as their produce was purchased and combined with essential goods, forming the core of these food packages. Rolling stores were set up in various *barangays*, providing a mobile distribution network that was communicated through both the Municipal Facebook (FB) page and *barangay* councils. This approach effectively promoted farmers' products, supported local businesses, and ensured that residents could access essential goods while adhering to safety measures.

Additionally, the *barangay* level also witnessed the establishment of community-oriented initiatives. An example is the community pantry organized by the *Sangguniang Kabataan* (SK) council (youth council representing the youth in a *barangay* or village) in Mantalongon, Dalaguete. This program aimed to distribute nutritious vegetables to residents, emphasizing the significance of healthy food during challenging times. The initiative was funded through donations, which were utilized to purchase vegetables directly from farmers. These vegetables were then distributed to different areas, fostering a sense of collective support and collaboration among community members. This approach not only assisted farmers in selling their produce but also attracted buyers from other regions, generating a positive impact on local agricultural trade.

Furthermore, marketing assistance programs were implemented at the *barangay* level as well, showcasing collaborative efforts between various government organizations. These programs aimed to empower farmers by facilitating direct orders and bulk purchases of their produce. For instance, partnerships were forged to enable the procurement of vegetables from farmers for distribution to high-risk areas such as hospitals and jails. These strategic alliances encouraged farmers to join organizations and register their products, thereby expanding their market reach and creating a more resilient marketing ecosystem. The utilization of social media like Facebook and YouTube platforms played a pivotal role in announcing these programs, reflecting the adaptability of the *barangay* councils in swiftly addressing the challenges brought about by the pandemic.

Nug-as, Alcoy

Mayor Sestoso and the Head of the Municipal Agriculture Office (MAO) emphasized the municipality's effective coordination with *barangays* to navigate the challenges of marketing vegetables during the pandemic. Recognizing that local produce met demand, the municipality capitalized on the strong role of *barangays* in facilitating adaptation. Despite the relatively minor challenges faced by farmers, proactive measures were put in place to ensure a seamless agricultural ecosystem.

Notably, certain *barangays*, such as Nug-as, experienced an oversupply of vegetables. In response, the LGU harnessed the *barangays*' potential by inviting traders to engage with surplus produce. This collaborative effort saw the MAO and the mayor coordinating with traders to streamline the purchase process. Additionally, recognizing the vital role of traders, the issuance of the Department of Agriculture (DA) passes by *barangays* alleviated logistical bottlenecks, ensuring efficient movement of goods and a balanced market.

Moreover, *barangays* played a significant role in safeguarding farmers' interests. The LGU, working in conjunction with the MAO, extended insurance coverage to protect the plant commodities of local farmers. This proactive measure highlighted the *barangays*' commitment to promoting the well-being of their agricultural communities.

Sudlon, Cebu City

Amidst the pandemic, the central Carbon Market, which served as the main hub for vegetable trading across many municipalities in the Province of Cebu, underwent temporary closure. This disruption reverberated through the local vegetable supply chain, causing impediments in selling and purchasing transactions. Sudlon I, Cebu City, faced an oversupply of vegetables, compelling farmers to lower prices due to diminished demand. With establishments shuttered and middlemen restrained by travel limitations, selling permits, and border passes, the ability of middlemen or vegetable traders to procure vegetables from Sudlon I was curtailed. In response, the Local Government Unit (LGU) of Sudlon I partnered with the City Agriculturist to mitigate this situation.

To counteract these challenges, the Sudlon I LGU initiated several interventions. The City Hall provided complimentary transportation services, enabling farmers to transport their produce from farms to the city center. The City Agriculturist assumed the role of selling these commodities and disbursing payments directly to farmers at equitable rates. This marked a departure from the pre-pandemic landscape, where middlemen dictated prices under the *Pakyaw* system – a wholesale model involving negotiated

bulk purchases from farmers. However, this arrangement encountered setbacks due to the aftermath of typhoon Odette, leading to crop spoilage.

To navigate these complex circumstances, concerted efforts emerged. The National Irrigation Administration (NIA) and the Municipal Agricultural Office (MAO) of Cebu City joined forces with diverse organizations and institutions as potential consumers of agricultural produce. This partnership paved the way for farmers from Sudlon I to supply vegetables to these agencies, diversifying their markets. Meanwhile, in Sudlon II, farmers encountered distribution challenges. Collaborating with business traders in Cebu City, the LGU of Sudlon II enabled direct purchases from farmers, bolstered by a simple *barangay* certification requirement to cross the Sudlon II border. This proactive step catalyzed direct trade between farmers and vegetable traders from other regions.

Furthermore, the LGU adopted a flexible approach to sales regulations. Farmers were permitted to vend their produce anywhere, subject to adherence to guidelines stipulated by the IATF. This pragmatic approach facilitated trade while maintaining compliance with safety protocols. Ultimately, these multifaceted interventions alleviated marketing difficulties, showcasing the adaptability and collaboration of local governments and stakeholders in navigating unprecedented challenges.

B. Municipality/City Interventions

The different local government intervention programs at the municipal level were gathered through Focus Group Discussions (FGD) and Key Informant Interviews (KII) with various municipal government officials and personnel. It was observed that farmers in the different municipalities had no awareness on the different government interventions implemented during the duration of the pandemic. Most marketing interventions conducted at the municipal-level involved delivery/transportation of farm produce, marketing assistance, bulk purchases of vegetables farmed, and regulating prices.

Despite these efforts, very few farmers noticed any marketing interventions done by the municipal government. Each municipality had differing interventions during the pandemic, with some municipalities claiming that their localities had minimal marketing problems during this period. The intervention programs implemented by municipality are explored further below.

Dalaguete

The Municipality of Dalaguete had different intervention programs that were implemented during the pandemic. During the pandemic, mobility was

severely restricted through the various guidelines and protocols implemented by the government, which resulted in farmers having difficulties in marketing their perishable commodities. To address this, the Municipality of Dalaguete implemented intervention programs aimed at providing marketing/promotional assistance, bulk purchasing of farm produce, and logistical assistance during the transport of these goods. Details of the intervention programs implemented by the Municipality of Dalaguete are shown below:

a) Rolling Store – A food delivery intervention initiated by the LGU to prevent the influx of people in the market and, at the same time help people purchase basic commodities. The intervention was implemented through close coordination with the Municipal Agriculture Office, Municipal Mayor, and the DSWD Procurement Department. In this program, the LGU purchased vegetables to farmers paired with basic commodities. Meanwhile, the LGU also invited business sectors to participate in the program. The program started during the height of the pandemic, with the schedule of visits being posted through the Municipal Facebook page or communicated to the *barangay* captain/council. At this point, the *barangay* council took over the planning as to where the rolling store will be situated for easy access of the residents in each *barangay*. Overall, 33 *barangays* were visited by the program and the program lasted for a year. The interview revealed that the farm products of farmers were sold with less hassle and paved the way for the business sectors to earn money. Additionally, the program helped residents in purchasing basic commodities during the pandemic.

b) Community Pantry/Barter System – a food bank or food service that provides aid to residents in the municipality by giving nutritious foods, specifically vegetables and binding people through giving and donating what they have. The program was initiated and led by the *Sangguniang Kabataan* (SK) council (youth council representing the youth in a *barangay* or village) in Mantalongon, Dalaguete, Cebu. The program was conducted through donations, which was used to purchase vegetables from the farmers. The purchased vegetables were then distributed to coastal areas and bartered with other basic commodities such as rice, noodles, and canned goods. The bartered products were then given to the farmers. The farmers were happy that their vegetables were sold, even though the sales were not enough to cover the production cost.

c) Online Promotion of Farm Products – The SK youth council initiated this program and was done by encouraging buyers from all other places to buy the farmers' produce. The SK council collaborated with the Cebu City Organization youth partners to help buy vegetables from farmers. The vegetables were then transported through the commissioner or to designated drop off points. The program was noted to have reduced the marketing problem.

d) *KADIWA* – *KADIWA* is an acronym of *Kabataang may Diwang Wagas* (literally “Youth with Noble Intent”) and is also a Filipino word for “fellow of the same purpose or thinking”, or “one idea, one thought” which is in consonance with the Department of Agriculture Secretary’s “New Thinking” for Agriculture paradigm. The marketing intervention titled “*KADIWA*” is a program developed in partnership with the Municipal Agriculture Office, Provincial Agriculture, and Department of Agriculture. Its primary objective is to assist farmers in marketing their farm produce during the pandemic. Under the *KADIWA* program, the Department of Agriculture directly places orders for vegetables from the farmers, working in coordination with the Municipal Agriculture Office. The program gives priority to farmers who are active members of the organization, followed by those who are not members. The purchase of vegetables is conducted once a week, providing a regular marketing opportunity for farmers. Through this program, farmers are able to sell their produce and generate income, despite the challenges brought about by the pandemic. Additionally, the *KADIWA* program also serves as a platform to encourage farmers to register or join the organization of farmers. By doing so, they can avail themselves of the benefits and support provided by the organization, further enhancing their marketing opportunities and access to resources. Overall, the *KADIWA* program plays a crucial role in facilitating the marketing process for farmers, ensuring a steady market for their produce and promoting the development of farmer organizations. This intervention supports the agricultural sector, enabling farmers to sustain their livelihoods and contribute to the local food supply chain during the pandemic.

e) Bulk Purchase of Vegetables (Provincial Capitol and Municipality of Dalaguete) – The marketing intervention involved the municipality of Dalaguete and the Provincial Capitol purchasing vegetables in bulk and distributing them to areas with a high number of COVID-19 cases. The initiative was led by the mayor of Dalaguete. The municipality of Dalaguete bought vegetables in large quantities and donated them to places such as hospitals and the jails, which were dealing with the impacts of the pandemic. This action aimed to provide nutritious food to those in need and support the healthcare system in their efforts to combat COVID-19. Similarly, the Provincial Capitol bought all the vegetables at the Mantalongon Public Market and distributed them to other municipalities. Instead of letting the vegetables go to waste or rot in the farms, they were sold to benefit other people. This approach not only prevented food waste but also allowed others to access fresh vegetables that they may have had difficulty obtaining otherwise. Overall, this marketing intervention focused on purchasing vegetables in bulk, donating them to areas with high COVID-19 cases, and distributing them to other municipalities. By doing so, it addressed the needs

of vulnerable populations, supported healthcare facilities, prevented food waste, and provided a benefit to the community.

f) *Kompra on Wheels* – *Kompra* is a Cebuano (language/dialect spoken in Cebu) term which means “to buy in bulk” or “purchase”. The marketing intervention was a community service program initiated by the SK Council in Mantalongon, Dalaguete. The primary objective of this program was to provide voluntary assistance to individuals and families in the community by purchasing necessities for them during the height of the pandemic. To spread the word about the program, the SK Council in Mantalongon utilized social media, particularly their Facebook page, to announce and promote it. They encouraged people to reach out and place orders for the commodities they needed. The SK Council members then volunteered to do the grocery shopping on behalf of the individuals or families and delivered the ordered items to them. By implementing the program, the SK Council in Mantalongon alleviated the concerns and worries of people in purchasing goods for their daily needs. The program provided a convenient and safe solution for individuals who may have been hesitant or unable to go out during the pandemic.

Alcoy

Interviews with the Mayor and the Municipal Agricultural Officer (MAO) revealed that there were no significant marketing problems within the municipality during the pandemic as the local produce was sufficient to meet demand. However, in response to the minimal issues faced by farmers during the COVID-19 pandemic, the municipality implemented simple programs to adapt. There were reports of oversupply of vegetables in Nug-as, but the LGU addressed this by inviting traders to purchase the produce through the coordination of MAO or the mayor and by issuing DA passes to alleviate the burden on the traders. Additionally, the LGU worked with MAO to provide insurance coverage for the plant commodities of the farmers. Details on the intervention programs in Alcoy can be seen below:

a) *DA Pass Issuance/Contact Traders from Neighboring Areas* – The intervention involved the issuance of DA (Department of Agriculture) passes to traders from neighboring places at the municipal hall. These passes served as permits or gateways for the traders to travel to Nug-as, where they could purchase vegetables. The objective of this intervention was to address marketing problems related to vegetables while also providing traders with an opportunity to engage in vegetable trade during that time. By issuing the DA passes, the Municipal Mayor enabled traders from neighboring areas to access Nug-as, where vegetables were likely produced abundantly. This intervention helped to alleviate marketing challenges by facilitating

the movement of traders and creating a more efficient supply chain for vegetables. By allowing traders to purchase vegetables directly from Nugas, the intervention likely reduced transportation costs and improved market access for both traders and vegetable producers.

b) Insurance Assistance for Farmers – The intervention program was initiated by the Municipal Agriculture Office (MAO). The primary objective of this intervention was to provide insurance assistance to farmers who experienced losses in their agricultural products due to decreased marketing opportunities. When farmers reported their losses to the MAO, the office would automatically process their insurance claims. This means that farmers who suffered from reduced marketing for their agricultural products could receive compensation through insurance coverage. The intervention aimed to mitigate the financial burden faced by farmers when their products were unable to reach the market as expected. By providing insurance assistance, the MAO sought to protect farmers against potential losses and provide them with some financial support during difficult times.

Cebu City

During the pandemic, Carbon Market, which is the primary market for vegetables in many municipalities in the Province of Cebu, was temporarily closed, resulting in disruptions in vegetable selling and purchasing transactions. This led to an oversupply of vegetables in Sudlon I, Cebu City, and farmers forced to sell their produce at lower prices due to low demand. Most establishments were closed, and middlemen or vegetable traders were unable to purchase vegetables in Sudlon I due to travel restrictions, selling permits, and border passes. To address this situation, the Local Government Unit of Sudlon I sought the assistance of the City Agriculturist in distributing the farmers' produce.

Furthermore, the City Hall provided free transportation for the farmers to transport their commodities from the farm to the city hall. The City Agriculturist oversaw selling the commodities and paying the farmers in cash at a fair price. This was different from the pre-pandemic period when middlemen set the vegetable prices, and farmers had no control over them since the purchasing system in Sudlon was *Pakyaw* – a Cebuano term that means a type of wholesale purchasing system where a group of buyers purchases goods in bulk from suppliers, usually farmers, at a negotiated price. However, the marketing arrangement between farmers and the City Agriculturist was halted due to the damage caused by typhoon Odette, leading to the spoilage of vegetables. To address these challenges, the National Irrigation Administration (NIA) and Municipal Agricultural Office (MAO) of Cebu City collaborated with other organizations and institutions

as potential consumers of agricultural produce. The farmers from Sudlon I will supply vegetables to these agencies. Additionally, farmers in Sudlon II, Cebu City encountered significant marketing challenges due to distribution issues. To solve this problem, the Local Government Unit (LGU) partnered with business traders in Cebu City to purchase vegetables directly from the farmers. Only a *barangay* certification is required to enter the Sudlon II border. This initiative has led to vegetable traders from Talisay, Minglanilla, and other areas in northern Cebu buying produce directly from the farmers. Furthermore, the LGU allowed farmers to sell their produce anywhere, if they adhered to the regulations set by the IATF. This measure has helped alleviate the marketing difficulties faced by the farmers. Further details of the intervention programs are shown below:

a) Community Pantries – The intervention is an initiative established and led by private agencies, cooperatives, and foundations in Cebu City. The objective of these community pantries is to provide food items to people in need during the pandemic. The City Agriculture Office played a crucial role in connecting farmers with these cooperating agencies, foundations, and cooperatives to facilitate the marketing and distribution of farm produce. Farmers were able to transport their produce within their area, and the vegetables were already packed at the farm site. Each pack consisted of assorted vegetables that were ready for pick-up. The city government's vehicles also assisted in transporting the farm produce from the farmers to the participating agencies and foundations involved in the community pantry initiative. This program not only helped farmers in marketing their farm produce but also generated some employment opportunities for residents within the farm site. By linking farmers to the community pantries, the initiative ensured that agricultural products were efficiently disposed of and marketed, while also addressing the food needs of the community. Overall, the program fostered collaboration between farmers, agencies, and foundations to provide essential food items to those in need during the pandemic.

b) Stand Display Program – The Farm Stand Display Program is an initiative recommended and initiated by the City Agricultural Office to provide alternative ways of marketing for farmers during the pandemic. Farmers set up makeshift stands along the road within their farming areas to display and sell their farm produce. The program is carried out in collaboration with the City Agriculture Office, which facilitates direct purchasing of vegetables from the farmers' stands by traders and potential buyers. To ensure fair pricing, the City Agriculture Office provides traders with a price list of vegetables upon purchase. The prices are based on suggested retail or wholesale prices for each vegetable. By directly connecting farmers with buyers, this program helps minimize the challenges

faced in agricultural marketing, providing a convenient and accessible platform for farmers to sell their produce. The program offers a practical solution for farmers to market their products and reduces the barriers they face during the pandemic. It promotes direct engagement between farmers and buyers, benefiting both parties and ensuring a smoother flow of agricultural products to the market.

c) Satellite Market – The program initiated by the local government unit (LGU) to provide convenience to residents in purchasing daily essentials and create opportunities for farmers to market their produce more easily and affordably. The LGU, in collaboration with the *barangay* council, designates specific areas or stations within each *barangay* as satellite markets. These satellite markets operate twice a week. The program invites and allows business sectors and farmers to participate. The LGU facilitates the transportation of agricultural products to the satellite markets by offering free transport using city vehicles as delivery trucks. This ensures that farmers can bring their produce to the markets without incurring additional expenses. The Satellite Market program was implemented during the height of the pandemic and continued until it became a normalized practice. It has proven beneficial to various stakeholders. Business sectors generated income during a challenging time, farmers were provided with a convenient platform to sell their produce, and consumers benefited from the accessibility of essential goods. Overall, the program has helped create a more efficient and accessible market for both farmers and consumers. It has played a vital role in supporting local businesses, promoting agricultural marketing, and ensuring that residents have convenient access to essential products.

d) Online Selling of Agricultural Products – The program is recommended by the City Agriculture office to assist farmers in marketing their produce despite movement restrictions during lockdown. The program began with the City Agriculture office showcasing farm products on their webpage, which attracted potential buyers and generated inquiries. Farmers were then advised to engage in online selling. The program involved not only farmers but also other business sectors. Motorcycle couriers or “riders for hire” were allowed to transport and deliver the ordered vegetables and other essential items. Additionally, the City Agriculture personnel volunteered to help farmers by purchasing farm inputs and materials on their behalf, providing this service free of charge. Technicians were responsible for purchasing the required materials and delivering them to the farmers upon receiving their requests through text or chat. This intervention allowed consumers to access fresh vegetables even during lockdowns, supported farmers in marketing their produce, and ensured that agricultural activities continued despite the challenges posed by the pandemic. The online platform facilitated the

connection between farmers and buyers, providing a convenient and efficient means of selling agricultural products.

e) Expanded Sure Aid Program – The marketing intervention is a joint initiative of the Department of Agriculture, specifically the Agricultural Credit and Policy Council, aimed at assisting farmers in recovering from the impact of the pandemic through a loan scheme. The program focuses on supporting small-scale farmers who are members of the Registry System for Basic Sectors in Agriculture (RSBSA), which is a registry of farmers, fisherfolk, and farm laborers that serves as a targeting mechanism for the identification of beneficiaries for different agriculture-related programs and services of the government. To participate in the program, farmers need to meet the eligibility criteria and undergo screening and validation by the City Agriculture Office. One of the key requirements is the submission of a farm plan. Qualified farmers can borrow up to PHP 25,000.00 with no collateral, zero interest, and a repayment period of 10 years. The funds provided through the program are released through financial institutions such as Landbank, COOP Bank, LAMAC, and People's Cooperative. This financial support aims to alleviate the losses experienced by farmers during the pandemic. The Expanded Sure Aid Program has played a crucial role in providing financial assistance to farmers, particularly those who have been adversely affected by the pandemic. By offering accessible and favorable loan terms, the program seeks to support farmers in their recovery efforts and enable them to sustain their agricultural activities despite the challenges they face.

Observing the findings from data on the municipal level revealed that there is a disparity in the awareness of government interventions among farmers, in the municipality of Dalaguete. Despite various municipal-level marketing interventions, only a small percentage of farmers (4.16%) acknowledged these efforts, with bulk purchases being the most recognized intervention. However, the “Rolling Store” initiative, coordinated with various local entities, successfully facilitated the purchase of vegetables from farmers, reducing hassles and ensuring access for residents. The “Community Pantry/ Barter System” organized by the SK council provided an innovative solution, creating a network for distributing nutritious vegetables while fostering community collaboration.

The “Online Promotion of Farm Products” and “KADIWA” program demonstrated Dalaguete's adaptability in utilizing digital platforms for marketing and building partnerships with higher-level agricultural organizations. The “Bulk Purchase of Vegetables” and “*Kompra* on Wheels” initiatives showcased the municipality's commitment to social responsibility, addressing both excess supply and the needs of vulnerable populations.

In Alcoy, where oversupply was reported in Nug-as, interventions were designed to connect traders with surplus produce. The issuance of

Department of Agriculture (DA) passes facilitated the movement of traders, alleviating marketing challenges and ensuring efficient supply chains. The “Insurance Assistance for Farmers” program, initiated by the Municipal Agriculture Office (MAO), demonstrated a proactive approach to mitigating losses faced by farmers during decreased marketing opportunities.

Cebu City faced challenges with the temporary closure of Carbon Market, leading to an oversupply of vegetables in Sudlon I. However, the collaboration between the Local Government Unit (LGU) and the City Agriculturist proved crucial. Free transportation services provided by the City Hall facilitated the transport of farmers’ produce, and direct selling to farmers ensured fair prices. The collaboration with the National Irrigation Administration (NIA) and other institutions diversified markets, allowing farmers from Sudlon I and II to supply vegetables to various agencies.

The “Community Pantries” initiative, although led by private agencies, showcased the active role of the City Agriculture Office in connecting farmers with cooperatives, ensuring efficient marketing and distribution of farm produce. The “Farm Stand Display Program,” “Satellite Market,” and “Online Selling of Agricultural Products” illustrated the city’s versatile approach, providing alternative platforms for farmers to directly engage with buyers, minimizing marketing challenges. The “Expanded Sure Aid Program” demonstrated the Department of Agriculture’s commitment to supporting small-scale farmers through favorable loan schemes, aiding in their recovery from pandemic-induced losses.

C. Provincial Interventions

In Cebu province, the government has implemented a range of interventions to address the challenges and struggles faced by the agricultural sector and the community. The province faced difficulties during the COVID-19 pandemic, including travel restrictions, decreased marketing opportunities, and disruptions in the food supply chain. In response, the government focused on empowering households to engage in agricultural activities, promoting self-sufficiency, and strengthening family ties. They provided financial support, infrastructure, and resources to encourage vegetable gardening and organic food production through the *SugBusog* Program. Additionally, they facilitated direct sales of agricultural products through initiatives like *KADIWA* on Wheels, minimizing intermediaries and ensuring market access for farmers. Financial assistance was also provided to farmers and other affected sectors through the Enhanced Countryside Development (ECD) Program. To ensure food security, they implemented the Bulk Purchase of Agricultural Products program, distributing vegetables

to institutions in need. Furthermore, the government facilitated the flow of essential goods and services by issuing food passes and coordinated the trading of goods through the *Bagsakan sa* South Bus Terminal program. Overall, these interventions aimed to empower the community, support farmers, promote economic growth, and ensure a stable food supply during challenging times. The details of each intervention program initiated at the provincial level are shown below:

a) *SugBusog* Program – *Sugbuanong Busog, Lawas, ug Himsog* (Cebuano phrase, literally “Cebuano Satiety in Body and Health”, often shortened to “*SugBusog*”) – a Vegetable Gardening Project of the Province of Cebu. This marketing intervention is a program initiated by the Provincial governor in collaboration with the Department of Agriculture, Provincial Agriculturist, and LGUs of every municipality and city in Cebu province. The program aims to provide families with the opportunity to engage in productive agricultural activities at home and produce their own food. The program was conceptualized during the Enhanced Community Quarantine to encourage households to stay productive and focus on cultivating their own food instead of dwelling on the increasing COVID-19 cases. Its main objectives are to inspire family members to engage in vegetable gardening, produce organic food in their backyards, and strengthen family ties. The program initially started with four participating households through the purok system, categorized into containerized and backyard gardening (Round 1). Due to its positive impact, it was expanded to the LGU and *Barangay* Level and extended to police stations (*SugBusog sa Istasyon*) and schools (*SugBusog sa Eskwelahan*) in Round 2. *Barangays* in each municipality are encouraged to join the program, and the provincial government provides financial support. Each *barangay* receives PHP 100,000.00, with 50% allocated for nursery construction and the remaining 50% for seeds and farm inputs. Additionally, each municipality is given PHP 1,000,000.00, with 50% for municipal nursery and 50% for seeds and farm inputs. The responsibility for the program lies with the *barangay* at the purok level, while the LGU oversees the household level. The program continues to evolve, and currently, the implementation of *SugBusog sa Ospital* (literally *SugBusog* at the Hospital) is being worked on as part of Round 3. To participate, households select five specific vegetables listed in the *SugBusog* program, and during evaluation, the planted vegetables should already bear fruit. Participants are required to document their activities through photos or videos, including land preparation, seedbed preparation, transplanting, fertilization, and other gardening activities until harvest. Incentive awards are given to participating LGUs and *puroks* (informal territorial subdivisions within a *barangay*) that demonstrate outstanding commitment, with winners determined based on set criteria and rubrics. The administration of awards is categorized at different

levels, with the *barangay* being responsible for the lowest level (*purok*), the LGU for the municipal level, and the provincial capitol for the district level. Overall, the *SugBusog* Program has successfully encouraged residents to engage in agriculture, promoting self-sufficiency and ensuring an adequate food supply for families during the pandemic.

b) Enhanced Countryside Development (ECD) Program – The marketing intervention titled “Enhanced Countryside Development (ECD) Program” is an initiative spearheaded by the Provincial governor with the aim of developing the countryside to benefit farmers, fishermen, and promote food security. The program focuses on providing loans to farmers and creating linkages between the agricultural sector and financial institutions. The major banks involved in the program, collectively known as “Lender Banks”, include Landbank of the Philippines, Development Bank of the Philippines, and Veterans Bank. A Memorandum of Agreement is signed between the cooperating banks to formalize the agreement. The program offers soft loans to farmers at minimal interest rates, typically 2-3% per annum, which are to be repaid after harvest. In addition to supporting farmers, the program has expanded its assistance to other sectors affected by events such as the devastation caused by typhoon Odette. This includes support for business establishments like hotels, livestock growers, and small to medium-sized enterprises. Any entity with the capacity to repay is eligible to avail of the program. To oversee the implementation, monitoring, and review of the ECD program, an ECD Task Force was created, composed of key officials, private stakeholders, and a representative from the Lender Banks. The province’s role in the program includes providing infrastructure, post-harvest facilities, and processing centers, although these aspects are still in progress. In summary, the Enhanced Countryside Development Program has provided financial assistance to farmers and various business establishments, enabling them to continue their livelihoods and improve their economic conditions. It promotes agriculture and economic development in rural areas, contributing to food security and the well-being of the local communities.

c) Bulk Purchase of Agricultural Products – The intervention is initiated by the provincial capitol in collaboration with the Agriculture Office and local government units (LGUs) in various municipalities and cities. The program aims to assist in marketing agricultural produce from Dalaguete, Cebu. The initiative took place in July when there was an excessive supply of vegetables due to decreased marketing opportunities and travel restrictions. Provincial capitol trucks were utilized to transport the purchased vegetables to different institutions. These vegetables were donated to establishments such as hospitals and jails. Additionally, selected municipalities received a distribution of the purchased vegetables. Farmers were directly paid for their produce at the time of purchase, and the price of the vegetables was

determined based on the prevailing market price during that period. This program has not only aided farmers in marketing their produce but has also assisted other municipalities and institutions in acquiring a stable supply of vegetables and other agricultural products during the pandemic.

d) Caravan on Provincial Services – The Caravan is a program initiated by the provincial capitol, led by the provincial governor, with the aim of providing a one-stop-shop for various services required by the constituents throughout the Cebu province. This program was launched once travel restrictions were lifted and continues to be implemented. The caravan offers a range of services including health services, animal services, distribution of seeds and fertilizers, and dental services. The program brings together the heads of various provincial government offices who are present during the caravan to provide their respective services. Throughout the year, a total of 40 caravans are conducted, organized into quarters. Each quarter represents one caravan, and within a caravan, 10 districts are visited. The caravan is conducted on a district-by-district basis, and the schedule of visits is communicated to the local government units. When selecting areas for the caravan, accessibility for the participating LGUs is taken into consideration. This ensures that the services offered are conveniently accessible to the constituents.

e) *KADIWA* on Wheels – The marketing intervention titled “*KADIWA* on Wheels” is a program initiated by the Department of Agriculture (DA) in partnership with Agriculture offices and local government units (LGUs) of different municipalities. The program aims to aid farmers by facilitating the direct sale of their goods and farm produce, thereby minimizing the involvement of intermediaries. The program initially existed under the name “*KADIWA*” and was later enhanced into “*KADIWA* on Wheels”. During the initial implementation, the DA allocated space for farmers to display their products. However, with the onset of the pandemic and the implementation of travel restrictions, there was a decrease in the marketing of agricultural products. As a response, the program was enhanced, and vehicles from the Department of Agriculture were utilized to transport agricultural products directly from farmers. The Department of Agriculture established partnerships with various non-government organizations (NGOs) and LGUs for the distribution of vegetables. Some farmers also preferred to deliver their farm produce directly to the DA office. Communication regarding available farm produce was coordinated between the LGUs, Agriculture offices, and the Department of Agriculture. Farmers would inform the LGU through the Agriculture office, which would then relay the information to the Department.

f) Issuance of Food Passes – The Issuance of Food Passes was initiated by the Department of Agriculture’s marketing division to ensure the uninterrupted flow of food supply throughout the province during Enhanced

Community Quarantine. The food pass is a privilege granted to farmers, traders, suppliers, and truckers involved in procuring and delivering food products and essential commodities. It allows them to travel to and from or pass through borders during the quarantine period. Initially, the issuance of food passes was carried out physically, but gradually transitioned to the digital platform, where passes were issued online. The food passes are in the form of laminated IDs. To be eligible for a pass, individuals must be legitimate farmers or traders. The intervention aimed to address concerns about food scarcity during the quarantine period by ensuring that the supply of food continued without major disruptions. By providing food passes, the Department of Agriculture facilitated the movement of essential personnel involved in the food supply chain, enabling them to procure and deliver food products across borders.

g) *Bagsakan sa South Bus Terminal* – *Bagsakan* is a Cebuano term that means “place where goods are delivered”, while the South Bus Terminal is the largest bus terminal in the Province of Cebu. The *Bagsakan sa South Bus Terminal* was initiated by the provincial government through the Provincial Agriculture Office to facilitate the trading of goods, specifically fishery products from the North and crops from the South, during the COVID-19 pandemic. The program began in March 2020 and ended in December 2020, lasting a few months as travel restrictions were gradually lifted. Effective communication and coordination between the LGUs and the border control authorities were established to ensure smooth entry and exit of institutional traders and buyers who possessed the required permits to cross borders. Strict implementation of health protocols was observed in the area, with all traders and individuals involved in the “*Bagsakan*” activities undergoing cleaning and disinfection measures. The “*Bagsakan sa South Bus Terminal*” program specifically catered to bulk purchases, where institutional traders delivered their products and only institutional buyers were allowed to make purchases. This initiative provided people with an avenue for economic benefit despite the ongoing pandemic, and the government’s assistance was felt by providing a platform for trade and commerce to continue amidst the challenging circumstances.

Based on the findings from the provincial level, the *SugBusog* Program emerged as a flagship initiative, leveraging collaboration between the Provincial governor, the Department of Agriculture, and local government units (LGUs). It aimed to inspire households to engage in agricultural activities, promoting self-sufficiency and community resilience during the pandemic.

The program’s success lies in its structured approach, commencing with a focus on containerized and backyard gardening at the purok level, and subsequently expanding to LGU and *Barangay* Levels (*SugBusog sa*

Istasyon (Station) and *SugBusog sa Eskwelahan* (School)). Financial support provided to *barangays* and municipalities, coupled with the incentive awards system, fostered active participation and commitment. This kind of initiative demonstrates a sustainable model for encouraging residents to cultivate their own food, enhancing food security at the household and community levels (O'Hara & Toussaint, 2021). The Enhanced Countryside Development (ECD) Program, spearheaded by the Provincial governor, focuses on economic development in rural areas by providing soft loans to farmers and fostering linkages between the agricultural sector and financial institutions.

Discussion

The comprehensive review of Local Government Units (LGUs) in this paper focused on three levels of LGU in the Philippines: *barangay* level, municipal/city level, and the provincial level. The study was conducted in the Province of Cebu in primarily three areas: the Municipality of Dalaguete, the Municipality of Alcoy, and Cebu City. Furthermore, the study focused on one *barangay* for each municipality/city, namely, *Barangay Mantalongon* in Dalaguete, *Barangay Nug-as* in Alcoy, and *Barangay Sudlon* in Cebu City; these three *barangays* are primarily mountainous *barangays* that produces most of the vegetables for the province. During the COVID-19 pandemic, the flow of trade was heavily disrupted, which is especially harmful for vegetable farmers due to the perishable nature of their produce. To address this, the different LGU levels instituted interventions aimed at aiding the agricultural sector.

As observed in the findings, in the *barangays* of Mantalongon, Dalaguete, Nug-as, Alcoy and Sudlon, Cebu, proactive interventions focusing on innovative approaches to support local farmers and residents are practiced by the residents. As affirmed by previous studies, food delivery programs and community-oriented initiatives like the community pantry have positive impact on local agricultural trade (Christ & Niles, 2018). These interventions at local levels provides valuable insights into the adaptability and collaboration of LGUs and stakeholders in addressing unprecedented challenges in the agricultural sector. As Gómez-Villarino & Ruiz-Garcia, 2021 affirmed, these multifaceted interventions not only alleviated marketing difficulties but also contribute to the resilience and sustainability of the local agricultural ecosystem.

The comprehensive analysis of municipal and city-level interventions in Cebu highlights the diverse strategies employed to address the challenges faced by farmers during the pandemic. According to Qu, & Zollet (2023) and Ma & Su (2024), while there is a need for improved awareness among farmers regarding these interventions, the initiatives undertaken by local

governments showcase adaptability, collaboration, and social responsibility. These interventions not only mitigated marketing difficulties but also contributed to the resilience and sustainability of the local agricultural ecosystem (Stefanakis *et al.*, 2021).

Finally for the provincial-level interventions, initiatives like the ECD Program contributes significantly to economic growth, empowering farmers and businesses to overcome challenges induced by the pandemic (Akurugu *et al.*, 2023). Another initiative by the province of Cebu is “the Bulk Purchase of Agricultural Products program”, initiated by the provincial capitol in collaboration with Agriculture offices and LGUs, addressed the challenge of excess vegetable supply in Dalaguete. This kind of initiative, the Bulk Purchase of Agricultural Products program, only supported farmers but also ensured a stable supply of vegetables to various establishments during the pandemic (Marsden *et al.*, 2023). The provincial interventions undertaken by the Department of Agriculture and the Provincial Agriculturist Office in Cebu reflect a comprehensive and adaptive approach to the challenges posed by the COVID-19 pandemic. From initiatives encouraging household agricultural engagement to programs catalyzing economic growth and ensuring uninterrupted food supply, these interventions showcase the resilience and commitment of the local government in supporting farmers and sustaining the agricultural sector (Mishra & Saxena, 2024; Efrat, 2014).

The biggest factors affecting the growth of the Philippine agricultural sector include insufficient government support services, increasing vulnerability to typhoons, droughts, and floods, and weak links between producers and markets (Cruz, 2022). As shown in this paper, the different levels of LGU have stepped up to address several of these concerns during the COVID-19 pandemic through the many production/marketing interventions. Despite the positive impact these interventions have had on local agricultural communities, most of these interventions ceased to exist once the pandemic restrictions were lifted. It should be noted that many interventions, such as the rolling stores & community pantries, have only existed due to specific conditions/protocols present during the COVID-19 pandemic, including social distancing and travel restrictions.

This study contributes to the current literature on agricultural governance and local development by focusing on how decentralized government units in the Philippines responded to a national crisis through locally led interventions in agricultural marketing. While existing literature has examined national-level agricultural policies and market disruptions during COVID-19 (Rasul, 2021), few have explored the specific role of local governments in enabling continued market access for farmers during lockdowns. This study addresses this gap by documenting real-time responses and innovations at the

provincial, municipal, and barangay levels, using qualitative evidence drawn directly from LGU stakeholders.

The study also adds theoretical depth by applying the “Developmental State” framework to a decentralized setting. While the concept is often used to describe centralized state-led industrial transformation, this research shows how local governments – when empowered with autonomy, resources, and coordination – can act as developmental agents in their own right. This extension of the framework highlights both its potential adaptability and its limitations, especially in the presence of fragmented governance structures or capacity gaps. As such, the findings offer both empirical and theoretical insights relevant to local governance, crisis response, and rural development.

Future studies may look into the long-term effects of the interventions, especially on farmers’ income and the stability of local vegetable markets beyond the pandemic period. It would also be helpful to further examine how factors such as local leadership, availability of funds, and coordination among government agencies contribute to the overall success of agricultural marketing efforts at the community level.

Conclusions

Considering the profound impact of the COVID-19 pandemic on the agricultural sector, specifically vegetable farming, this study rigorously examined and documented the interventions executed by Local Government Units (LGUs) in Cebu, Philippines. The exigencies posed by the pandemic mandated nimble and strategic responses to bolster farmers and sustain the vegetable industry. Our research meticulously scrutinized the diverse interventions at distinct levels of governance, spanning from the *barangay*, municipal, city, to provincial initiatives.

At the *barangay* level, proactive interventions such as food delivery programs, rolling stores, community pantries, and marketing assistance programs were set in motion. These initiatives aimed to ensure the availability of essential goods for residents while concurrently advocating for local produce and supporting farmers’ livelihoods. On the other hand, municipal and city-level interventions focused on streamlining the marketing of agricultural products through delivery and transportation strategies, marketing assistance, bulk purchases, and price regulation. These endeavors proved pivotal in upholding the uninterrupted flow of agricultural products to consumers and maintaining market stability for farmers. Moreover, the provincial interventions showcased a synergized approach designed to fortify the agricultural sector. Financial support, infrastructure development, direct sales initiatives, and food pass issuance played a critical role in incentivizing

vegetable gardening, bolstering farmers, and ensuring food security across the province. These interventions underscore the indispensable role of LGUs in mitigating the challenges presented by the pandemic, emphasizing the adaptability and collaborative spirit required to navigate uncharted territories.

Apprehending the efficacy and subtleties of these interventions holds paramount importance for policymakers and stakeholders. It furnishes invaluable insights into successful strategies and can serve as a compass for shaping future policies, thereby fortifying agricultural resilience during times of crisis. By disseminating these findings through esteemed platforms such as Scopus-indexed journals, we aspire to enrich the expansive scholarly dialogue on crisis management and agricultural sustainability, ultimately nurturing a more resilient and robust agricultural sector.

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Conflict of Interest

The authors declare no conflict of interest.

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Rosalyn P. Alburo

Cebu Technological University – Argao Campus, Philippines

Ed Kintanar St., Lamacan, Argao, Cebu, 6021, Philippines

E-mail: rosalyn.alburo@ctu.edu.ph

She holds a Bachelor of Science degree in Agricultural Chemistry from the Visayas State College of Agriculture (now Visayas State University, 1993), a Master of Arts in Public Administration major in Public Policy and Governance from the International Christian University in Tokyo, Japan (2002), and a Master of Science in Chemistry from the University of San Carlos (2015). She earned her Doctor of Philosophy in Technology Management from Cebu Technological University – Main Campus (2004) and is currently completing her Doctor of Philosophy in Chemistry at the University of San Carlos. Her research interests are in agricultural chemistry particularly natural products, environmental chemistry and ecological policy and governance.

Hemres M. Alburo

Cebu Technological University – Argao Campus, Philippines

Ed Kintanar St., Lamacan, Argao, Cebu, 6021, Philippines

E-mail: hemres.alburo@ctu.edu.ph

He holds a Master of Science in Environmental Management from the University of Southern Philippines Foundation (2004), a Doctor of Philosophy in Technology Management from Cebu State College of Science and Technology – Main Campus (2007), and a Master of Arts in Public Administration from the International Christian University in Tokyo, Japan (2012). He is currently pursuing a Doctor of Philosophy in Biology, major in Environmental Science, at the University of San Carlos, Cebu City. He is a Professor VI at the College of Agriculture, Forestry, and Environment, where he teaches courses in Forestry and Environmental Sciences. With 30 years of teaching experience, he has served in various academic and administrative roles and presently serves as the Center Director of the Biodiversity, Environment and Natural Resources Research Center. His research interests include biodiversity, ecology, environmental management, and policy studies.

Lorelie Q. Escabal

Cebu Technological University – Barili Campus, Philippines

Cagay, Barili, Cebu, 6036, Philippines

E-mail: lorelie.escabal@ctu.edu.ph

She holds a Bachelor of Science degree in Agricultural Economics from the Visayas State College of Agriculture (ViSCA, 1984) and a Master of Science in Agricultural Economics from Cebu Technological University – Barili Campus (2025). Her research interests include agricultural policy, farm enterprise management, rural development, and the economic sustainability of local farming communities.

Roberto C. Cutillar

Cebu Technological University – Argao Campus, Philippines
Ed Kintanar St., Lamacan, Argao, Cebu, 6021, Philippines
E-mail: roberto.cutillar@ctu.edu.ph

He holds a Bachelor of Science degree in Agricultural Technology from Cebu Technological University (formerly Cebu South Agro-Industrial School, 1988) and a Master of Science in Agriculture major in Horticulture from Cebu Technological University – Barili Campus (2016). He is currently pursuing a Doctor of Philosophy in Technology Management at Cebu Technological University – Argao Campus. His research interests include horticulture, sustainable agriculture, crop production systems, and agricultural technology management.

Tylo Junior L. van Steenhuyse

Cebu Technological University – Argao Campus, Philippines
Ed Kintanar St., Lamacan, Argao, Cebu, 6021, Philippines
E-mail: tylovansteenhuyse@gmail.com

He holds a Bachelor of Science degree in Agricultural and Biosystems Engineering from Visayas State University (2022) and is a licensed Agricultural and Biosystems Engineer. Since 2022, he has been serving as a Science Research Assistant at the Biodiversity, Environment and Natural Resources Research Center (BENRC), where he contributes to project proposals; technical reports; intellectual property drafting, application, and processing; field-based data collection; and research extensions and training. His research focuses on the fields of agriculture, social sciences, environmental science, forestry, and other relevant fields of the BENRC.

Anesito L. Cutillas

Cebu Technological University – Argao Campus, Philippines
Ed Kintanar St., Lamacan, Argao, Cebu, 6021, Philippines
E-mail: anesito.cutillas@ctu.edu.ph

He is an Associate Professor V at Cebu Technological University Argao Campus. He finished his Doctor in Development Education at Cebu Technological University, Cebu in 2014 and his Master of Arts in Education major in Administration and Supervision in 2012 at the same University. As a CHED Scholar, he also finished a Master of Arts in Philosophy (MA Philosophy), in line with his specialization, at Silliman University, Dumaguete City in 2021. He previously served as Dean of the Graduate School. At present, he is the University Director of University Research Ethics and the Director of the Center for Social Innovations (CSI). His research interests include social, political and environmental ethics studies.



Economic Diversification for Women's Livelihoods in the Tea Supply Chain: Insights from India and Thailand

Siya Uthai*,^a

^a Chiang Mai University, Thailand

Abstract

Northeast India boasts a long history of large-scale tea estates dating back to the colonial era. Assam is India's largest tea production area and contributes over half of India's tea products. The backbone of this industry is the tea tribe women who are tea pluckers. Despite their crucial role, these women face significant economic, social, and political challenges that need greater empowerment. Meanwhile, tea production in Thailand has expanded significantly because of increasing domestic consumption. This research employs qualitative methods to explore economic diversification and tea supply chains in Northeast India and northern Thailand, with a focus on enhancing women's resilience. Data were collected via in-depth interviews with 27 key informants in Assam, India, and 25 participants in Chiang Rai and Chiang Mai, Thailand, between May 2022 - December 2024. Open coding and manual categorization are employed to organize and interpret narrative analysis based on diversification concepts. The study found that women workers in Assam rely solely on tea plucking, earning low wages due to a lack of educational opportunities and double-burden circumstances, compared to women in Thailand, who have more flexibility through diversified livelihoods. Assam requires multi-stakeholder collaboration in both vertical and horizontal diversification.

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* *Corresponding author:* Siya Uthai - Faculty of Social Sciences, Chiang Mai University, Thailand. E-mail: Siya.uthai@cmu.ac.th.

Introduction

Northeast India is the area where tea plantations were first established in India following British colonization, which led to the establishment of large-scale tea estates that became significant exporters of tea to the rest of the world. The influx of migrant workers in Northeast India during colonial times consisted of women and children who became tea pluckers in tea estates, particularly in Assam, India's largest tea-producing region. The tea industry in Assam began in 1837 when the British established plantations, recruiting large numbers of impoverished laborers from Bihar, Odisha, Madhya Pradesh, Uttar Pradesh, Andhra Pradesh, and West Bengal (Magar & Kar, 2016).

Indian and Assamese investors have taken over the industry, managing their own estates and sourcing tea from over 60,000 smallholders (Das & Mishra, 2018). Recently, the workforce in India's tea industry, which encompasses both permanent and temporary employment, has exceeded 2.4 million people (Sarma, 2019). From 1939 to 1950, Assam's tea industry spurred the creation of the Tea Board. An auction center opened in 1970, and FERA was amended in 1973 to boost Indian ownership. Tea prices rose in 1977-78, encouraging small growers to join production (Magar & Kar, 2016).

Women have long been integral to tea production since colonial times, having been brought in from other places like Bihar and West Bengal to work in Assam's tea estates (Das & Mishra, 2018). They have been key laborers in Northeast India's tea plantations, particularly among the Adivasi tea tribes (Wolf, 2022). Despite their vital role, these women face marginalization in Assamese society due to the intersection of gender, ethnicity, and class, highlighting their ongoing struggle for social inclusion.

With rapid economic growth in India, improvements occurred in women's education and fertility rates, but participation in the female labor force remains low. Societal norms restrict women's ability to work, while legal, cultural, and economic barriers limit job opportunities for women (Fletcher *et al.*, 2017). In Assam's tea industry, women workers continue struggling in tea plantations. With permanent contracts declining, temporary tea workers face worse conditions. Many migrate for better pay, but youth often fall victim to human trafficking (Wolf, 2022). Colonial India revealed intricate and exploitative practices targeting women, particularly in the tea industry, in terms of marriage, labor, and sexual exploitation (Sen, 2010). Assam's tea workers face a harsh reality: low wages, limited mobility, and heavy dependence on estate systems. They pay for housing, rations, and medical care, which eats up much of their income (Kalarivayil *et al.*, 2024). Limited access to anti-poverty social security programs and other social welfare

schemes, including formal financial services, is constrained to cycles of poverty and marginalization (Dutta *et al.*, 2021).

In northern Thailand, tea is a part of traditional cuisine as a snack, known as 'Miang' or fermented tea leaves (*Camellia sinensis* var. *assamica*). Miang is a significant food item in traditional religious ceremonies (Khanongnuch *et al.*, 2017). Chiang Rai Province in northern Thailand occupies Thailand's largest tea plantations, covering approximately 13,600 hectares (Thai PBS, 2020). Tea is a local plant in high mountain forests in northern Thailand, particularly in Chiang Rai, where local tea plants in the same genus of Assam tea are found. Tea production in Thailand has been continuously increasing due to the rising demand in the domestic market. However, labor shortages in Thailand's tea industry, particularly in the sourcing process (Department of Trade Negotiation, 2023), caused many tea enterprises to diversify their business.

Economic diversification is a strategy to build multiple income sources through two main approaches: vertical diversification and horizontal diversification. Efficient diversification can reduce inequality and improve both business profits and laborers' wages (Dominguez & Nkurunziza, 2024). Tea supply chains need vertical diversification as a strategy to reduce reliance on wholesale trade, but provide retail with their own brands. Moreover, the horizontal strategy of investing in other products and services within the tea gardens opens broader markets. The diversification approach encourages community engagement to improve entrepreneurial profits and workers' welfare (Sugiardi, 2024).

The labor situation in the tea supply chain raises questions about how economic diversification strategies can be integrated to enhance the livelihoods of women workers. Differences in supply chain models between Northeast India and Northern Thailand present an opportunity to explore initiatives that promote diversification and empowerment. Previous studies, such as Rajbangshi and Nambiar (2020) on the health vulnerabilities of Indian women tea workers and Dutta *et al.* (2021) on their financial challenges, have provided valuable insights; however, the connection between the global supply chains and tea worker conditions has received less attention. This study aims to apply the idea of economic diversification and supply chains to understand the constraint issues in Northeast India. The integrated management can lift women workers in tea production and initiate diversification of the tea supply chains in Northeast India by case comparison with tea supply chains in northern Thailand, which lacks a study of the aspects of the labor force. Data collection was conducted from May 2022 to December 2024.

1. Women in India's tea industry

In 2024, the rate of tea production in West Bengal was reduced by 20.8% compared to the previous year. The labor issues are linked to the decrease in India's tea production. In Assam, the report found the main barriers to worker development as low income and a lack of education (Dutta, P., 2024). The Assam tea industry, a historical pride, faced challenges in both environmental and economic conditions. Climate change has disrupted the weather patterns in Assam, affecting tea cultivation (Bhattacharjee, 2025). Moreover, the industry struggled with significant economic decline in global exports. Production costs have risen by 20% over the last three years, whereas market prices have tended to decline (Dutta, 2024).

Labor crisis

The Assam tea industry is also experiencing labor shortages because the younger generation is less interested in working in tea gardens due to exploitation and poor working conditions. This trend leads to delays in tea plucking, a vital process for maintaining tea quality. Diversification and skill development programs are necessary to keep younger generations engaged (Bhattacharjee, 2025). The historical legacy of exploitation in India's tea industry, particularly through practices involving marriage, labor, and sexual exploitation, has left traumas that continue to shape the challenging conditions faced by women workers today.

Nowadays, female temporary workers often have to rely on very low wages. Recently, the labor wages of tea workers in Assam have been increased to 232 INR per day for those in the Brahmaputra Valley, while those in the Barak Valley receive 210 INR, excluding other benefits such as housing and medical care (Dutta, 2022). The circumstances constrain them into a cycle of debt and lead to mental health problems. Indian social norms supporting male dominance and normalizing domestic violence as a private family matter exacerbate the lack of support from both law enforcement and communities. Women often depend on religion and faith to relieve abusive situations (Sabri *et al.*, 2022).

Gender role

The Indian tea industry employs approximately 1.2 million people, with women engaged in nearly half of the workforce. Tea plucking is the main task for most female tea workers in India (Dutta, 2022). In Assam, women, largely migrants from other regions like Odisha, West Bengal, and Madhya Pradesh, formed the backbone of the tea industry's labor force during the

colonial period. These workers and their descendants are now known as the “tea tribe,” a population exceeding 5 million people in the region, forming a significant focus of political and social debates, despite not being officially categorized as a scheduled tribe or indigenous groups under Assam’s laws (Sharma, 2018), hence claiming political rights and basic social welfare are difficult.

Primarily, women have been recognized for their significant contributions to tea plantations (BASIC, 2019), particularly in tea plucking, where they are perceived as more skilled in selecting high-quality leaves. Men, conversely, are typically employed in factory tasks, pesticide spraying, and handling heavy loads (Dutta, 2022). In Northeast India, women have 10% higher rates of entrepreneurship than the national average. This phenomenon is pronounced among various hill tribes and within Assamese society, where women have historically played significant roles in market economies. The absence of a dowry system in many ethnic cultures may have contributed to more outstanding economic agency for women, reducing financial burdens in marriage and potentially fostering substantial entrepreneurial opportunities (Saikia, 2020).

Women’s roles in Indian society are limited and constrained by their social, economic, and political empowerment, perpetuating gender inequality. Often the poorest in their families, they disproportionately bear the disadvantages faced by men (Biswas & Mukhopadhyay, 2018). The factors related to women’s empowerment are caste, wealth, urban surroundings, and family form. In addition, jobs in cash flow, education, and media are crucial sources of women’s empowerment. Women in urban areas tend to hold better positions than those in rural areas. Moreover, women from South India are the most empowered, women from Northeast India are less empowered, and the scheduled tribe women are the least empowered (Mishra & Tripathi, 2011).

Tribal societies in Northeast India are diverse, comprising both matrilineal tribes, such as the Khasi and Garo, and patrilineal tribes, including the Bodo, Mishing, and Karbi. In Assam, 95% of scheduled tribes are patrilineal (Mal & Saikia, 2024). Furthermore, the tea tribe group is excluded from Assam’s scheduled tribes, which leaves tea tribe women vulnerable and less empowered due to rights deprivation. Tea tribe women are regarded as inferior by men who often treat them as personal assets. These women, at the bottom of the social hierarchy, endure abuse from both male partners, especially if they object to alcohol spending, and mistreatment from tea company managers. Such incidents are rarely reported by companies, leading to compounded oppression for women at home and work (Bhuyan, 2024). Tea tribe women in Assam face marginalization in both political and social

aspects. Furthermore, they face employment segregation in tea plantations. A sustainable diversification strategy in the tea supply chain is likely to be implemented through initiatives that empower women workers in the tea supply chain, in line with the SDGs' mission for gender equality.

Diversification opportunities

Apart from market challenges, the labor issue, particularly for women workers, is a significant factor in readjusting and reimagining the tea industry's direction for global consumers. Approximately 50% of tea production in Northeast India comes from bought-leave factories, as the government supports local farmers in setting up their own tea gardens. However, the quality has declined due to excessive pesticide usage (Bhattacharjee, 2025). The strategies and sustainable practices are involved in creating value-added products. Rasel *et al.* (2022) stated that agricultural entrepreneurs and on-farm diversification should utilize their farms to create new business ventures such as agro-tourism, farm sales, product processing, care farms, and daycare.

Agritourism is gaining popularity in Thailand's tea plantations, especially in Chiang Rai Province, northern Thailand. The entrepreneurs create activities to diversify their income. Visitors can learn, practice, and enjoy recreational activities on farms (Rasel *et al.*, 2022). Tourism plays a key role in rural development by leveraging local resources, creating direct income, and fostering broader economic growth through local integration. The integrated rural tourism concept suggests combining resource controllers and business activities (Saxena & Ilbery, 2008). Agri-food supply chains are increasingly viewed as structured networks integrating economic and social relationships. The concept of supply chain responsibilities emphasizes balancing profits and social responsibilities through collective action across the supply chain, supporting community well-being, and aligning with sustainable practices (Liu *et al.*, 2022).

2. Research methods

This study employed qualitative research techniques to gain an in-depth understanding of the social relations within tea supply chains. The research sites were selected in two countries, India and Thailand. Northern Thailand's tea plantations initially grew due to domestic demand but faced labor shortages. Chiang Rai's tea enterprises are diversifying into tourism alongside wholesale tea. Given that Chiang Rai's *Camellia sinensis* var. *assamica* shares species with Assam, Northeast India, a region known for its large-scale tea

production and reported labor exploitation. Assam and Chiang Rai are chosen as comparative case studies. Both regions feature prominent tea production and significant female workforce participation. Cross-country qualitative comparison aims for a broader understanding of the global tea supply chain in different models and how to implement diversification in the policy.

Data collection

Documentary research is applied as a guideline to select areas of tea plantations and tea companies before requesting permission to access and conduct interviews. The committee approved the ethical review before the first fieldwork was conducted. Convenience sampling was applied to study the private sector, as many tea enterprises in Assam rejected participation. Tea companies and individuals that declined to participate in this research were excluded. Snowball sampling was added for Chinese entrepreneurs in Chiang Rai to reach the initial participants. Two tea enterprises in Chiang Mai were selected randomly from available documents after completing cases in Chiang Rai. The key informant interview was the main data collection method in this research. The pilot study was conducted in Chiang Rai, northern Thailand, in May 2022, due to travel restrictions imposed during the COVID-19 pandemic. A semi-structured interview technique is applied for data collection in 25 cases in Thailand (8 workers, 7 farmers, 5 company owners, 5 managers). The questions were divided into three parts: (1) the participants' general background, (2) their knowledge, skills, and working conditions in the tea industry, and (3) their opinions on gender roles and the future of the tea business.

Table 1 - Northern Thailand's key informants

Interviewees	Roles	Age	Sex
01	Tea farmer	46-50	F
02	Tea farmer	31-35	F
03	Tea farmer	56-60	F
04	Tea farmer	51-55	F
05	Tea worker	41-45	F
06	YK company owner	31-35	M
07	H company owner	56-60	F
08	WW company owner	66-70	M
09	WP company owner	36-40	M

10	Marketing manager	31-35	F
11	Tea worker	31-35	F
12	Tea worker	46-50	F
13	Tea worker	21-25	F
14	Tea worker	31-35	F
15	Sale manager	41-45	F
16	Tea worker	41-45	F
17	Tea worker	36-40	F
18	Tea farmer	46-50	F
19	Tea farmer	31-35	F
20	Tea farmer	51-55	F
21	Marketing manager	36-40	F
22	PP company owner	66-70	M
23	BK general manager	51-55	M
24	General manager (CM)	36-40	M
25	General worker (CM)	21-25	F

Source: Author's own elaboration.

In Assam, Northeast India, recognizing the local linguistic and cultural context, the researcher engaged an Assamese research assistant to facilitate data collection and an interpreter to bridge potential language barriers with participants. Due to communication limitations between the researcher and tea workers, structured interviews were the primary method used by the Assamese interpreter, who translated them into English for the researcher on a case-by-case basis. The questions were set on a paper sheet divided into three parts: (1) to explore key informants' backgrounds; (2) to assess their knowledge, skills, and working conditions; and (3) to gather opinions on gender roles and perceived limitations within the tea business. Semi-structured interviews were conducted with other participants who can communicate in English. These 27 cases of interviews (20 workers, 2 entrepreneurs, 3 dealers, 1 manager, 1 broker) took place in Jorhat and Guwahati, Assam, during July-August 2023 and December 2023.

Table 2 - Assam's key informants

Interviewees	Roles	Age	Sex
01	Temporary tea worker	21-25	F
02	Temporary tea worker	31-35	F
03	Temporary tea worker	46-50	F
04	Temporary tea worker	26-30	F
05	Temporary tea worker	31-35	F
06	Permanent tea worker	31-35	F
07	Permanent tea worker	36-40	F
08	Permanent tea worker	36-40	F
09	Permanent tea worker	46-50	F
10	Permanent tea worker	41-45	F
11	Tea company manager	46-50	M
12	Local worker	16-20	F
13	Local worker	31-35	F
14	Local worker	51-55	F
15	Local worker	46-50	F
16	Local worker	46-50	F
17	Small tea grower	56-60	M
18	Local worker	21-25	F
19	Local worker	36-40	F
20	Local worker	41-45	F
21	Small tea grower	36-40	M
22	Local worker	26-30	F
23	Local worker	26-30	F
24	Tea broker staff	51-55	M
25	Tea dealer S1	46-50	M
26	Tea dealer S2	46-50	M
27	Tea dealer M	51-55	M

Source: Author's own elaboration.

Field observation was conducted to understand the environmental context, cultural practices, and interactions. This method involved taking field notes and conducting informal interviews with people within the observed environment.

Data analysis

The interview transcripts were translated into English, which the research assistant did for Assam's case. Field notes from informal communication and observation were included for narrative analysis. The narratives based on their actual experiences (Sevilla-Liu, 2023) with related elements through field observation are included for interpretation. The researcher read all transcripts and field notes in English before applying open coding to group the data into descriptive codes. This process involved labeling concepts and organizing them into defined categories (Mohajan & Mohajan, 2022). The dataset reached saturation when no new descriptive codes emerged after a double review of several transcripts and field notes. In the coding process, special attention was paid to narratives that diverged from common themes, ensuring that different viewpoints were not overlooked. Manual categorization was arranged to link key concepts and interpret, analyze, and evaluate the complex meaning from multiple perspectives. Narrative analysis helps to understand individual perspectives from diverse backgrounds, experiences, and environments, particularly those of marginalized groups.

3. Findings

3.1. Tea supply chains

In India's tea supply chains, the large-scale tea producers have their own tea plantation areas. They hire workers in the process of sourcing tea leaf collectors, and most of them are known as the tea tribes, who were born and raised on the tea plantation. No training in any skills from the tea companies, "We learned how to pick tea leaves from the previous generation, parents and neighbors; the tea company provided no training" (permanent workers, August 2, 2023). Women's tea plucking skills, derived from colonial times, have confined generations to subordinate roles within the gardens (Dutta, 2022). Besides tea leaves from their own plantation, tea companies also buy fresh tea leaves from nearby communities. At the factory, only male workers process all collected tea leaves on a shift basis, including nights, due to daily processing demands and quality testing by the tea manager. After the raw materials are transformed into end products for wholesale trade, tea brokers play a key role in coordinating and providing price information and product samples to buyers and dealers who will purchase tea through India's e-auction system in three days a week (a tea broker staff and a tea dealer M, December 6, 2023).

According to state regulations, the wages in tea plantations are the same as those in garden jobs and factory jobs, at 232 INR (3 USD) per day (a

tea company manager, July 30, 2023). In comparison to other sectors in Assam, factory workers earn approximately 400-500 INR (6 USD) per day (Tea Dealer S1 and S2, December 5, 2023). Both permanent and temporary workers (August 1-2, 2023) stated that the wage is paid in cash every 15 days, and the company provides them with the amount of rice and tea leaves every month. Temporary workers gain equivalent wages, but the hiring period is about six months per year, during the peak tea leaf season.

In Chiang Rai, both large and small tea enterprises produce tea in their own factories. Also, small tea growers in some communities collect tea leaves for sale to tea enterprises. The first step begins with raw materials sourced from their own tea plantations. In the case of high demand, tea enterprises buy tea leaves from other sources (YK company owner, September 19, 2024). Large tea enterprises are collaborating with local communities in regions where tea trees naturally grow. This partnership involves providing training to local people on tea planting techniques to ensure a larger supply of tea leaves, thereby satisfying the needs of their dealers (BK General Manager, December 8, 2024). Women are the primary workers in tea gardens, collecting tea leaves as an informal job, and are paid according to the weight of the tea leaves they collect.

Usually, they can collect about 20-30 kilograms of tea leaves per day, while men can collect in lower amounts. The weight of the tea leaves ranges from 11-14 THB (0.40 USD) per kilogram. The price varies depending on the weather. For instance, the price will be lower during high humidity because the tea leaves will have a high moisture content (WP and WW tea company owners, May 13-14, 2022). Two tea workers (October 14, 2022) stated the cause that no men work as tea pluckers, "The tea stalk is sticky and difficult to remove. You must use your fingernails to help pull it out, or some people use nail clippers. However, men usually don't know how to use them". Moreover, the WP company owner (October 19, 2022) mentioned that male villagers who typically work as drivers and carriers get paid 300-500 THB (9-15 USD) per job. The tea enterprise also hired men (mostly migrant workers) as full-time workers for factory jobs to process the fresh tea leaves after they were collected. This reflects gender roles in the working class as women used their hands to work, while men work with equipment that requires physical strength (Alesina *et al.*, 2011).

Tea withering processes must be done before being dried by machine to remove all the moisture. The tea processing in Chiang Rai employs Chinese techniques, separating young tea leaves from old tea leaves to produce different products at varying prices (WW company owner, May 13, 2022). Tea entrepreneurs contact dealers directly (H company owner, September 20, 2022), both in the domestic and international markets, and no tea brokers in Thailand's supply chains.

Table 3 – The tea supply chain management between cases in India and Thailand

Issue	India	Thailand
Type of hiring	Permanent/Temporary	Part-time/full-time
Wage System	Fix rate (3 USD)	Flexible (8-12 USD)
Sources of tea leaves	Own plantation/small tea grower	Own plantation/ small tea grower
Type of trade	Wholesale via e-auction	Wholesale/retail via marketing plan

Source: Author's own elaboration.

3.2. Tea pluckers' livelihoods

Women in Assam's tea plantations work hard under extreme and constantly changing environmental conditions. Tea plucking is a labor-intensive task that requires continuous effort for long hours, leading to exhaustion. Moreover, they receive very low wages compared to other jobs in different sectors (Sharma, 2018; Elks, 2018). According to the tea company manager (July 30, 2023) and permanent female workers (August 2, 2023), they stated that working hours in the tea gardens are set at 8 hours per day, with Sundays being a day off. Women prepare themselves for work before 8 am, and the work in the tea garden typically ends at 4 pm (permanent and temporary workers, August 1-2, 2023).

As observed by the researcher at the tea company, workers can hear the bell ringing at 8:00 a.m., and they must be at the factory. At the factory, the head worker organizes the workers into their designated sections. Women are assigned to work in tea gardens for plucking jobs in specific areas, while men work in both the factory and the gardens. At noon, another bell rings, signaling the start of a one-hour lunch break. The next bell rings again, calling workers back to their afternoon shifts. Finally, at 4 pm, the bell rings to signal the end of the workday. The bell rings symbolized disciplinary power that controls workers instead of a warden watching (Lilja & Vinthagen, 2014).

Women are confined to being only tea pluckers, even though complex processes involve tea production, like spraying, trimming, tree and grass cutting, and various factory jobs. However, those tasks need to work with machines. "When the company brought huge machinery to produce large-scale tea products every day, we did not hire women to work at the factory because the factory's tasks need physical strength that is more suitable for male workers" (the tea manager, July 30, 2023). The conditions emphasize

the segregation of women from machinery skills (Alesina *et al.*, 2011). Therefore, the skills of women in tea gardens are limited, resulting in powerless workers. These conditions force them to accept unfair wages and working conditions.

In Chiang Rai, northern Thailand, women working as tea pluckers live in nearby communities and collect tea leaves as a part-time job, for which wages are calculated based on the weight of tea leaves collected daily (PP tea company owner, March 13, 2024). Tea plucking usually begins in the late morning, after 8 AM, once morning moisture dissipates, until 4 PM, when the final harvest is delivered for processing. There is a company staff check and weight tea leaves. However, Chiang Mai's tea businesses diversify beyond tea, focusing on products like strawberries and vegetables to boost tourism. Migrant workers cultivate these contracted crops on allocated land, selling them back to the company for their income (a general worker, December 10, 2024). Another company trains and employs locals for various gardening tasks, paying them a daily wage (a general manager, December 2, 2024). Livelihood diversification among women workers in Chiang Mai can tackle gender vulnerability in adaptive livelihoods (Helmy, 2020).

Table 4 - Women's livelihoods in tea plantations between cases in India and Thailand

Issue	India	Thailand
Working Hours	8:00 AM - 4:00 PM (8 hours/day, Sunday off)	After 8:00 AM - 4:00 PM (depending on moisture)
Task segregation	Women confined to plucking and excluded from machinery	Women are involved in varied agricultural tasks
Work monitoring	Bell system for the strict schedule	Staff check the amount of tea leaves
Other job opportunities	Limited	More diversified

Source: Author's own elaboration.

3.3. Intersectionality and double burden

In Assam, women workers in the tea plantations face not only economic constraints but also social and political dimensions. Adivasi women are tea tribe workers born and raised in tea plantations for generations. In Chotanagpur, Adivasi groups have received Scheduled Tribe (ST) status,

but not yet in Assam (Sentinel Digital Desk, 2023). Therefore, those Adivasi become marginalized people in Assamese society, and their right to social services and economic rights can be exploited (Sinha, 2022). In Indian society, women's opportunities are limited by their primary responsibility for household and family duties (Nandy & Dutta, 2020). After marriage, they care for their husband's entire family, while unmarried women often face social stigma, "I did get a chance to attend a school, but now I am married. My husband has gone to Chennai for work, and I also dream of leaving Assam someday to build a better life" the 24-year-old local worker (August 3, 2023) who work at the small tea gardens in her communities talked about her intention. Women workers face a 'double burden' of unpaid care work, such as housework, childcare, and family care, and the need to earn daily wages outside (Greenhaus & Beutell, 1985), leaving them little time for education, unlike married men who have greater freedom.

According to the interview, three temporary workers and two permanent workers described their daily tasks as the same: "Every day, I wake up early in the morning at around 4 am (2 of them start at 3 am) to finish the household work at my place and then come here to work" (August 1- 2, 2023). All female workers at Assam's tea company said that apart from tea plucking, they do not have any idea how to work other jobs, as they have no skills at all. "If I do not pick the tea leaves, it is hard to know what else I can do because I did not go to school", A 45-year-old permanent worker (August 2, 2023) referred to schooling. Articles 341 and 342 of India's Constitution protect indigenous rights by granting Scheduled Tribe status, which provides access to education and benefits (National Human Rights Commission, India, 2021). However, Adivasi women in Assam lack this status, limiting their educational opportunities. Social norms require women to marry and manage the home, while poverty forces them into paid work, compounding their disadvantages. These intersectional discriminations are the glass ceiling against women's access to education and employment (Crenshaw, 1991), which confines them to the same position.

Women in northern Thailand seem to have better educational opportunities, despite many of them not obtaining Thai citizenship. Asai, an ethnic woman tea farmer (March 14, 2024), said, "I moved from Myanmar to Thailand when I was 15 years old and studied primary education at Chiang Mai before moving to stay with my husband here." Therefore, her knowledge of Thai enabled her to learn new skills like sewing and tailoring. She and her three neighbors explained, "I face difficulty with jobs that require machinery" (March 14, 2024). The Thai language brought her more job opportunities, but the machinery jobs are not her choice (Alesina *et al.*, 2011). Despite mainly handling childcare and housework, ethnic women in

Chiang Rai found ways to earn extra income from working outside as flexible jobs to support their families alongside their husbands' earnings (Hossain, Md., *et al.*, 2013).

In Chiang Rai's tea plantations, workers often live with their families nearby rather than at the workplace. Sang, an ethnic tea worker, said, "Working without a contract like this is flexible for me as the time that my family has any urgent affairs such as bringing my child or my stepmother to hospital, I can freely avoid working on that day" (October 20, 2022), her two colleagues agreed with this point to work in tea plantation as a part-time job and earn wages supporting their family together with housework responsibilities (Hossain, Md., *et al.*, 2013). Married women face a 'double burden' of unpaid home duties and paid work for family expenses (Greenhaus & Beutell, 1985). As one WW tea company worker explained, "My husband gains monthly wages, which go towards a vast expense such as children's tuition fees, and my daily wages can go to support food expenses" (October 20, 2022). Although female workers face this double burden, informal jobs offer flexibility to balance work and family life.

Table 5 - Intersectional circumstances of women workers between cases in India and Thailand

Issue	India	Thailand
Legal status	Adivasi women, tea tribe workers, have limited access to benefits, education, and social services	Some women migrant workers lack citizenship, but are generally less restricted in access
Education Access	Limited	Better access through the Thai language
Double burden	Severe long hours working and few alternatives	A combination of housework and flexible jobs
Economic constraints	Low wages and a lack of skills	Supplementing family income
Social mobility	Low opportunities, restricted by social, legal, and economic barriers	Higher opportunities via language skills

Source: Author's own elaboration.

3.4. *Economic diversification strategies*

Adivasi women in Assam face difficulty accessing schools, even though some tea companies collaborate with Assam State to build primary schools close to the tea plantations. “Our company provided accommodation, a health care center, and a primary school as the company’s welfare for our workers” (a tea manager, July 30, 2023). Nowadays, government and private efforts aim to improve education for tea tribe workers, but low wages force many children to leave school for plantation work. Moreover, men who own women and their children as assets spend their earnings on alcohol, which women are also involved in, and cause domestic violence (Bhuyan, 2024). In August 2023 interviews, most women shared hopes that their children could pursue education and escape life on the tea estates.

Education has become a key strategy for women workers to diversify their livelihoods. In order to empower them, economic diversification is necessary to apply to the tea supply chains for the mutual benefit of both workers and owners. A 57-year-old Assamese small tea grower (July 31, 2023) built his own tea garden within 30 hectares of his ancestral land. He divided his 6 hectares into various plantations and paddy fields, using land diversification to boost income from multiple crops. As an Assamese living in an Adivasi community, he hires 5-10 daily tea pluckers who are available to work on his tea gardens. “I hire 5-10 workers per day; they are mostly villagers from this community, who are mostly women; sometimes, aged men also request to work here”, the Assamese tea grower (case no. 17) mentioned to labor management. Women in this community have choices; if they have work on their family’s paddy fields, they can reject working in the tea garden. Hence, the tea plucking job depends on their decision.

Besides diversified crops that utilize the entire land for multiple activities to generate income from various sources, the Assamese tea grower is engaged in manual tea processing. This involves transforming fresh tea leaves harvested from their gardens into dried ones for sale to family and friends. Meanwhile, other local small tea growers divided their small land to plant various crops for household consumption, and tea gardens for tea leaf selling because of insufficient budget and knowledge (a local small tea grower, case no. 21, August 4, 2023). Black pepper trees are grown within small tea gardens and large tea estates, providing essential shade for the tea plants. The tea company also sells black pepper as part of its product offerings, diversifying income (a tea company manager, July 30, 2023). Meanwhile, the government initiated a tea tourism project in Sontipur district to promote tea estates as a tourist destination that aims to create more job opportunities for locals (Northeast Today, 2025).

Women workers in northern Thailand rely less on tea plucking because they have gained other skills for alternative part-time jobs. They earn comparable

tea-picking wages to other agricultural jobs, supplementing their income by selling local products to tourists in northern Thailand's tourist season, when tea leaves are scarce. "I weave these bags by myself for sale when I cannot collect tea leaves during the dry season", the researcher said to a 41-year-old tea worker (October 22, 2022) who set her stall in front of YK Tea Company. Women attempt to find livelihood diversification strategies to cope with their vulnerability by earning income from various abilities (Helmy, 2020). Both Thai and non-Thai workers from impoverished families rely on primary education as a foundation for language acquisition. The Thai language provides a crucial foundation for broader job opportunities and livelihood diversification.

Economic diversification is a strategy to enhance communities by expanding their income sources (Sugiardi, 2024). In northern Thailand, many tea enterprises boost their earnings by adding tourist activities alongside tea production. A tea company's sales manager (October 22, 2022) explained, "Our company opens its plantation for tourists to walk along the garden, pick tea leaves, and take photos wearing Akha ethnic dress". The enterprise integrated tourism to earn revenue from entrance fees at the tea garden, dress rental costs, and the sale of tea products in its small shop (Saxena & Ilbery, 2008). WP Tea Company (October 20, 2022) offers an educational tour of organic tea knowledge and the whole process. The WW company (May 13, 2022) opened a Chinese restaurant and small bungalows in the tea garden area for visitors to experience the variety of tea tastes and the mountainous atmosphere. Meanwhile, tea entrepreneurs in Chiang Mai diversified their businesses to capitalize on the city's strong reputation as Thailand's top tourist destination on an agro-tourism strategy (a general manager, December 2, 2024).

Table 6 - Economic diversification strategies between cases in India and Thailand

Issue	India	Thailand
Women's livelihoods	– Dependent on tea plucking and subsistence crops – Often leave school for work	– Vary on tea and local product sales during tourist season – Language skills
Land use	Tea gardens intercropped with paddy, vegetables, and fruits	Diversifies with tea and other crops for multiple activities
Agro-tourism	Limited	Widely adopted
Income sources	Land & crop diversification for extra income	Land & crop, product diversification, and integrated with tourism

Source: Author's own elaboration.

In addition, Chiang Rai's tea enterprises invented their signature taste of tea as a kind of 'specialty' tea for selling directly to online markets. To overcome limited land and labor shortages, northern Thai tea enterprises are expanding their market reach to Chinese dealers. Many enterprises produce more premium products, such as organic leaves, aged-tree tea, and Pu-er, according to Chinese buyers' demand (WW Tea Company, October 20, 2022). Therefore, tea prices in Thailand are high, and tea leaf collectors earn at a similar rate to Thailand's minimum wage, which sometimes gets higher. Thus, many tea beverage companies imported tea leaves to mix with domestic tea leaves due to low supply (WP, tea enterprise, May 14, 2022; BK tea enterprise, December 8, 2024). Meanwhile, Assam's tea company manager (July 30, 2023) and two small tea growers referred to the low selling price of tea, especially compared to coffee. The diversification strategy obviously increased tea entrepreneurs' income, while women workers are possibly gain more income through new skill learning and spend more working time. In other words, women are required to allocate their time to income-generating activities.

4. Discussion

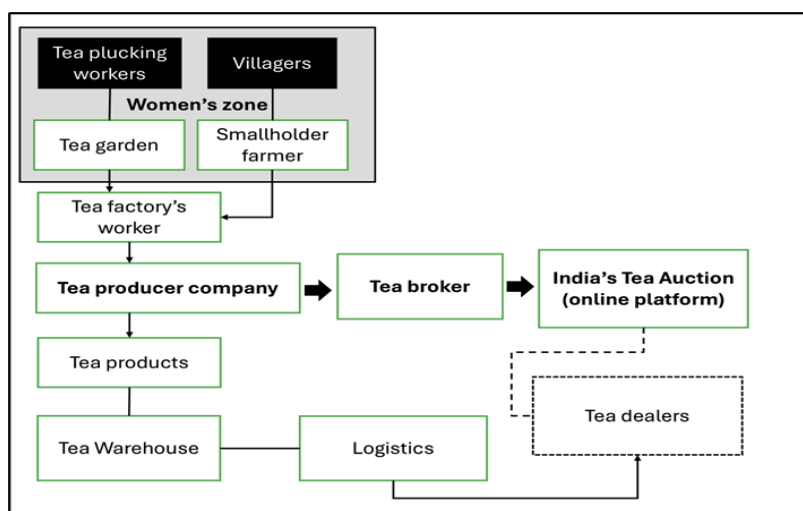
This study highlights how intersectional factors restrict women's roles in Assam's tea supply chains, confining them to the lowest positions (Bhuyan, 2024). Meanwhile, women workers in Chiang Rai faced similar dimensions because they are ethnic and migrant groups, but Thailand has flexible regulations for children's rights in education. Therefore, Thai language skills enable them to pursue diverse livelihoods, reducing their vulnerability (Helmy, 2020). In contrast, women workers in Assam struggle with extremely low wages, forcing their children to leave school for work and trapping families in a cycle of poverty. Similarly, women workers in Chiang Rai earn an income from part-time jobs, and the price rate, based on the weight of the tea leaves, makes their income unpredictable. Access to resources is crucial to women's empowerment, requiring government policy and pro-women programs with community support (Biswas & Mukhopadhyay, 2018).

Limited access to education restricts Adivasi women in Assam from developing skills and exploring other income-generating activities. Without education or skills, they have a heavy dependence on tea plucking, making them highly vulnerable to fluctuations in income due to decisions made by tea companies (Dutta *et al.*, 2021). Additionally, social norms confine women to get married and become their husbands' assets, especially women from poor families who are in 'double burden' circumstances. Empowering them requires addressing these systemic barriers and creating opportunities for

skill training. Compared to the cases in Chiang Mai, companies trained both locals and migrant workers for diverse roles, supporting economic diversification. In Chiang Rai, women workers have become less reliant on tea plucking, adapting to tourism-related jobs (Sugiardi, 2024). Livelihood diversification enhances resilience and reduces vulnerability beyond dependence on the tea supply chain.

Tea entrepreneurs are the key actors in the supply chain to empower their workers, balancing profits and social responsibilities to support social well-being (Liu *et al.*, 2022). Addressing fair wages and transparent practices is essential, especially since low global tea prices keep wages in tea plantations lower than in other sectors, threatening the Assam tea industry's future. Economic diversification benefits both workers and entrepreneurs. In Chiang Rai, tea businesses sustain themselves by branching into tourism, educational tours, restaurants, and specialty premium tea products, creating new sources of income (Rasel *et al.*, 2022). In the meantime, Assamese small tea growers exemplified farm diversification in multiple crops and manual processing for extra income. Tea producers in Assam need to integrate resource management and business activities, encouraging workers to develop multiple skills (Saxena & Ilbery, 2008). Diversifying into other crops and tourism can boost income, while promoting Assam's premium and specialty teas can help establish a unique product identity.

Figure 1 - The tea production process in Assam depends on tea brokers, and women are limited to work only in the tea gardens

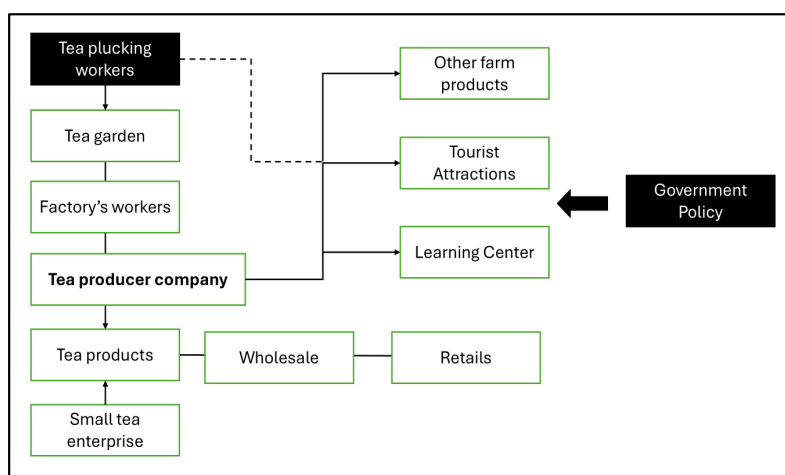


Source: Author's own elaboration.

Figure 1 illustrates Assam's complex tea supply chain, but women workers were confined in the tea garden because of intersectional discrimination. Economic upgrading in value chains is necessary for suppliers, leading to social upgrading of workers (Barrientos *et al.*, 2011). Tea enterprises in northern Thailand have launched economic upgrading and diversified activities that can benefit workers' wages and working conditions. However, workers' social upgrading also means the rights and freedom of collective bargaining (Marslev *et al.*, 2022). Workers can improve their skills more through diversification, but some groups can be segregated. In the tea industry in India and Thailand, women often work less machinery-intensive jobs. Also, married women in northern Thailand were segregated into informal jobs because of the double burden of housework and childcare (Carranza *et al.*, 2023).

Fairtrade certification in the value chain helps promote gender equality because it is perceived to have more transparent procedures (Riisgaard *et al.*, 2010). However, recruitment that segregates women into specific tasks disadvantages women from improving new skills. Women workers in Assam and northern Thailand have less bargaining power. Although women in Chiang Rai earn better wages and have flexible working hours, the tea entrepreneur's decision changes the price of tea leave without a negotiation process. As women gain skills and diversify their work, dependence on the tea industry drops, leading to labor shortages (Marslev *et al.*, 2022). Therefore, the price of tea leaves is higher during tourist season.

Figure 2 - The diversification model for tea producers gaining benefits in various dimensions and workers can gain more income from other jobs in tea companies by support from the government



Source: Author's own elaboration.

Figure 2 illustrates the role of the government in contributing to economic diversification, leading to social upgrading of workers to have multiple skills and choices. Government plays a key role in advancing gender equality, particularly through education. In Thailand, educational opportunities have helped women migrants adapt their livelihoods by the Thai educational system. In Assam, granting Adivasi workers ST status would improve access to education and skill development programs in combination with the economic diversification of tea producers. Although Assam plans to promote tea tourism, the state needs better training and infrastructure (Sarmah & Upadhyaya, 2024). The government is the primary contributor to linking external stakeholders and investing in the infrastructure to create various economic activities, including women's engagement in policy decisions. Diversified skills can bring about social upgrading that improves resilience and welfare among women workers (Sugiardi, 2024).

This study is subject to some limitations that should be considered in data collection, which may affect results. As the research was designed for cross-country analysis, collecting data during the COVID-19 pandemic made it difficult to follow the sampling design. Travel restrictions and limited access to the area led to the application of convenience sampling, which may be less representative than intended. Limited timeframe for fieldwork, especially in Assam, most participation requests sent via email are being declined by tea enterprises. The selected tea producers were joined only by personal contact. Inadequate engagement from both the private and government sectors limited the depth of contextual understanding. Also, language barriers further complicated worker interviews, as multiple languages are spoken among local and tribal groups. Interpreters struggled with direct translations, so the interview questions were set to accommodate effective communication, which may affect the information gathered. The environmental issues related to tea production were not addressed in the analysis due to the complicated communication between researchers and locals through the interpreter's limited subject knowledge. For further studies, collaboration with local researchers and CSOs to leverage their contextual expertise should be considered. Additionally, addressing the impacts of climate change on tea supply chains and necessary adaptation strategies are recommended for future studies.

Conclusions

Assam, India's largest tea-producing region since colonial times, relies heavily on women workers, mainly Adivasi tea tribes forced to migrate during British rule. About half of the tea workforce is female, mostly limited

to tea plucking under poor conditions. In contrast, men take on more diverse tasks, such as factory work and operating machinery, which require greater physical strength. This division limits women's roles and wages in the industry. Although tea workers in Assam earn a daily wage of 3 USD, lower than in other sectors, women's opportunities are restricted due to being marginalized and the lack of Scheduled Tribe (ST) status, limiting access to education and social services.

The double burden of balancing household duties and childcare while working outside the home discriminated against women in access to education and skill development. In northern Thailand, ethnic women are the main workforce in tea gardens, paid by the weight of leaves collected. Many, lacking Thai citizenship, access educational opportunities and work informally in tea production to balance domestic duties and earn extra income. In Assam, women are limited to tea plucking, leaving them vulnerable to income fluctuations and low wages due to market pressures. Social norms around marriage and gender roles further restrict their access to education and employment.

Livelihood diversification through education access is a key strategy for empowering women. Economic diversification and responsible management are important for both business and social upgrading. Tea entrepreneurs play a vital role in improving working conditions and wages, but challenges remain in gender segregation and limited bargaining power. Promoting shared responsibilities and eradicating glass ceiling barriers in employment requires action from the government in policy implementation in collaboration with the stakeholders and women's groups. The significant action from the government to support women is the improvement of labor rights and wages, at least to be equal with other industries. The policy needs to address accessible and inclusive education for girls in both the formal and informal systems. And the government initiative in Sontipur can be expanded upon to work with other local communities to gain benefits for all units in the tea supply chain.

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Siya Uthai

Faculty of Social Sciences, Chiang Mai University, Thailand

239 Huai-Kaew Rd., Muang Chiang Mai, 50200, Thailand

E-mail: siya.uth@cmu.ac.th

She is an Assistant Professor in the Department of Social Science and Development. She holds a Ph.D. in Southeast Asian Studies from Humboldt University of Berlin (2015). Her research focuses on food security, intersectionality, civil society in organic food networks, and the global food chain.



Assessing Agricultural Support Policy Impact through Traditional versus Machine-Learning Techniques

Orjon Xhoxhi^a, Engjell Skreli^a, Edvin Zhllima^a, Drini Imami^{*,a}

^a Agricultural University of Tirana, Albania

Abstract

This paper analyses the impact of agricultural subsidies using traditional quasi-experimental research design that combines genetic matching procedure with regression analysis and causal forests, an adaptation of the random forest algorithm of Breiman (2001) for treatment effect estimation. The study is based on a structured orchard farm survey conducted in Albania, an EU candidate country. By employing both traditional and machine learning methods, the comparative methodological approach represents a notable contribution by enhancing the robustness of the findings, while highlighting the advantages of the random forest algorithm. The research results indicate that policy support significantly increased on-farm investments by approximately 4.7 million ALL (representing a 39% increase relative to the sample average investment for the analysed period), and direct apple revenues by about 2.48 million ALL (a 29% increase relative to the sample average revenue). Moreover, the policy had a substantial impact on altering the variety cultivation structure - beneficiary farmers replaced lower-quality apple varieties with higher-quality, market-demanded varieties, while non-beneficiaries showed no significant changes in their variety structure. As a result, the policy support enabled beneficiary farmers to better align their production structure with market demand, potentially boosting their future competitiveness.

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* *Corresponding author:* Drini Imami - Professor - Faculty of Economics and Agribusiness, Agricultural University of Tirana, Albania. E-mail: dimami@ubt.edu.al.

Introduction

Public transfers to agriculture have risen sharply: global support averaged USD 842 billion per year in 2021-2022 – more than twice the 2000-2002 level (OECD 2024). Albania, an emerging economy (the focus of this paper) follows this trend, albeit on a smaller scale. Under the Strategy for Agriculture, Rural Development and Fisheries (SARDF) 2021-2027, public appropriations reached EUR 90 million in 2023 (2.3% of national GVA) (Stojcheska *et al.*, 2024). Because the country is an EU-candidate state, evidence on the effectiveness of these transfers is indispensable for both domestic budget prioritisation and alignment with the Common Agricultural Policy (CAP).

Existing empirical findings on agricultural subsidies are heterogeneous. Subsidies and investment support for orchard farms can significantly improve farm productivity, income, and sustainability – because subsidies are associated with improved cultivars, high-density planting, integrated pest management, and precision agriculture (Ciaian *et al.*, 2015). In EU policy, there is broad consensus on the effects of subsidy types. Coupled payments, tied to output, can depress technical efficiency by distorting relative prices, whereas decoupled or investment-linked support can relax liquidity constraints and foster productivity growth (Latruffe and Desjeux, 2016; Latruffe *et al.*, 2017). However, in non-EU candidate countries the results are vaguely described. Effect magnitudes differ across countries, sectors, performance indicators and the temporal lag between investment and outcome. Short-term income effects may be limited, since orchards have long gestation periods. Problems of reverse causality are critical since larger, high incomes and capital endowed farms are also more able to acquire investments subsidies.

Methodological heterogeneity further clouds inference (Minviel & Latruffe, 2017). Most CAP appraisals still rely on simulation models or parametric regressions that are vulnerable to functional-form misspecification and selection bias (Colen *et al.* 2016). Quasi-experimental estimators – propensity-score matching, difference-in-differences, or instrumental variables – offer improvements, yet they remain sensitive to unobserved confounders or to data loss induced by pruning unmatched observations. Recent methodological advances, notably generalised random forests (GRF), allow causal estimation in high-dimensional settings with minimal parametric assumptions and explicit modelling of treatment-effect heterogeneity (Athey & Wager 2019). Applications of such machine-learning estimators in lower-income or pre-accession economies, however, are still limited.

The Albanian apple sector represents a suitable research setting. National apple output has expanded rapidly since 2010 owing to both area and yield

gains. Production is concentrated in the high-altitude district of Korça, which contributes more than half of national supply and has a long tradition of commercial orcharding (Gerdoci *et al.*, 2015). Accelerated growth has exposed structural bottlenecks – outdated varietal structures, insufficient cold storage, and weak processing and export capacity. In response, the Ministry of Agriculture has operated a co-financed orchard-investment grant scheme that subsidises new plantings, varietal renewal, and on-farm cold rooms. The intervention is was expected to increase investments, adjust varietal composition towards market-preferred cultivars, and improve revenues and employment (AGT-DSA 2021). To date, no study has deployed causal inference techniques to verify these claims.

This study pursues two research objectives: first, it quantifies the causal impact of Albania's orchard-investment grants¹ on key apple-farm outcomes – capital investment, direct sales revenue, hired labour, and varietal composition – during the 2013-2018 programme period; second, it examines how the resulting effect estimates vary when calculated with a refined quasi-experimental estimator, genetic-matching regression, compared with those obtained via the state-of-the-art machine-learning algorithm, generalised random forest.

By addressing these objectives, the study (i) provides a rigorous evaluation of an agricultural investment programme in an EU-candidate country and (ii) offers empirical guidance on the relative merits of modern machine-learning techniques versus conventional matching estimators in mid-sized farm-survey settings.

Analysis relies on a cross-sectional survey of Albanian apple farms targeting both subsidies/programme beneficiaries (treated) and non-beneficiaries (controls) sampled from the same villages. Observable heterogeneity is mitigated through genetic matching, which iteratively searches for a weighting matrix that minimises multivariate imbalance. Post-matching least-squares regressions yield average treatment effects (ATEs). In parallel, causal forests recursively partition the covariate space and average treatment predictions over many trees; cross-validation determines optimal tuning parameters, and asymptotically valid standard errors enable inference. Analysing the two estimators highlights considerations related to bias control, efficiency, data utilization, and interpretability.

The rest of the paper is structured as follows, section 2 reviews the international literature on subsidy impacts and evaluation methods. Section 3 consists of methods including the econometric and machine-learning

1. Orchard investment grants correspond broadly to Investments in physical assets (Pillar II) of Common Agricultural Policy but is strictly related to grants for plantation of grafted seedlings of certified cultivars.

estimators. Section 4 presents ATE estimates and heterogeneous effects, juxtaposing the two methodologies. Section 5 discusses policy implications for Albania's CAP convergence and offers concluding remarks.

1. Literature Review Background

According to Kumbhakar and Lien, (2010) both coupled and decoupled subsidies can impact prices (and alter relative prices), incomes and labour, in turn affecting labour distribution and investment decisions, farm growth and income. Subsidies represent a stable source of farm income, since they are less variable than the other sources of income and contribute to higher farm income (Bojnec and Ferto, 2019). Subsidized investments in new orchards, especially those adopting modern cultivars and drip irrigation systems, tend to result in higher yields and better-quality output, leading to increased farm incomes (Ciaian *et al.*, 2015; Bartolini and Viaggi, 2013). Kirchweger *et al.* (2015) found no impact of Austrian agriculture subsidies on impact on revenues. In light of these mixed findings, it is relevant to examine whether, and to what extent, subsidies have influenced farm income in the context under study.

H1: *Subsidies positively impact farmers income.*

Support schemes may have a strong effect on farm investment. On one hand, increased and stable income coming from subsidies may encourage farmers to undertake investments (Gallerani *et al.*, 2008). Furthermore, investments subsidies such as plantation subsidies reduce entry barriers for perennial crops investments that are typically capital-intensive and risk-laden. They act as a “first-loss guarantee” – by covering a portion of upfront costs they encourage farmers to take the risk. Since in most areas, subsidies provided for plantation of orchards is carried in fallow land or land planted with annual crops, the incentive provided create additional multiplier effects: farmers are more likely to invest in complementary assets such as erosion control, support structures, irrigation systems, fencing, hail nets, and pest management systems. Reise *et al.* (2012) found that German farmers investment decisions are mainly driven by capital costs and the subjective perception of the risk resulting from the investment – only about half of the amount of the subsidy, is reflected in an increased willingness to invest (*ibid*). In the case of study, we expect that the subsidy should have an impact on investments, also given that they are provided as co-financing of investments.

H2: Subsidies positively impact farm (current or planned) investments.

Another area of interest is the impact of support schemes on employment. While about CAP effects there is a vast and contradicting literature (Olper *et al.*, 2012; Powell *et al.*, 2016; Petrick and Zier, 2012). Considering the differences in eligibility criteria and conditionalities, the investment subsidies may differ in terms of effect on family farm labour versus the paid labour (Bojnec and Fertő, 2022). While in plantation subsidies the need for labour increase (due to labour intensive starting process and increased need for pruning, spraying, thinning and harvesting) in investment subsidies lead to mechanization it can reduce the need for family labour. There is a scarcity of recent literature on the effect on labour. Further research is needed to assess whether, and to what extent, subsidy schemes have contributed to changes in farm employment in the context of this study.

H3: Subsidies positively impact farm employment.

EU CAP policies are found to have had a significant impact of farm size (Bartolini, and Viaggi, 2013). In non-EU countries investment grants may motivate farmers to convert fallow land to orchard land or even to lease or purchase neighbouring parcels – either temporarily (long-term leases) or permanently – thus increasing the operational farm size, even if legal ownership remains fragmented. Skreli *et al.* (2024) found that subsidy in the dairy sector results in increased flock size (increased production capacities). On the other hand, Skreli *et al.* (2015) and Gecaj *et al.* (2019), found that government subsidy scheme linked to investment (similar to the schemes which are subject of the analysis of this paper) had a clear net impact on increasing areas under perennial plantation in Albania. It is therefore relevant to examine whether investment support schemes have also contributed to an overall expansion of cultivated area.

H4: Subsidies positively impact cultivated area.

Subsidy investments in orchard farming play a crucial role in shaping varietal choices, often steering farmers toward commercially favoured, high-yield cultivars. However, when subsidy schemes are not inclusive of local or traditional varieties, there is high probability that these cultivars are abandoned or uprooted. These effects are already acknowledged in EU and globally (Hammel and Arnold, 2012). Farmers may obtain subsidies in the form of grants for seedlings, but only for improved or pure varieties (FAO, 2021). While during the early stages of post-communist development of the agriculture and rural development policies in Albania the focus was increasing cultivated area (production quantities), over the years, overproduction has increased the pressure to shift the focus toward quality. In

the case of apple, there emerged the need to promote even substitute existing varieties with more market demanded varieties (Skreli and Imami, 2019). It is therefore of interest to assess, if or to what extent subsidies have contributed to changing/improving apple variety structure.

H5: *Subsidies impact apple variety structure (shifting to more market demanded varieties).*

2. Data and methods

The study draws on a structured face-to-face farm survey conducted in 2019 in Korca, the leading fruits/apple production region (as highlighted in the Introduction). The questionnaire was developed based on the literature review and semi-structured, in-depth interviews with value chain actors and sector experts carried out in 2018 and 2019. The sample universe consisted of all farmers who benefited from policy support during the period 2013-2018, while non-beneficiaries were randomly selected from the same villages where the beneficiaries were located.

The analysis of the impact of subsidy schemes in the apple sector is based on data from $n = 244$ apple farmers, 90 of whom have benefited from subsidy schemes during 2013-2018 and 154 have not benefited. Table 1 presents the main sample characteristics for the beneficiary and non-beneficiary groups. The shaded columns are the exploratory variables (i.e., variables used for matching), and the non-shaded columns are the outcomes of interests for assessing the impact.

The farmers' characteristics (covariates) used to create a homogenous group of farmers on observables include: farmers' age; household size; emigration (i.e. whether, there are emigrants in the family); household education level; farm/household agriculture land in ownership; (financial) record keeping and costs calculation (i.e. whether the farmers calculate production costs).

To assess the subsidy scheme impact two approaches are employed: causal forests and matching.

Causal effects are defined via the potential outcomes model (Imbens and Rubin, 2015): For each sample i , it is assumed that the potential outcomes $Y_i(0)$ and $Y_i(1)$ corresponding to the outcome we would have observed had we assigned control or treatment (W) to the i -th sample, and assume that we observe $Y_i = Y_i(W_i)$. The average treatment effect is then defined as $\tau = [Y_i(1) - Y_i(0)]$, and the conditional average treatment effect function is $\tau(x)=[Y_i(1) - Y_i(0)|X_i = x]$. In order to identify causal effects, we assume un-confoundedness (i.e., that treatment assignment is as good as random conditionally on covariates (Rosenbaum and Rubin, 1983).

Table 1 - Sample characteristics

Category (variable)	Beneficiaries (N = 90)		Non-Beneficiaries (N = 154)	
	Mean	Std.Dev	Mean	Std.Dev
Farmers' Age (years)	51.29	12.6	48.42	15.3
Farm size area (Ha)	25.78	24.64	18.62	16.3
Farmers' Education (years)	11.94	3.11	11.53	2.43
Household size	4.38	1.44	4.32	1.41
Keep notes & Calc. prod cost (yes/no)	28.0%	0.45	26.0%	0.44
Buyer – cold storage	37.0%	0.48	36.0%	0.48
Designated Successor (yes/no)	37.0%	0.48	26.0%	0.44
Revenue's apple (direct) (ALL)	11,123,946	11,040,887	7,005,715	8,115,956
Revenue's apple (indirect) (ALL)	17,151,567	30,924,866	9,766,672	11,166,596
Farm investment 2013-2018 (ALL)	16,974,444	22,320,603	8,861,779	16,538,388
Plans to invest in the next 5 years (ALL)	8,666,667	30,314,827	3,721,429	9,385,533
No Hired workers	6.21	5.89	4.03	4.84
Land area planted with apples (dynym)	16.27	20.54	10.72	6.96
Number of apple trees	2,184.91	2,721.41	1,193.56	1,357.98
Number of Starching trees	993.22	1350.05	487.11	620.6
Number of Reinnet trees	34.5	177.32	9.61	37.43
Number of Ida red trees	107.11	201.17	123.61	264.49
Number of Granny smith trees	176.62	352.96	72.82	161.99
Number of Golden trees	399.57	1006.31	284.65	502.45
Number of Fuji trees	427.56	744.23	192.41	573.71
Number of other apple trees	46.33	166.8	23.34	113.87

Note: Dynym is 0.1 Ha; Y/N → the answer is a yes or no and the mean value shows the share of respondents that have answered yes; ALL → Albanian Lek (old format – has one more zero) – 1 EUR = 100 ALL (or 1000 Old ALL) (approximate average exchange rate during 2024)

In the first approach, the impact is evaluated with causal forests, which is an adaptation of the Breiman (2001) random forest algorithm for treatment effect estimation. Causal forest is a non-parametric method for heterogeneous

treatment effect estimation that allow for data-driven feature selection while maintaining the benefits of classical methods, i.e., asymptotically normal and unbiased point estimates with valid confidence intervals (Athey, *et al.*, 2019). Its estimate can be thought of as an adaptive nearest neighbour method, where the data determines which dimensions are most important in selecting nearest neighbours. While classical methods such as k-nearest neighbours seek the k closest points to x according to some pre-specified distance measure (e.g., Euclidean distance), tree-based methods define closeness with respect to a decision tree, and the closest points to x are those that fall in the same leaf. The advantage of trees is that their leaves can be narrower along the directions where the signal is changing fast and wider along the other directions, potentially leading to a substantial increase in power when the dimension of the feature space is even moderately large.

The causal forest estimation is done through the *grf* R package, which starts by fitting two separate regression forests to estimate $\hat{m}(\cdot)$ (main effect function) and $\hat{e}(\cdot)$ (propensity function). It then makes out-of-bag predictions using these two first-stage forests and uses them to grow a causal forest (see Athey and Wager, 2019). The causal forest is trained and its parameters (e.g., min node size) are tuned by cross-validation (i.e., the parameters that minimize the objective function are selected). In addition, to improve precision as suggested by Athey and Wager (2019) first a pilot random forest is trained on all features (not all are presented here), and then a second forest is trained on only those features that saw a reasonable number of splits in the first step. Given good estimates of $\hat{Y}$ and $\hat{W}$, this approach eliminates confounding effects (see Ertefaie (2018) for a further discussion).

In the second approach matching is used to match beneficiaries and non-beneficiaries on observables (see shaded area of table 1 for all covariates used in matching) to make them as similar as possible. In other words, to equate (or “balance”) the distribution of covariates in the treated and control groups (See figure in Annex 1 for the covariate balance), so that the only thing that they would differ is treatment (benefiting from the subsidy). Then, to assess subsidy impact the average treatment effect (ATE) is estimated by regressing the treatment and covariates used during matching on the outcomes (see non shaded area of table 1 for descriptive statistics of outcome variables of interest).

On the other hand, the second estimation procedure of the impact of subsidy schemes that relies on matching employs genetic matching, which uses a search algorithm to iteratively check and improve covariate balance (see section 4.1 Sample balance and identification checks), and it is a generalization of propensity score and Mahalanobis Distance (MD) matching (Rosenbaum and Rubin 1985). It is a multivariate matching method that

uses an evolutionary search algorithm aimed at maximizing the balance of observed covariates across matched treated and control units. (Diamond and Sekhon 2013). Then, to assess subsidy impact on an outcome the average treatment effect (ATE) is calculated by regressing the treatment and covariates used during matching on the outcome of interest on the matched data.

3. Results

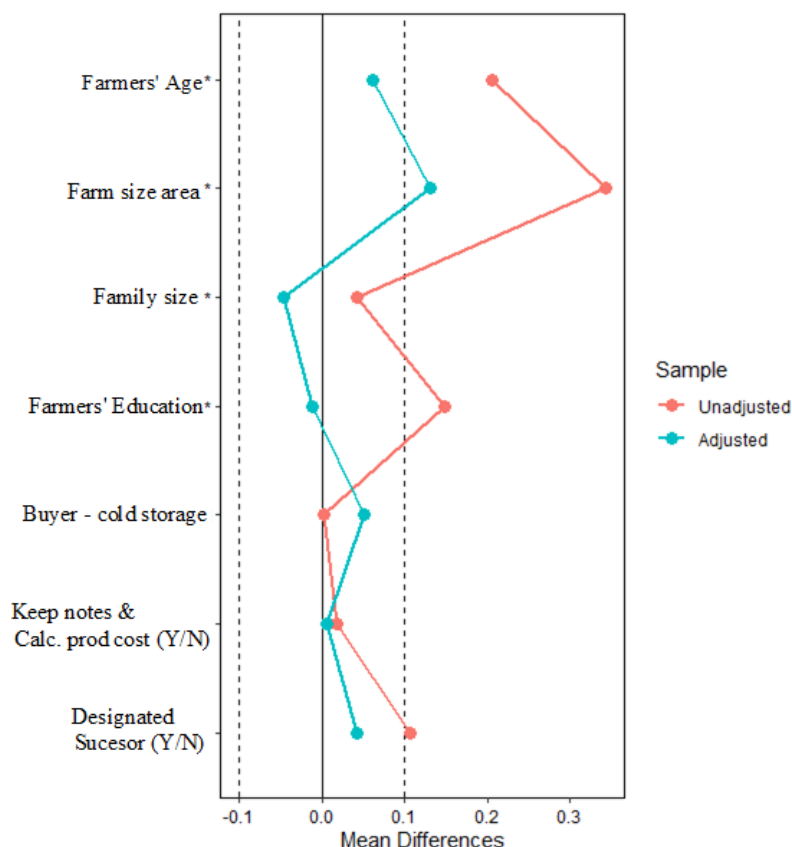
3.1. Sample balance and identification checks

Figure 1 plots standardised mean differences for every matching covariate before and after genetic matching. All covariates fall below the ± 0.10 threshold post-matching (aside farms size area, which is very close to the threshold), confirming that treated and control groups are comparable on observables. Multivariate imbalance (L1) drops from 0.889 to 0.735, and the share of observations inside common support rises from 6.8% to 17.6% (Table 2). These diagnostics support the un-confoundedness assumption.

Table 2 - Univariate imbalance measures

Category (variable)	Type	Pre-Matching		After Matching	
		Statistic	L1	Statistic	L1
Farmers' Age	(diff)	2.873	0.000	-0.245	0.000
Farm size area	(diff)	7.161	0.009	1.322	0.000
Farmers' Education	(diff)	0.412	0.019	0.000	0.000
Family size	(diff)	0.060	0.040	0.000	0.000
Keep notes & Calc. prod cost (Y/N)	(diff)	0.018	0.018	0.000	0.000
Buyer - cold storage	(diff)	0.003	0.003	0.000	0.000
Designated Successor (Y/N)	(diff)	0.107	0.107	0.000	0.000

Figure 1 - Covariate balance statistics



Note: Matched sample 98 of which 49 Beneficiaries and 49 non-Beneficiaries.

3.2. Average treatment effects on investment, revenue and scale

Table 3 compares average treatment effects (ATE) from the causal forest (CF) and genetic matching (GM).

H1: *Subsidies positively impact capital investment – Supported.*

Evidence shows that beneficiary farms invested significantly more than non-beneficiaries over the 2013-2018 period. The covariate balancing method (CF) estimates an average additional investment of ALL 4.70 million, which corresponds to a 39% increase relative to the sample-wide mean, and is statistically significant at the 10% level ($p < 0.10$). The generalized matching

(GM) estimate is slightly lower at ALL 3.63 million and not statistically significant at the 5% level, indicating some efficiency loss when unmatched observations are excluded. Nevertheless, both estimates suggest a positive and economically meaningful effect of subsidies on capital investment.

H2: *Subsidies positively impact farm income – Partially supported.*

The analysis reveals a positive effect of subsidies on direct apple revenue. The covariate balancing method (CF) estimates a statistically significant gain of ALL 2.48 million, equivalent to a 29% increase relative to the sample mean ($p = 0.037$), with a 95% confidence interval that excludes zero. The generalized matching (GM) approach yields a slightly larger estimate of ALL 3.42 million, though only marginally significant at the 10% level. However, when farm income is estimated indirectly through the price-quantity decomposition, the results are imprecise in both models, suggesting greater measurement error. Overall, the evidence provides moderate support for a positive income effect, particularly when using direct revenue data.

H4: *Subsidies positively impact cultivated area – Supported.*

Findings indicate that subsidies led to a measurable expansion in farm scale. Beneficiary farms increased their planted area by 3.0 dynym according to the covariate balancing method (CF, $p < 0.10$), and by 2.5 dynym under the generalized matching approach (GM, $p < 0.05$). Additionally, farms added approximately 600 apple trees (CF) and 535 trees (GM), with both estimates statistically significant at the 5% level. The consistency across models suggests that these changes reflect genuine scale enlargement, not just reallocation of existing resources, thereby confirming a positive effect of subsidies on cultivated area.

3.3. *Shifts in varietal composition*

H5: *Subsidies positively impact apple variety structure – Supported.*

The grant programme appears to have contributed to a shift toward more market-demanded apple varieties. According to covariate balancing (CF) estimates, there were statistically significant reductions in the share of 'Idared' (-4.8 percentage points) and 'Golden' (-8.3 pp), accompanied by a symmetric increase in 'Fuji' (+7.2 pp) – all significant at the 5% level. These varietal adjustments are consistent with the difference-in-differences comparison of varietal shares between 2013 and 2018. Although the generalized matching (GM) results confirm the same direction of change, the standard errors are larger, underscoring the greater precision and data

retention advantage of CF. Overall, the results support the hypothesis that subsidies have influenced varietal upgrading in apple production.

Table 3 - Estimation of the ATE with causal forest and genetic matching approach

Category (variable)	Causal Forest ATE & 95% CI	Genetic Matching ATE & 95% CI
Revenue's apple (direct) (ALL)	2,480,202 +/- 2,288,947	3,420,673 +/- 3,850,755
Revenue's apple (indirect) (ALL)	4,139,887 +/- 5,686,389	10,002,284 +/- 13,74,7544
Farm investment 2013-2018 (ALL)	4,704,232 +/- 4,839,640	3,629,974 +/- 4,923,947
Plans to invest in the next 5 years (ALL)	5,049,054 +/- 7,031,487	1,148,768 +/- 2,237,387
Number of hired workers	1.292 +/- 1.33	1.409 +/- 2.098
Land area planted with apples (dynym)	2.957 +/- 3.502	2.501 +/- 2.029
Number of apple trees	599.537 +/- 528.59	534.851 +/- 446.112
Share of Starking to total apple trees	3.7% +/- 6.5%	2.6% +/- 4.9%
Share of Ida Red to total apple trees	-4.8% +/- 4.3%	3.4% +/- 2.8%
Share of Golden to total apple trees	-8.3% +/- 5.2%	-3.3% +/- 3.8%
Share of Granny smith to total apple trees	1.9% +/- 4.0%	-2.2% +/- 3.8%
Share of Fuji to total apple trees	7.2% +/- 6.3%	-0.7% +/- 5.1%
Share of Reinnet to total apple trees	0.7% +/- 1.5%	0.2% +/- 0.8%
Share of the difference in number of Ida red 2018-2013 to total apple trees	-4.6% +/- 4.8%	0.2% +/- 1.5%
Share of the difference in number of Golden 2018-2013 to total apple trees	-1.0% +/- 3.0%	-5.1% +/- 3.2%
Share of the difference in number of Fuji 2018-2013 to total apple trees	5.3% +/- 4.3%	6.6% +/- 3.7%

Note: The outcomes in the green area are calculated by taking the difference in number of trees for the variety of interests between 2018 and 2013 divided by the number of apple trees in 2018.

3.4. Employment effects

H3: *Subsidies positively impact farm employment – Not supported.*

The evidence does not point to a strong or consistent employment effect. The covariate balancing method (CF) estimates a modest increase of 1.29 hired workers, which is marginally significant at the 10% level, but not at the more conventional 5% threshold. The generalized matching (GM) model shows a similarly sized increase (1.41 workers), though the estimate lacks statistical precision. These results, observed in a context of labour scarcity due to out-migration and ongoing mechanisation in the Korça region, are in line with mixed findings from the EU and point toward capital deepening rather than labour expansion as the primary adjustment channel.

4. Discussions and conclusions

This article assessed Albania's orchard-investment grant programme through two lenses: (i) its causal impact analysis on apple-farm performance during 2013-2018 and (ii) the comparative merits of two identification strategies – genetic-matching regression and the generalised random-forest (GRF) algorithm. Drawing on a survey of 244 farms in Korça and anchoring the analysis in the extensive subsidy literature, the section concludes by highlighting policy implications and study limitations.

The evidence confirms the study hypotheses. First, beneficiary farms realised a 39 % increase in capital outlays – comparable to the 20-35% uplift reported for Austrian “modernisation” grants (Kirchweger *et al.*, 2015) and to the credit-constraint relief observed under Ireland's decoupled payments (Toole & Hennessy, 2015).

Second, grants translated into a 29 % gain in direct sales revenue. The result converges with Gallerani *et al.* (2008), who found that orchard investments in Emilia-Romagna lifted gross margins once trees reached maturity, and is directionally opposite to Kirchweger *et al.*'s (2015) null revenue finding for annual-crop holdings – suggesting that perennial sectors capture investment returns more directly.

Third, the programme prompted structural upgrading, a marked shift away from ‘Golden’ and ‘Idared’ towards the higher-valued ‘Fuji’ (confirming H4 by demonstrating that targeted subsidies can influence product mix, not merely scale). This corroborates Skreli & Imami's (2019) qualitative diagnosis of cultivar mismatch and resonates with the CAP-driven varietal renewal documented for Italian and Spanish fruit farms (Gallerani *et al.*, 2008).

Employment effects were modest and statistically fragile, mirroring the mixed EU record, Olper *et al.* (2012) reported positive labour responses to

Pillar I transfers, whereas Powell *et al.* (2016) and Petrick & Zier (2012) found neutral or negative effects once mechanisation and rising wages were considered. In the context of relatively high labour abundance characterizing Albania during the time the survey was implemented, limited job creation should not be viewed as policy failure; rather, it can indicate capital-deepening association without extensive labour absorption (or with better utilization of household labour), as foreseen by Bartolini & Viaggi's (2013) model of structural change. Recent causal-forest evidence from Albania's dairy sector likewise detected no significant employment impact of coupled and headage payments (Skreli *et al.*, 2024).

Collectively, the results position Albania's orchard scheme within the mainstream of European evidence, it relaxes liquidity constraints, triggers productivity-oriented investments and nudges production towards higher market value, thereby supporting the income-stabilisation findings of Bojnec & Fertő (2019).

The comparison of genetic-matching regression with GRF provides new insights for impact evaluators. Both estimators confirmed the sign of programme effects, reinforcing internal validity. However, GRF yielded slightly larger investment impacts and smaller revenue impacts than matching. This divergence reflects their conceptual differences: matching minimises observable imbalance but trims observations outside common support, a weakness stressed by King & Nielsen (2019); GRF retains the full sample, captures high-order interactions and produces individualised treatment effects, in line with the robustness arguments of Athey & Wager (2019) and the consistency proofs of Wager & Athey (2018).

Our moderate sample size ($n = 244$) did not unduly penalise GRF – consistent with Scornet *et al.*'s (2015) claim that ensemble methods stabilise predictions in small datasets – but it did limit the granularity of heterogeneous-effect plots. In practice, GRF revealed that farms already keeping cost records captured the largest revenue gains, a nuance the matching model could not easily uncover. For policymakers planning performance-based disbursement, this level of detail is useful.

Looking ahead, policymakers can strengthen the programme on four fronts. First, tighten budget calibration and cross-compliance, keep the grant envelope healthy – perhaps even expand it – while tying future payouts to clear food-safety and environmental benchmarks that mirror upcoming CAP-2030 rules. Second, pursue integrated value-chain support: the shift toward higher-value cultivars will pay off only if growers also gain access to modern cold-storage and grading facilities, so new calls should pair orchard renewal with post-harvest investments. Third, broaden targeted advisory services, subsidising training in cost accounting and marketing could help smaller, less business-oriented producers catch up. Finally, it is important to

make evidence-based improvements a regular part of monitoring to ensure that public funds are used as effectively as possible. This can be achieved by implementing the Farm Accountancy Data Network (FADN) in Albania, which remains one of the few countries in the region without such a system in place.

Despite these contributions, the study's inferences must be viewed in light of several manageable limitations, its cross-sectional design cannot eliminate all unobserved heterogeneity (DiPrete & Gangl, 2004); both estimators assume selection on observables, leaving room for hidden bias; the Korça-focused sample, while covering over half of national output, may not capture regional idiosyncrasies; the moderate sample size restricts very fine accurate subgroup analyses; and outcome variables exclude long-run yield, quality and profitability. Future panel data, broader geographic coverage, and administrative records will enable more robust cost-effectiveness assessments without compromising the advancements presented here.

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Annex

Table A1 - Univariate Imbalance Measures

	Type	Pre-Matching		After Matching	
		Statistic	L1	Statistic	L1
Farmers' Age	(diff)	2.873	0.000	-0.245	0.000
Farm size area	(diff)	7.161	0.009	1.322	0.000
Farmers' Education	(diff)	0.412	0.019	0.000	0.000
Family size	(diff)	0.060	0.040	0.000	0.000
Keep notes & Calc. prod cost (Y/N)	(diff)	0.018	0.018	0.000	0.000
Buyer - cold storage	(diff)	0.003	0.003	0.000	0.000
Designated Successor (Y/N)	(diff)	0.107	0.107	0.000	0.000

Note: Pre-Matching – Multivariate Imbalance Measure: L1 = 0.889, Percentage of local common support: LCS = 6.8%; After Matching – Multivariate Imbalance Measure: L1 = 0.735, Percentage of local common support: LCS = 17.6%.

Table A2 - Measure and objectives

Measure (CAP 2023-27 code)	Pillar	Key objective(s)
Coupled income support (CIS) – “Voluntary Coupled Support”	I	Prevent the abandonment or decline of sectors that are economically, socially or environmentally important but face structural difficulties, by boosting their competitiveness, sustainability and/or quality ² .
Decoupled income support – “Basic & complementary payments” (e.g., BISS, CRISS)	I	Provide a stable income safety-net and enhance farm resilience , while letting farmers follow market signals and deliver public goods (climate, environment, animal welfare) through reinforced conditionality ³ .
Investments in physical assets	II	Improve the economic and environmental performance of holdings and processors, raise resource-efficiency , enhance animal-welfare/food-safety , and supply enabling infrastructure for agriculture and forestry ⁴ .

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Orjon Xhoxhi

Faculty of Economics and Agribusiness, Agricultural University of Tirana
Rruga Paisi Vodica 1025, Tiranë
Email: oxhoxhi@ubt.edu.al

He is an Associate Professor at Agricultural University of Tirana. He earned a PhD in development economics from the University of Copenhagen in 2017. His main research interests lie in the field of value chain governance and power. He is experienced in quantitative analyses and has assisted several research activities and projects in the framework of the development assistance in Albania and other emerging economies.

Engjell Skreli

Faculty of Economics and Agribusiness, Agricultural University of Tirana
Rruga Paisi Vodica 1025, Tiranë
Email: eskreli@ubt.edu.al

He earned his title as a Professor at Agricultural University of Tirana. Currently he is a researcher and lecturer at Department of Agricultural Economics and Rural Development Policies, Agricultural University of Tirana. His main research interests lie in the fields of collective action consumer preferences, non-market valuation and impact evaluation. He has a very long experience in education and policymaking.

Edvin Zhllima

Faculty of Economics and Agribusiness, Agricultural University of Tirana
Rruga Paisi Vodica 1025, Tiranë
Email: ezhllima@ubt.edu.al

He has a PhD in agri-food economics and policy from the University of Bologna and is currently a Professor at the Faculty of Economics and Agribusiness, Agricultural University of Tirana. Edvin is a researcher and lecturer of development and institutional economics and has conducted research in several fields of study such as resource economics, behaviour economics, and gender economics. He has a long experience in development assistance toward the socio-economic empowerment of vulnerable communities.

Drini Imami

Faculty of Economics and Agribusiness, Agricultural University of Tirana
Rruga Paisi Vodica 1025, Tiranë
Email: dimami@ubt.edu.al

Drini Imami earned a PhD in agri-food economics and policy from the University of Bologna in 2011 and is currently a Professor at the Faculty of Economics and Agribusiness, Agricultural University of Tirana. He has conducted research in several leading European research institutions and has worked as a consultant for various development agencies. Research interests include behavioral, political, and institutional economics.



Foreign Direct Investment, Skilled Labour, and Technical Efficiency: Perspective from Indonesia's Foods and Beverages Exports

Kabiru Hannafi Ibrahim^{a,b}, Rossanto Dwi Handoyo^{*b}, Nur Istifadah^b

^a Federal University Birnin Kebbi, Nigeria

^b Universitas Airlangga, Indonesia

Abstract

In this study, we examined the roles of foreign direct investment (FDI), skilled labour, and technical efficiency in determining the exports of the food and beverage industries in Indonesia. To address this issue, we utilised data from industry micro firms for the period 2010-2015. We applied the maximum likelihood estimation (MLE) technique to the logistic model and the stochastic frontier analysis (SFA). Findings revealed that the food and beverage industries are operating below the possible technical efficiency (TE). However, foreign direct investment, skilled labour, technical efficiency, and industrial concentration assert a significant positive effect on the probability of firms' exports. In the food and beverages sector and the beverages industry, firm size promotes exports; however, in the food industry, firm size has the opposite effect, reducing exports. The imported raw materials have an insignificant effect on the firms' probability of exporting. Interestingly, findings on the mediating roles of technical efficiency and industrial concentration, as well as technical efficiency and firm size, revealed an increasing influence on the probability of exporting. Skilled labour and firm size only positively promote exports in the foods and beverages sector and the food industry, but not in the beverages

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* *Corresponding author:* Rossanto Dwi Handoyo - Department of Economics, Faculty of Economics and Business, Universitas Airlangga - Surabaya 60286, Indonesia. E-mail: rossanto_dh@feb.unair.ac.id.

industry. These findings are novel and present an important pathway for policy-making related to the food and beverage industry, potentially shaping future strategies and initiatives in the Indonesian food and beverage sector.

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Introduction

Exporting is a key indicator of firm performance, particularly for firms engaged in foreign markets and competition (Lestari *et al.*, 2024). Exporting offers firms an avenue for growth and access to foreign markets, which stimulates dynamism in an economy (Edwards *et al.*, 2017). Business firms are attempting to enhance their competitive position by entering foreign markets through exports, a trend that is not exclusive to the Indonesian food and beverage (F&B) industries, nor to similar ones. To maintain a competitive position, product and service quality must be improved, and this will pave the way for further innovation (Rehman, 2017). In this study, we aim to address the issues of exporting in Indonesia's food and beverage sector. This is because, at the global level, the demand for food has increased significantly, and Indonesia has played a crucial role in meeting this global demand. This is because Indonesia is a key player in the food and beverage sector, as it is one of the world's largest suppliers of food and beverages. The food and beverage sector is a key component of the Indonesian economy. The industries in the sector continued to be a source of value addition, employment generation, and expanding economic activities. An analysis of the F&B sector is important as these food items tend to experience a rapid increase in consumption over supply. This trend has also been accompanied by an expanding global conflict and population growth, which mostly hamper food distribution (Rozi *et al.*, 2023). The F&B sector is growing rapidly in Indonesia and contributes heavily to the growth of manufacturing and other sectors (Tamin *et al.*, 2024; Yasin, 2021). The sector is the second-largest contributor to the Indonesian economy (Bui *et al.*, 2022). Indonesia can play a crucial role in the global food and beverage supply chain by exporting and contributing to the mitigation of impending global food insecurity.

Export is key to the growth, expansion, and survival of firms in the food and beverage industry. It has resulted in increased competitiveness and productivity for many years. Various factors determine the engagement of firms within the industry in international markets. Therefore, understanding and assessing the factors influencing exports in the F&B sector will be of immense significance. Indonesia is a relatively large, open market economy that makes a significant contribution to global exports. Considering the role

of exporting in Indonesian food and beverage firms and the economy as a whole, it is essential to examine this issue.

The state of Indonesia's exports experienced an average annual growth of 13% from 2010 to 2019, with the highest export recorded in 2011, valued at \$ 203.5 billion (USD). Meanwhile, the lowest export value was recorded in 2016, at \$ 144.49 billion. This is based on the Indonesian Foreign Trade Statistics, as per the 2018-2019 ISIC code, published by the Indonesian Statistics Bureau. Increased exports are associated with improved performance in the food and beverage industries. In Indonesia, the gross manufacturing value-added contribution of the F&B industries is 23.15% with a strong linkage with upstream and downstream sectors (Tamin *et al.*, 2024).

Empirically, two theories explain the reason why firms that export have higher productivity than firms that do not export. The first theory is the self-selection condition, which applies only to firms with high productivity and those that engage in exporting (Gupta *et al.*, 2018; Rachbini, 2017; Serti & Tomasi, 2008). Engaging in the international market and exporting is restricted by barriers or additional costs, such as marketing and transportation costs (Niringiye & Tuyiragize, 2007; Rachbini, 2017). The second theory is learning by exporting (LBE), where firms that export will become more productive and efficient. This occurs because business firms that engage in exporting gain knowledge, such as new technologies and information from foreign buyers.

Additionally, firms are motivated to improve product quality and continue innovating to fulfil foreign consumer tastes and increase competitiveness (Lemi & Wright, 2020). The validation of these theories remains unclear and is still debated to date. However, the theory of self-selection has been recognised more than the theory of LBE, and some researchers have reported biased findings (Granér & Isaksson, 2009; Thomas & Narayanan, 2012).

The existence of foreign investment is also a factor that affects the company's decision to export. Foreign direct investment (*FDI*) through spillover can carry information, knowledge, and new technology, as well as access to international market networks (marketing) that can benefit the firm (Niringiye & Tuyiragize, 2007). The role of *FDI* in influencing a firm's decision to export has been shown to have a significant and positive impact on export (Fu, 2011; Hoekstra, 2013; Wignaraja, 2008a, 2008b). Furthermore, the existence of skilled labour can accelerate the absorption of new technology, as well as the development of business strategies and company management capabilities that can increase competitiveness (Wignaraja, 2008a). The role of skilled labour has proven to have a significant and positive influence on exports (Díaz-Mora *et al.*, 2015; Wignaraja, 2008a).

From Indonesia's perspective, studies that explain the factors influencing exports are limited, with very few exceptions, such as Handoyo *et al.* (2023b)

who examined trade margins of rubber exporters and Saputra (2014), who examined the presence of self-selection theory where technical efficiency (*TE*) affects firms' exports in 6 Indonesian industrial sectors. However, in this study, we aim to investigate the influence of *FDI*, skilled labour, and *TE* on the export of the F&B sector. We utilised firms' level micro data and appropriate econometric techniques and assessed the role of these factors in determining exports of the F&B industries. To date, there is no existing study that specifically focuses on the export of food and beverage firms. This signifies a gap in existing studies, which our present study intends to bridge.

Additionally, the present study contributes to existing works by further investigating the mediating influence of *TE* and skilled labour among other variables on the export of F&B firms. Our empirical strategies indicate that, regardless of the control variables incorporated into our formulated models, *FDI*, skilled labour, and *TE* positively influence the probability of firms' exports in the F&B sector and specifically in each of the industries operating within the sector. However, firms' size and industrial concentration also influence the probability of firms' exports. Interestingly, findings on the mediating roles of *TE* and industrial concentration, as well as *TE* and firm size, and skilled labour and firm size, reveal an increasing impact on firms' exports. Although our results are specific to Indonesia, the findings will serve as a guide for policy-making in the food and beverage industries of other economies.

The remaining components of this work are organised into the following four segments: Part One presents a review of the literature and theoretical underpinnings, Part Two discusses the research methods, Part Three presents the findings, and lastly, the study provides a conclusion.

1. Literature and Theoretical Basis

There exist two hypotheses that explain why firms that engage in exports are more inclined to be productive and efficient compared to non-exporting firms. These prepositions are self-selection, which posits that companies that have high productivity can penetrate the international market (export more). This is due to additional costs, such as transportation, marketing, and network-building expenses abroad, as well as costs incurred to employ skilled labour to manage networks abroad or develop product innovations for export. It has been well-documented that firms engaging in exports record more success than their counterparts (or non-exporting firms) due to increased competitiveness and productivity (Harris & Li, 2008; Imbriani *et al.*, 2014). The second premise, known as "learning-by-exporting" or "learning-by-doing", posits that the knowledge acquired from foreign buyers

and competitors helps the potential firm to improve and effectively handle the advent of new competitors after entering the market. In addition, companies that engage in international sales face greater exposure to competition in comparison to domestic enterprises. Consequently, they must enhance their performance at a faster pace and strive for flawless execution to outperform their local counterparts. (Haidar, 2012; Bernard & Jensen, 1999; Bernard & Wagner, 1997). By entering foreign markets, firms tend to gain greater knowledge through innovation and the adoption of new productive techniques (De Loecker, 2013). Although many studies have established evidence of self-selection, Aggrey *et al.* (2010) observed the non-existence of self-selection in the case of East African firms' export decisions.

Export is influenced by many factors, as reported by many other recent studies (Handoyo *et al.*, 2022a; Handoyo *et al.*, 2023a; Handoyo *et al.*, 2023b; Handoyo *et al.*, 2024a; Handoyo *et al.*, 2024b; Handoyo *et al.*, 2024c; Ibrahim *et al.*, 2024), among many others. In addition, existing studies explained that skilled labour, firm size, foreign investment, raw materials imports, industrial concentration, and technical efficiency affect firms' exports. For instance, exporting firms tend to recruit skilled labour, offer higher remuneration, and are more technologically inclined than their counterparts (Trofimenko, 2008). In Máté's (2015) study, an industry is deemed highly skilled if it possesses a proportion of skilled labour that exceeds the average by 20%. An industry is considered medium-skilled if its skill requirement is 5% higher than the average across industries. If, however, none of the mentioned characteristics exist, the industry is considered low-skill. The relationship between skilled employment and exports has been well-documented by numerous studies. In the case of the Chilean manufacturing industry, Balat *et al.* (2016) report that companies that use skilled labour tend to export more to developed countries. Lundberg & Wiker (1997) discovered that highly educated workers tend to specialise in exports that require advanced skills and meet international standards. Coxhead & Li (2008) revealed that Indonesia, as a labour-abundant economy, could have seen greater benefits from skill-intensive exports if it had managed to attract more *FDI* and highly trained labour. Cieřlik *et al.* (2015) and Cieřlik *et al.* (2018) report that skilled labour employment promotes export performance in Baltic and Central European firms as well as MENA countries. Contrary to these studies, Fakihi & Ghazalian (2013) revealed a decreasing impact of skilled labour on the probability of firms' export in the MENA sample.

Firm size does affect exports, because large firms have the wherewithal to expand their market beyond the domestic market. Large firms enjoyed a lower cost advantage due to their economies of scale (Roth *et al.*, 2014). Expanding into the international market requires efficient operations by the participating firm, and there is a high tendency for the firm to increase its

exports as it grows in size (Arnold & Hussinger, 2005). Firm size is therefore a crucial determinant of efficiency and productivity, which stimulates export performance (Handoyo *et al.*, 2022b). Studies on the factors influencing exports have confirmed a positive and significant relationship between firm size and exports. For instance, Handoyo *et al.* (2024b) and Saputra (2014) have documented evidence of an increase in export performance due to an increase in firm size. In studies by Cieřlik *et al.* (2015) and Cieřlik *et al.* (2018), as well as Fakić & Ghazalian (2013), the probability of exporting increases with firm size in Baltic and Central European manufacturing firms, as well as in the MENA region. Contrarily, Iyer (2010) observed that an increase in firm size reduces agricultural exports in New Zealand.

The impact of Foreign Direct Investment (FDI) on exports is a topic of significant interest and has been the subject of numerous studies. It has been reported that foreign companies often outperform domestic companies (Din *et al.*, 2009). *FDI* can impact a country's export composition in two distinct ways (Harding & Javorcik, 2012). Firstly, multinational corporations possess superior productive capabilities and technology, enabling them to produce more sophisticated goods than the host country. Secondly, foreign firms possess a significant advantage in terms of knowledge and technology over local firms. According to a study by Head & Ries (2003), foreign firms are more likely to engage in exports, with firm size being a key factor. However, there is a link between firm productivity, market size, and factor incomes in host countries, emphasising the need for careful consideration. In Turkey, for instance, foreign-owned companies contributed a greater percentage to the economy's exports, and a long-run causal link exists between *FDI* and exports (Temiz & Gokmen, 2011). Foreign capital increases the probability of exporting to foreign markets, as noted by Cieřlik *et al.* (2015, 2018) and Fakić & Ghazalian (2013). Findings from studies by Prasanna (2017) and Sahoo & Dash (2014) revealed that the inflow of *FDI* into the Indian economy is crucial in promoting the export sector, highlighting the significant role of foreign investment in international trade.

Industrial concentration is an important factor influencing export performance (Handoyo *et al.*, 2021). Industrial concentration has proven records of promoting export resilience (Zaclicever, 2016). This suggests that the greater the concentration of industry, the higher the probability of surviving in international competition. However, firms can import raw materials/input to meet foreign demand for their products. Importing can enhance the quality of exports (Xu & Mao, 2018). By importing inputs, the company can leverage the latest technology to enhance the quality of its existing products (Castellani & Fassio, 2019). Sourcing raw materials from foreign markets can pave the way for higher productivity and quality, which in turn leads to increased exports (Edwards *et al.*, 2017). Business enterprises

that simultaneously engage in export and import activities experience greater capital intensity, productivity, and employment gains than those involved in either export or import alone (Edwards *et al.*, 2017). A study by Halpern *et al.* (2015) found that high productivity gains and quality output result from mixed sources that utilise both domestic and foreign inputs. Studies on the link between exports and raw materials imports include Xu & Mao (2018), who, in the case of China, scrutinised and examined the relationship between export quality and intermediate imports. They report that increased import is closely linked to high-quality exports. Edwards *et al.* (2017) examined the link between manufacturing exports and imports of intermediate inputs, observing that imports of intermediate inputs from developed countries promote exports in South Africa. This corroborates with Grazzi *et al.*'s (2017) finding.

In the case of Indonesia, Saputra's (2014) empirical strategies revealed that technical efficiency influenced export intensity in six sub-manufacturing sectors. While examining the effect of allocative efficiency (*AE*) and *TE* on exports for Slovenian firms, Pušnik's (2010) study revealed that export orientation is high in more efficient firms, and the role of *TE* in promoting exports is more pronounced than that of *AE*. As reported by Náglová & Šimpachová Pechrová (2021), foreign companies were found to be more efficient than local firms in the Czech Republic's food and beverage sector, and firm size also influences technical efficiency. The impact of F&B exports on *TE* in Iran has been investigated by Kazerooni *et al.* (2013), who employed SFA and dynamic panel modelling to data covering the period 2000-2009. The strategies unravelled that exports and research and development (R&D) spending positively and significantly influence the *TE* of F&B exports, while human capital in terms of skill reduces *TE*.

Using data from the Halal F&B industry in five countries (Indonesia, Pakistan, South Africa, Malaysia, and Singapore), Rusmita *et al.* (2023) analysed the effect of technical efficiency on firms' value. The panel estimation strategy reveals that, except in the case of Pakistan, technical efficiency has a significant impact on firm value in all countries. At the same time, stock market performance is crucial for firms' technical efficiency. Over the period from 2009 to 2019, Hamidi *et al.* (2022) analysed the technical efficiency of Indonesian and Malaysian palm oil exports to 59 major importing countries. Their principal findings are that there exist inefficient exports of the world's palm oil, although the two countries dominate different markets with high export potential in the same markets. During the study period, Indonesia proved to be more efficient than Malaysia. Therefore, the two countries need to harmonise their policies related to palm oil to tap their existing export potential in partner countries fully. A study by Setiawan *et al.* (2012) examined the relationship between technical efficiency and industrial

concentration in the Indonesian food and beverage industry. Their findings suggest that the industry is less efficient with high industrial concentration, and a one-way Granger causality exists, with concentration negatively affecting technical efficiency.

A study by Rifin (2017) examined the influence of firm size, location, imported inputs, and foreign capital on exporting in Indonesia's food processing sector. Findings indicate that location, imported inputs, and foreign capital affect processed food exports in Indonesia. The dynamics and competitiveness of Indonesian food industry exports, along with their determinants, have been analysed by Wardani *et al.* (2018). Their strategy, based on revealed comparative advantage, indicates strong competitiveness in Indonesia's Regional Comprehensive Economic Partnership (RCEP) countries, as recorded by the food industry. Likewise, the dynamics of the food industry indicate a rising trend, driven by GDP and population growth in importing countries, as well as factors such as distance, trade openness, tariffs, and export prices, influencing food exports to RCEP countries. In the case of Indonesia's palm oil exports, Teguh *et al.* (2024) report that exports are influenced not only by product comparative advantage but also by export prices, previous market demand, and an increase in the downstream industry. Sugiharti *et al.* (2020) revealed that Indonesia's food exports have a more price elastic supply, implying that price volatility could mainly affect food exports, with improved logistics enhancing exports. Based on firm-level data (2008-2015), Solow's residual growth accounting and fixed effect (FE) model, Yasin's (2021) study shows that the F&B industry exhibits an increasing total factor productivity (TFP).

Additionally, firm size, market concentration, and absorptive capacity increase the TFP of F&B-producing firms. The intensity of imported raw materials reduces the growth of TFP, although firms that import raw materials perform more than non-importing firms. Similarly, Widodo & Firmansyah (2017) demonstrate that the F&B industry experienced greater TFP and productivity growth than any other industry in Indonesia over the period 2000-2009. Furthermore, the main drivers of F&B's TFP growth are *TE*, scale efficiency, and technical progress. The Indonesian food and beverage industry experienced a steady decline in productivity due to a low level of innovation, as reported by Setiawan *et al.* (2022). Only after the commencement of Indonesian competitive law has innovation had a positive influence on dynamic productivity growth.

Between 2001 and 2021, Abdullahi *et al.* (2024) employed the gravity model of trade. They found that the economic size of China, African population growth, and trade costs promote agricultural food exports between China and 48 African countries. Similarly, in the case of Nigeria's bilateral agricultural food exports to European Union (EU) countries, Abdullahi *et*

al. (2021a) report that Nigeria and EU's GDP and transport cost increases agricultural food exports from Nigeria to EU member states, while their per capita income, exchange rate, and EU new membership negatively affect export to EU. Using the gravity model of trade, fixed effect (FE), ordinary least square (OLS) estimate, Poisson Pseudo Maximum Likelihood (PPML), and Heckman models Abdullahi *et al.* (2021b) show that Nigeria's agricultural exports to its 70 major trading partners are positively affected by its GDP and importer partners' GDP, importers population, ECOWAS and EU memberships, and contiguity. Exchange rate, distance, Nigeria's population, and landlocked status negatively affect agricultural food exports. Nzewi (2017) established a link between Nigeria's processed food exports and global demand for processed food during the period from 1995 to 2004.

In another study, Aktas *et al.* (2023) employed the gravity model to examine the determinants of Turkey's exports of dried fruit and dried fruit products from 2005 to 2021. Their empirical strategy, based on the PPML estimator, indicates that Turkey's GDP, the GDP of importing countries, EU membership, trade agreements with importing countries, and temperature change all increase the production of dried fruits and dried fruit products. The transport cost, as measured by distance, reduces exports. Shariar *et al.* (2019) employed the gravity model, PPML, and Heckman models to examine the factors influencing Chinese food meat exports to its 31 trading partners over the period 1970-2016. The study shows that exchange rate, GDP, land mass, common language, common border, 'Belt and Road' initiative, and WTO membership influence food meat export. In the Kea *et al.* (2019) study, the dynamic gravity model, PPML, generalised least squares (GLS), and the Heckman models were employed to analyse the factors influencing Cambodian rice exports. Findings indicate that agricultural land reform, exchange rates, and historical ties have a positive impact on rice exports to China, ASEAN, and EU countries. On the contrary, factors such as economic recession and macroeconomic issues can reduce exports to trading partners. A study by Kumar *et al.* (2024) analysed the opportunities and determinants of the Indian rice trade with its selected trading partners using the Heckman selection model. The study results indicate that WTO membership, historical trade ties, and economic factors influence rice trade. At the same time, the population, per capita income, and higher GDP of trading partners promote the prospect of rice trade.

Meanwhile, exchange rate volatility and differences in income levels reduce trade. Additionally, transport costs, as well as logistical complexities, affect trade decisions. Rehman (2017) analysed the relationship between exporting, productivity, and innovation in 29 Eastern/Central Eurasian economies. Findings indicate that innovation and R&D tend to promote exports. Due to managerial skills and innovation, foreign enterprises are more productive than their domestic counterparts.

2. Data and Methodology

2.1. Sample and Variables

During the analysis of this study, we employed panel data comprising a sample of F&B firms in Indonesia. The utilised data are secondary, obtained from the Central Statistics Agency of the Indonesian Industry Group (CSAIIG), which conducted a survey covering the period 2010-2015. The data from CSAIIG is particularly valuable due to its comprehensive coverage of the F&B industry in Indonesia during the specified period. The data comprises a panel of 2491 F&B business firms. Our sample period only covered 2010-2015 because the survey from which the data was obtained only covered this period, and there is no extension to this data coverage. Every survey conducted by the Central Statistics Agency comes with different data classifications, and there is no identification code for each firm in the food and beverage industry. The variable's operational definitions, measurement, and theoretical a priori are also explained and reported in Table 1.

Table 1 - Variable Measurement, A Priori Expectation, and Data Source

Variable	Measurement	A priori	Data source
<i>Y</i>	Output is measured as the firm's level of output in a thousand Rupiah		CSAIIG
<i>K</i>	The capital stock is measured in thousand Rupiah	+	CSAIIG
<i>L</i>	Labour is measured by the number of workers employed by a given firm	+	CSAIIG
<i>M</i>	Imported raw materials measured in thousands of rupiah amount	+	CSAIIG
<i>E</i>	Energy consumption measured in thousand Rupiah amount	+	CSAIIG
<i>Export</i>	Export measure as a dummy with one if a given firm exports and zero otherwise		CSAIIG
<i>FDI</i>	Foreign investment is measured as a dummy variable with a value of one if the firm receives foreign investment worth 10% or more, and zero otherwise	+	CSAIIG
<i>Skill</i>	Skilled labour is measured by human resource intensity, represented as a dummy variable with a value of 1 if the ratio of non-production workers to productive workers is 30% or more, and zero otherwise	+	CSAIIG
<i>Eff</i>	Technical efficiency is measured by an efficiency score, which lies between 0 and 1	+	Authors' estimate (see Section 2.2)
<i>Size</i>	Firm size is measured by the ratio of the firm's output to the total industry output in thousands of Rupiah	+	CSAIIG
<i>HHI</i>	Herfindahl-Hirschman-Index measures the industrial concentration	+	CSAIIG

The output is measured in thousand Rupiah. The capital stock comprises the land, buildings, vehicles, and other assets, and is expressed in thousands of Rupiah. The labour (L) variable is measured based on the number of workers employed by firms, including both production and non-production workers. The amount of energy comprises gasoline, diesel, and electric energy used by the company, expressed in thousand Rupiah. The imported raw material is the total of all raw materials used to produce output and is measured in thousands of Rupiah. The *export* variable is represented as a dummy variable, equal to 1 if a given firm exports and zero if it does not. The *FDI* is measured using a benchmark, namely, companies that receive foreign capital worth 10% or more. This is done following a study by Krugman *et al.* (2012). In this case, we also used a dummy variable for *FDI*, assigning a value of 1 if the firm receives *FDI* of 10% or more and 0 otherwise. Technical efficiency measures a company's ability to produce the highest possible output with a given combination of inputs. The technical efficiency variable, which lies between 0 and 1, is estimated using SFA (Aigner *et al.*, 1977), as detailed in Section 2.2. The size of the company is calculated as the ratio of the firm's output level to the total output of the industry:

$$Size_{it} = \frac{Q_{it}}{Q_{jt}} \quad (1)$$

In Equation (1), Q_{it} is the output level of firm i at time t , and Q_{jt} is the total output of industry to j which the firm belongs. t represents the time. The industrial concentration in the F&B processing sector is measured using (i.e. the Herfindahl-Hirschman-Index), which is expressed as:

$$HHI_{it} = \left(\frac{Q_{it}}{Q_{jt}} \right)^2 \quad (2)$$

The skilled labour is calculated using the human resource intensity, i.e. the ratio of non-production workers to productive workers. A dummy variable is used, taking the value of 1 if human resource intensity is greater than or equal to 30% and zero otherwise (Sugiharti *et al.*, 2019).

2.2. Stochastic frontier model

The theoretical model upon which the analytical models in this study were formulated is the production function. The production theory is centered around the transformation of inputs into outputs. The mechanism connecting

resource transformation is known as the production function, which expresses the technical link between the inputs needed and the corresponding final outputs that can be obtained. The production function determines the highest possible output that can be manufactured with a given amount of resource quantities, which may include machinery, skill, and knowledge (Sari, 2019). The relationship between input and output or production function can be modelled as:

$$Q = f(K, L, X, \dots) \quad (3)$$

In Equation (3), Q is the output level, which is a function of K (representing capital) and L (representing labour), and X is the vector of other inputs. A firm in an industry may face constant returns to scale, increasing returns to scale, and decreasing returns to scale. In most cases, when factors are held constant, doubling the unit of capital and labour can lead to a proportionate increase in output, especially for small and medium-scale industries (Wulan *et al.*, 2018). An important concept related to production theory that is of interest to this study is technical efficiency (TE), which refers to a company's ability to obtain the maximum possible output for a given combination of inputs. Technical efficiency can be examined from various perspectives. According to Coelli *et al.* (2005), there are two types of technical efficiencies: output-oriented and input-oriented. The output-oriented technical efficiency measures "by how much can output quantities be proportionally expanded without altering the input quantities used?" (Coelli *et al.*, 2005, p. 137). The input-oriented technical efficiency measures "by how much can input quantities be proportionally reduced without changing the output quantities produced?" (Coelli *et al.*, 2005, p. 137). Technical efficiency is only one aspect of general efficiency, which can enhance a firm's performance and competitive position (Kumbhakar & Lovell, 2000; Kumbhakar & Lovell, 2015). In this study, we consider the output-oriented TE , which is defined as the ratio between the actual and the highest possible amount of output. Therefore, TE takes a value between 0 and 1, where a value of 1 indicates the firm is fully technically efficient. For example, a value of 0.82 indicates that the firm is producing 82% of its maximum possible output.

In this study, the firms' level of technical efficiency is estimated using the technique of stochastic frontier analysis (SFA), as proposed by Aigner *et al.* (1977). SFA assumes the following model:

$$\ln y_{it}^* = f(x_{it}, \beta) + v_{it} \quad v_{it} \sim i.i.d. N(0, \sigma_v^2) \quad (4)$$

$$\ln y_{it} = \ln y_{it}^* - u_{it} \quad u_{it} \sim i.i.d. N^+(0, \sigma_u^2) \quad (5)$$

In Equations (4) and (5), i denotes the specific firm, t denotes the time (which in our case is 2010-2015), y_{it} is the actual amount of output, y_{it}^* is the highest possible amount of output, x_{it} is the vector of the input variables, f is the deterministic part of the production function characterised by the unknown parameter vector β , and random variables v_{it} and u_{it} represent the deviation from the production frontier due to exogenous factors and inefficiency. The v_{it} are assumed to be independent and normally distributed with zero mean and constant variance σ_v^2 . In contrast, the u_{it} are assumed to be independent of each other and the v_{it} , and follow a half-normal distribution with zero mean and constant variance σ_u^2 (Martey *et al.*, 2019). Since u_{it} are non-negative, the observed output y_{it} always falls below the maximum possible output y_{it}^* , therefore $y_{it} < y_{it}^*$ for a technically inefficient firm. According to Equation (5), the output-oriented technical efficiency for a given firm i at time t depends only on u_{it} , and is given by the following formula:

$$TE_{it} = \frac{y_{it}}{y_{it}^*} = \exp(-u_{it}) \quad (6)$$

The ratio $\gamma = \frac{\sigma_u^2}{\sigma^2}$, where $\sigma^2 = \sigma_v^2 + \sigma_u^2$, is the proportion of deviations from the production frontier attributable to inefficiency, whereas the remaining proportion is due to exogenous factors.

Compared to other techniques for estimating technical efficiency, such as data envelopment analysis (DEA), SFA has the advantage of distinguishing inefficiency from deviations due to exogenous factors (Bonfiglio *et al.*, 2020). This is because the production frontier is stochastic due to the presence of the random term v_{it} (Afrin *et al.*, 2017; Martey *et al.*, 2019). In this study, we specify f as a translog production function, leading to the following model:

$$\begin{aligned} \ln y_{it} = & \delta_0 + \delta_1 \ln K_{it} + \delta_2 \ln L_{it} + \delta_3 \ln M_{it} + \delta_4 \ln E_{it} + \frac{1}{2} \delta_5 (\ln K_{it})^2 + \frac{1}{2} \delta_6 (\ln L_{it})^2 + \frac{1}{2} \delta_7 (\ln M_{it})^2 + \\ & \frac{1}{2} \delta_8 (\ln E_{it})^2 + \delta_9 (\ln K_{it})(\ln L_{it}) + \delta_{10} (\ln K_{it})(\ln M_{it}) + \delta_{11} (\ln K_{it})(\ln E_{it}) + \delta_{12} (\ln L_{it})(\ln M_{it}) + \\ & \delta_{13} (\ln L_{it})(\ln E_{it}) + \delta_{14} (\ln M_{it})(\ln E_{it}) + \delta_{15} t + \delta_{16} t^2 + \delta_{17} (\ln K_{it})(t) + \delta_{18} (\ln L_{it})(t) + \delta_{19} (\ln M_{it})(t) + \\ & \delta_{20} (\ln E_{it})(t) + v_{it} - u_{it} \end{aligned} \quad (7)$$

In Equation (7), K represent the value of capital in a given firm, L is labour as measured by workers employed by the firm, M represents the material imports, E is energy consumption, and $\delta_0, \delta_1, \delta_2, \dots$, are unknown parameters to be estimated.

2.3. Logit Model

However, to analyse the factors that influence exports in the F&B industry, the study used the following logit model, as expressed in Equations (8) – (14). Equation (8) is the baseline model upon which all the remaining models would be compared to determine the robustness of the effect of the variables of interest on firms' exports.

$$L_{it} = \ln\left(\frac{Pr_{it}}{1-Pr_{it}}\right) = \eta_1 + \eta_2 FDI_{it} + \beta\eta_3 Skill_{it} + \eta_4 Eff_{it} + u_{it} \quad (8)$$

$$L_{it} = \ln\left(\frac{Pr_{it}}{1-Pr_{it}}\right) = \eta_1 + \eta_2 FDI_{it} + \beta\eta_3 Skill_{it} + \eta_4 Eff_{it} + \eta_5 Size_{it} + u_{it} \quad (9)$$

$$L_{it} = \ln\left(\frac{Pr_{it}}{1-Pr_{it}}\right) = \eta_1 + \eta_2 FDI_{it} + \beta\eta_3 Skill_{it} + \eta_4 Eff_{it} + \eta_5 HHI_{it} + u_{it} \quad (10)$$

$$L_{it} = \ln\left(\frac{Pr_{it}}{1-Pr_{it}}\right) = \eta_1 + \eta_2 FDI_{it} + \beta\eta_3 Skill_{it} + \eta_4 Eff_{it} + \eta_5 Import_{it} + u_{it} \quad (11)$$

$$L_{it} = \ln\left(\frac{Pr_{it}}{1-Pr_{it}}\right) = \eta_1 + \eta_2 FDI_{it} + \beta\eta_3 Skill_{it} + \eta_4 Eff_{it} + \eta_5 (Eff \times HHI)_{it} \quad (12)$$

$$L_{it} = \ln\left(\frac{Pr_{it}}{1-Pr_{it}}\right) = \eta_1 + \eta_2 FDI_{it} + \beta\eta_3 Skill_{it} + \eta_4 Eff_{it} + \eta_5 (Eff \times Size)_{it} \quad (13)$$

$$L_{it} = \ln\left(\frac{Pr_{it}}{1-Pr_{it}}\right) = \eta_1 + \eta_2 FDI_{it} + \beta\eta_3 Skill_{it} + \eta_4 Eff_{it} + \eta_5 (Skill \times Size)_{it} \quad (14)$$

Where, in Models (8) – (14), P_{it} is the probability that firm i exports to a foreign market at time t . Therefore, L_{it} is the logit of the same event. The FDI represent the foreign investment, $Skill$ is a measure of skilled labour, and Eff represent technical efficiency. In addition to the variables of interest, we also control for other vital factors, such as firm size ($Size$), imported raw materials ($Import$), and export concentration (HHI), as measured by the Herfindahl-Hirschmann Index (HHI). This index is best known as a measure of product or export concentration (Handoyo *et al.*, 2021). We estimate the indirect effect of firms' technical efficiency Eff (), export concentration (HHI), firm size ($Size$), and skilled labour ($Skill$). This is as demonstrated in Models 12 – 14 by interacting ($Eff \times Size$), ($Skill \times Size$), and ($Eff \times HH$). The η_1 , η_2 , η_3 ... are the model parameters to be estimated. At the same time, u is the classical white noise or error term. As mentioned earlier, to estimate technical efficiency, we applied the production function with the *SFA* approach. A logarithmic transcendental production function model (trans log) is estimated using the MLE (i.e. the maximum likelihood method) on the logistic model. We applied the trans-log production function model because it is considered more flexible, which can reduce the risk of errors in model specifications (Sari *et al.*, 2016). Since we have a categorical or binary explanatory variable, the use of logistic regression has become necessary in this study. The use of the logit model is necessitated by the fact that we are faced with binary

or categorical dependent variables, which assume either 0 or 1. The export variable is derived from the survey conducted by the Central Statistics Agency of the Indonesian Industry Group (CSAIG). In the survey, business firms that participate in exporting are assigned a value of 1, and those that do not participate are assigned a value of 0. Therefore, the logit model is the most suitable technique for handling this type of dependent variable. In addition, the software program used for this estimate is Frontier 4.1 (Coelli, 1996).

3. Results and discussion

Table 2 presents the data description, including the average value, maximum and minimum values, as well as the standard deviation, for the following variables: export variable (the proportion of goods produced for export), skilled labour (the proportion of skilled workers in the workforce), technical efficiency (the ratio of actual output to maximum potential output), company size (measured by revenue or number of employees), imported raw materials (the proportion of raw materials imported), industrial concentration (the degree of market power held by a few firms), and *FDI* (foreign direct investment). From the descriptive statistics, in terms of variability, as measured by the standard deviations, which are low in our case, there are no high variations among the sample firms. This implies that the firms under study exhibit similar characteristics, which will help in reducing cross-sectional heterogeneity in our empirical analysis.

Table 2 - Variable Statistical Description

Variable	Mean	Std.Dev	Min	Max
<i>lnY</i>	15.47	1.97	10.03	23.80
<i>lnK</i>	13.86	2.04	4.33	26.35
<i>lnL</i>	3.92	1.02	2.99	9.54
<i>lnM</i>	14.78	2.18	5.12	23.49
<i>lnE</i>	11.87	1.98	4.32	20.14
<i>Export</i>	0.076	0.27	0	1
<i>FDI</i>	0.04	0.19	0	1
<i>Skill</i>	0.25	0.44	0	1
<i>Eff</i>	0.61	0.19	0.26	1
<i>Size</i>	0.04	0.26	9.2E-1	9.50
<i>HHI</i>	0.07	1.71	9.7E-1	90.16
<i>Import</i>	0.07	0.25	0	1

Source: Authors' processed data.

Tables 3, 4, and 5 present the estimated results of the translog production function, obtained using the MLE method with Frontier 4.1 software. The production function uses 20 independent variables. In the case of the food industry, 15 of these variables are found to be significant (mostly at a level of less than 1%). For the beverages industry, we observed that of these 20 variables, only 11 variables assert a significant influence on output, mainly at 1% level of significance. An estimate of the combined food and beverage industries reveals that 18 of these variables have been found to have a significant effect on the industry's output at a high level of significance (mostly at a p-value of less than 0.01). In the foods and beverages industry, variables K , L , and E have a positive and significant effect on output, while variable M shows a negative influence on output.

Furthermore, variables K^2 , L^2 , M^2 , and M^2 show a positive and significant influence on output. This implies that an increase in input is associated with an increase in output, a finding that has significant implications for the industry. The presence of interaction terms is intended to reveal an interaction link between inputs and to determine whether there is a substitution or complementary nexus. Almost all the interaction terms show a significant effect except for L and E . The interaction variables K and L yield positive results, indicating a complementary effect between variables L and L . The interaction variables K and M , K and E , L and M , and M and E show negative and significant results, indicating a substitution effect. The variables that interact with time (t) show positive and significant results, indicating technological progress over time, as seen in the interaction variables K and t , and L and t .

In contrast, M and t have a negative and significant effect, implying that technological lapse occurs. While E and t do not have a significant effect on output. A small sigma square indicates that inefficiency is usually distributed, while the gamma value indicates the ratio between inefficiency and random error. A gamma value of 0.58 means that 58% of the residual comes from inefficiency in production, and the rest (42%) comes from random error. The estimates for the two different industries revealed almost identical patterns to those of the combined industries. This demonstrates the inseparable nature of Indonesia's food and beverage sector. The estimated value of γ for the food industry is 0.5376. This shows that 53.8% of the deviation from the production frontier is due to inefficiency, while 46.2% is due to exogenous factors. Moreover, the estimated value of γ for the beverages and combined F&B industries is 0.4046 and 0.585, respectively. This indicates that 40.46% and 58.5% of the deviation from the production frontier is due to inefficiency, while the remaining 59.54% and 41.5% are due to exogenous factors, respectively.

Table 3 - Results of maximum likelihood estimation (MLE): Trans log model for the food Industry

Production Function: The Dependent Variable is Output (Y)			
Variable	Coefficient	Standard error	t-ratio
δ_0	4.3497***	1.0503	4.1412
$\ln K$	0.1788**	0.0844	2.1180
$\ln L$	0.5411***	0.2477	2.1842
$\ln M$	0.5081***	0.1211	4.1946
$\ln E$	-0.0569	0.1210	-0.4705
$(\ln K)^2$	0.0041	0.0028	1.4585
$(\ln L)^2$	0.0077	0.0243	0.3178
$(\ln M)^2$	0.0631***	0.0039	16.1347
$(\ln E)^2$	0.0450***	0.0048	9.4784
$(\ln K)(\ln L)$	0.0292**	0.0136	2.1418
$(\ln K)(\ln M)$	-0.0415***	0.0077	-5.3629
$(\ln K)(\ln E)$	0.0242***	0.0077	3.1526
$(\ln L)(\ln M)$	-0.0497***	0.0170	-2.9179
$(\ln L)(\ln E)$	-0.0037	0.0160	-0.2309
$(\ln M)(\ln E)$	-0.0831***	0.0082	-10.1295
T	0.1255	0.0901	1.3938
t^2	-0.0128***	0.0054	-2.3471
$(\ln K)(t)$	0.0022	0.0049	0.4426
$(\ln L)(t)$	0.0208*	0.0110	1.8832
$(\ln M)(t)$	-0.0098	0.0061	-1.6104
$(\ln E)(t)$	0.0048	0.0055	0.8742
σ^2	0.4265***	0.0516	8.2610
γ	0.5376***	0.0372	14.4548

Source: Authors' processed data.

Notes: The significance levels are; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4 - Results of maximum likelihood estimation (MLE): Trans log model for the Beverages Industry

Production Function: The Dependent Variable is Output (Y)			
Variable	Coefficient	Standard error	t-ratio
δ_0	4.1807*	2.2675	1.8437
$\ln K$	-0.1128	0.2617	-0.4309
$\ln L$	1.7504***	0.6018	2.9088
$\ln M$	-0.0281	0.1963	-0.1431
$\ln E$	0.5496***	0.2380	2.3093
$(\ln K)^2$	0.0067	0.0076	0.8818
$(\ln L)^2$	0.0463	0.0415	1.1148
$(\ln M)^2$	0.0614***	0.0059	10.4923
$(\ln E)^2$	0.0294***	0.0062	4.7191
$(\ln K)(\ln L)$	-0.0021	0.0300	-0.0704
$(\ln K)(\ln M)$	0.0172	0.0150	1.1444
$(\ln K)(\ln E)$	-0.0271*	0.0165	-1.6422
$(\ln L)(\ln M)$	-0.1795***	0.0295	-6.0798
$(\ln L)(\ln E)$	0.0811***	0.0281	2.8841
$(\ln M)(\ln E)$	-0.0658***	0.0095	-6.9676
T	0.0489	0.1903	0.2573
t^2	-0.0266***	0.0095	-2.7936
$(\ln K)(t)$	0.0126	0.0109	1.1581
$(\ln L)(t)$	0.0084	0.0223	0.3786
$(\ln M)(t)$	-0.0003	0.0121	-0.0286
$(\ln E)(t)$	-0.0019	0.0110	-0.1750
σ^2	0.2750***	0.0619	4.4439
γ	0.4046***	0.1278	3.1672

Source: Authors' processed data.

Notes: The significance levels are; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5 - Results of maximum likelihood estimation (MLE): Trans log model for F&B Industries

Production Function: The Dependent Variable is Output (Y)			
Variable	Coefficient	Standard error	t-ratio
δ_0	4.055***	0.2030	19.977
$\ln K$	0.179***	0.0196	9.1430
$\ln L$	0.880***	0.0484	18.196
$\ln M$	-0.114***	0.0201	-5.662
$\ln E$	0.456***	0.0228	20.024
$(\ln K)^2$	0.005***	0.0008	5.7475
$(\ln L)^2$	0.018***	0.0054	3.3647
$(\ln M)^2$	0.073***	0.0007	107.685
$(\ln E)^2$	0.034***	0.0013	26.140
$(\ln K)(\ln L)$	0.015***	0.0031	4.887
$(\ln K)(\ln M)$	-0.019***	0.0015	-12.322
$(\ln K)(\ln E)$	-0.004**	0.0018	-2.190
$(\ln L)(\ln M)$	-0.068***	0.0033	-20.357
$(\ln L)(\ln E)$	-0.001	0.0041	-0.316
$(\ln M)(\ln E)$	-0.070***	0.0017	-40.390
T	0.124***	0.0220	5.656
t^2	-0.004*	0.0025	-1.486
$(\ln K)(t)$	0.006***	0.0017	3.713
$(\ln L)(t)$	0.006**	0.0036	1.795
$(\ln M)(t)$	-0.011***	0.0017	-6.397
$(\ln E)(t)$	0.001	0.0020	0.479
σ^2	0.149***	0.0050	29.716
γ	0.585***	0.0108	54.105

Source: Authors' processed data.

Notes: The significance levels are; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The firms' annual technical efficiencies, as measured by SFA, are presented in Figures 1, 2, and 3 over the study period (2010-2015). Technical efficiency in the combined sample of F&B processing industries decreased by 4 to 6 per cent annually, as demonstrated in Figure 3. On a scale of 0 to 1, the industry average technical efficiency is 0.576, with the highest value

of 0.6161 recorded in 2010 and the lowest value of 0.5258 recorded in 2015. This value is far from the frontier value of 1, implying that the use of inputs in production is not optimal. An estimate of technical efficiency that falls below the average estimate indicates technical inefficiency. The estimate of technical efficiency in the food industry followed the same pattern as in the combined foods and beverages sector. This is because, in this industry, the efficiency has been declining over the years, with an average efficiency level of 0.4355. The highest efficiency recorded in this industry was 0.4734 in 2010, and the lowest was 0.3975 in 2015. Unlike in the combined food and beverage (F&B) sector, technical efficiency has been increasing over the years in the beverages industry. In this industry, the average efficiency level was 0.4753, with a high value of 0.5315 and a low value of 0.4184.

Figure 1 - The food industry's average technical efficiency

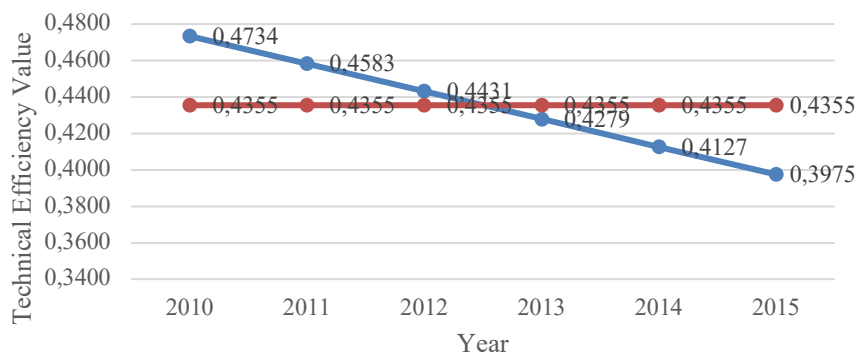


Figure 2 - The Beverages industry's average technical efficiency

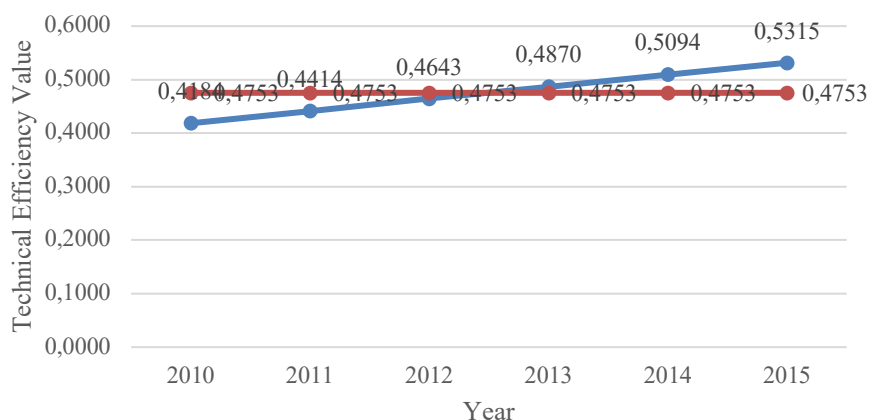
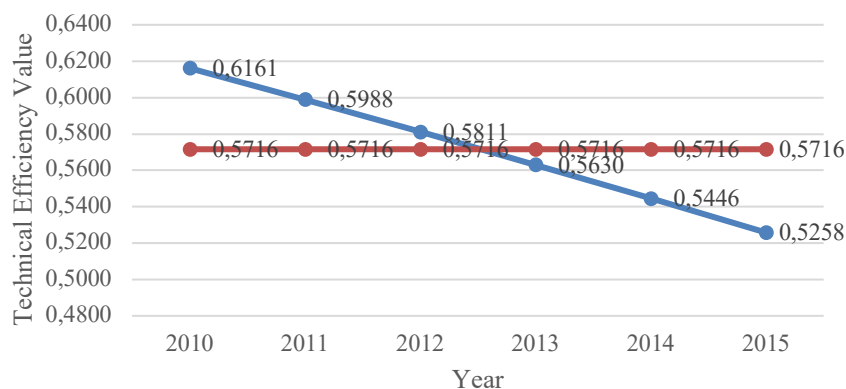


Figure 3 - The food and beverage industries' average technical efficiency



The result from our baseline model, as presented in Column 1 of Table 6, indicates *FDI* that has a positive and significant influence on firms' exports. This signifies the role of *FDI* in stimulating export performance, implying that business firms with *FDI* (i.e., foreign ownership or foreign capital) can export more compared to companies that do not have foreign investment as capital. These results support the work of Amornkitvikai & Harvie (2018), which examined manufacturing firms in Thailand. They observed that *FDI* can increase export activities and raise the intensity of both small, medium, and large business firms. In Columns 2-7, despite controlling for firm Size, industry concentration, imported raw materials, and interaction terms, foreign ownership still maintains a positive and increasing effect on exports. This result remains robustly observed in all estimates despite controlling for different firms' characteristics. The skilled labour employed asserts a significantly increasing impact on the probability of exporting and export performance in the F&B industries. That is, companies that employ skilled workers have a higher tendency and probability of exporting more food and beverages (F&B) to global markets. These findings are consistent with Cieřlik *et al.* (2015), Cieřlik *et al.* (2018), and Wignaraja (2008a), who examined Baltic and Central European manufacturing firms, companies in the MENA region, and Chinese electronics manufacturers. Their research demonstrates that firms employing skilled labour are more likely to increase exports, as skilled workers enhance technology absorption and contribute to the design and implementation of strategic business plans. In the case of technical efficiency, we observed that firms' *TE* have an increasing influence on the probability of exporting by firms and export performance. This implies that an increase in a firm's *TE* will be accompanied by higher chances of exporting and an improvement in export performance. This

finding supports the self-selection theory, which posits that only companies with high productivity and efficiency can successfully export to foreign markets. However, the findings are consistent with studies by Cieřlik *et al.* (2015), Cieřlik *et al.* (2018), and Puřnik (2010), who examined the influence of allocative and technical efficiencies on the exports of Baltic, Central European, MENA, and Slovenian manufacturing firms.

Table 6 - The Results from the Maximum Likelihood (ML) on the Logistic Model for F&B Industries

	1	2	3	4	5	6	7
<i>Constant</i>	-4.244*** (0.201)	-4.280*** (0.202)	-4.270*** (0.202)	-4.290*** (0.202)	-4.266*** (0.203)	-4.223*** (0.203)	-4.257*** (0.202)
<i>FDI</i>	1.866*** (0.118)	1.917*** (0.116)	1.910*** (0.117)	1.878*** (0.121)	1.910*** (0.117)	1.869*** (0.118)	1.890*** (0.117)
<i>Skill</i>	0.181*** (0.086)	0.211** (0.085)	0.203** (0.085)	0.200** (0.086)	0.203** (0.085)	0.185** (0.086)	0.177**1 (0.087)
<i>Eff</i>	2.401*** (0.312)	2.468*** (0.310)	2.451*** (0.311)	2.472*** (0.311)	2.445*** (0.311)	2.374*** (0.313)	2.434*** (0.311)
<i>Size</i>		0.322*** (0.094)					
<i>HHI</i>			0.024* (0.013)				
<i>Import</i>				0.158 (0.134)			
<i>Eff</i> × <i>HHI</i>					0.033* (0.018)		
<i>Eff</i> × <i>Size</i>						0.410*** (0.134)	
<i>Skill</i> × <i>Size</i>							0.250*** (0.098)
<i>n</i>	9964	9964	9964	9964	9964	9964	9964
<i>Pseudo R²</i>	0.069	0.68	0.067	0.067	0.067	0.068	0.067
<i>LR Chi² (4)</i>	369.57	364.54	361.04	359.47	361.24	367.82	364.17

Source: Authors' processed data.

Notes: The significance levels are; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors (SE) were in parentheses.

Based on our estimate, the variable *Size* which measures firm Size, also affects the probability of firms' exports. This implies that as firms increase in size, there is an increasing tendency for them to export more food and beverage products to foreign markets. The estimated parameter of this

variable, *Size*, appeared to be significant and positive, implying that the higher the company's size, the higher its export performance. Large firms are more inclined to export due to their economies of scale in production and the use of modern technologies. This conclusion aligns with Cieřlik *et al.* (2015), Imbriani *et al.* (2014), Rehman (2017), and Sebolao *et al.* (2019), who found that firm *Size* affects the firm's decision to export and its export intensity. The effect of *Size* on the probability of exporting is triggered by cost, especially the sunk cost, which occurs as firms start engaging in export activities. However, small-sized firms cannot bear the sunk costs associated with participating in the international market. This implies that small-sized firms faced an obstacle to penetrating foreign markets. While our results support some studies, they also contradict Van Beveren & Vandenbussche's (2010) finding. The export concentration, as measured by the *HHI*, asserts a significantly increasing influence on the intensity of the firm's export. These results validate the "Nationale Champion Rationale" theory, which posits that a high concentration of industries in the domestic market can necessitate a company to achieve a high magnitude of economies of scale, thereby increasing competitiveness in foreign markets. This finding supports Zaclicever's (2016) study, which reports that the greater the export concentration of the industry, the greater the tendency of the firm to continue exporting in Uruguay. In the case of raw material imports, although the coefficient is positive, there is no statistically significant evidence of an impact on exports. This shows that, irrespective of whether a firm imports raw materials or not, it will not affect the tendency to export more or less to international markets. In furtherance of this, since the effect of imported raw materials remains neutral, the firm can resort to using locally sourced raw materials whose quality is superior to foreign ones, thereby increasing its export share in the international market. This finding is contrary to Xu & Mao's (2018) finding, which observed an increasing influence of material imports on export quality.

We tested and examined the secondary or indirect influence on export through the use of the interaction effect. These include the indirect impact of *TE* and export concentration ($Eff \times HHI$), and *Size* ($Eff \times Size$), and *Skill* and *Size* ($Size \times Skill$), all of which show positive and significant effects on export. The findings indicate that firms that are highly and technically efficient, and have industrial concentration, tend to export more F&B products to foreign markets. This signifies the indirect effect of industry efficiency and concentration on exports. We observed that the indirect influence of *TE* is much lower than the direct influence on firms' exports. For the export concentration or industrial concentration, its indirect effect via technical efficiency is significantly larger than the direct effect. This, thus, underlines the role of technical efficiency in influencing F&B exports. The indirect effect of firm *TE* and firm *Size* revealed a statistically increasing

impact on exports. The result, therefore, indicates that larger companies with high industrial concentration tend to export more food and beverages (F&B) to foreign markets. The indirect effect of *Size* and efficiency only exceeds the direct effect of *Size* but not that of efficiency. The same increasing influence on export has been observed for *Skill* and *Size* interaction terms. That is, larger firms that employ highly skilled labour tend to export more than those firms that rely on semi-skilled and unskilled labour. The interaction between the company's technical efficiency and its size has a significantly increasing influence. The estimated coefficient in this regard is greater than the coefficient for company size. This signifies that companies with high technical efficiency and larger *Size* are more inclined to export than firms with smaller only.

Table 7 - The Results from the Maximum Likelihood (ML) on the Logistic Model for the Food Industry

	1	2	3	4	5	6	7
<i>Constant</i>	-1.56 (1.50)	-1.05 (1.55)	-1.57 (1.50)	-1.12 (1.53)	-8.40*** (2.53)	-1.64 (1.51)	-0.51 (1.54)
<i>FDI</i>	0.82*** (0.32)	0.84*** (0.32)	0.89 (0.60)	0.73** (0.32)	0.69** (0.33)	0.79** (0.32)	0.72** (0.33)
<i>Skill</i>	0.70** (0.27)	0.74*** (0.28)	0.69** (0.28)	0.69** (0.28)	0.66** (0.28)	0.84** (0.38)	0.77*** (0.28)
<i>Eff</i>	3.53*** (1.23)	3.53*** (1.23)	3.49*** (1.24)	3.64*** (1.28)	3.43*** (1.24)	3.54*** (1.27)	3.92*** (1.32)
<i>Size</i>		-2.08*** (0.31)					
<i>HHI</i>			1.07** (0.42)				
<i>Import</i>				0.10 (0.69)			
<i>Eff</i> × <i>HHI</i>					0.033* (0.018)		
<i>Eff</i> × <i>Size</i>						2.11*** (0.53)	
<i>Skill</i> × <i>Size</i>							4.97*** (1.91)
<i>n</i>	5336	5336	5336	5336	5336	5336	5336
<i>Pseudo R²</i>	0.1923	0.1946	0.1924	0.1981	0.2307	0.1929	0.2253
<i>LR Chi² (4)</i>	87.08	88.11	87.1	89.69	104.46	87.35	102.01

Source: Authors' processed data.

Notes: The significance levels are; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors (SE) were in parentheses.

Table 8 - The Results from the Maximum Likelihood (ML) on the Logistic Model for the Beverages Industry

	1	2	3	4	5	6	7
<i>Constant</i>	-1.71 (1.75)	-2.10 (1.76)	-1.68 (1.75)	-2.21 (1.85)	-0.84 (2.95)	-1.99 (1.77)	-0.89 (1.78)
<i>FDI</i>	1.64*** (0.39)	1.64*** (0.39)	1.51*** (0.58)	1.53*** (0.40)	1.64*** (0.39)	1.55*** (0.39)	1.68*** (0.40)
<i>Skill</i>	0.81** (0.40)	0.81** (0.40)	0.81** (0.40)	0.83** (0.41)	0.79** (0.40)	0.79* (0.41)	1.36*** (0.46)
<i>Eff</i>	6.26*** (1.34)	4.24** (2.12)	6.28*** (1.35)	6.49*** (1.36)	6.22*** (1.35)	6.20*** (1.32)	6.54*** (1.35)
<i>Size</i>		2.63*** (0.37)					
<i>HHI</i>			0.22 (0.74)				
<i>Import</i>				0.24 (0.65)			
<i>Eff</i> × <i>HHI</i>					0.033* (0.018)		
<i>Eff</i> × <i>Size</i>						10.94*** (2.73)	
<i>Skill</i> × <i>Size</i>							-2.7 (2.34)
<i>n</i>	4628	4628	4628	4628	4628	4628	4628
<i>Pseudo R</i> ²	0.4283	0.4312	0.4285	0.4564	0.4286	0.4308	0.4439
<i>LR Chi</i> ² (4)	201.25	202.58	201.34	214.42	201.39	202.42	208.55

Source: Authors' processed data.

Notes: The significance levels are; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors (SE) were in parentheses.

Comparable results for the disaggregated food and beverage sector are reported in Tables 7 and 8. Similar to the estimates obtained in the case of the F&B sector, in both the food and beverage industries, *FDI*, *Skill*, and *Eff* have a statistically significant influence on the probability of exporting to foreign markets. This highlights the significant role of *FDI* in enhancing the competitiveness of Indonesia's food and beverage industries. The effect of these variables of interest remained robust in all estimates of Tables 7 and 8 despite controlling for *Size*, *HHI*, *Import*, and interaction terms. While the firm size asserts a positive influence on export in the F&B sector and the beverages industry, it asserts an adverse effect in the case of the foods industry, as reported in Column 2 of Table 7, i.e. only in the food industry does an increase in firm size reduce the firm's competitive position. We

established strong evidence that export concentration increases the probability of exporting, but not in the case of the beverages industry. The use of foreign raw materials neither promotes nor decreases exports, based on the statistically insignificant coefficient of *Import* in both estimates.

In the analysis of the F&B sector, which encompasses both the food and beverage industries, we observed that firms that are highly technically efficient and have high export concentration have a better chance of exporting foods and beverages to foreign markets. Moreover, firms that are highly technically efficient and larger tend to export more than their counterparts.

Table 9 - The Results from the Maximum Likelihood (ML) on the Logistic Model for F&B Industries (Dummy Variable of Food Industry)

	1	2	3	4	5	6	7
<i>Constant</i>	-4.356*** (0.232)	-4.364*** (0.232)	-4.350*** (0.232)	-4.342*** (0.232)	-4.366*** (0.232)	-4.353*** (0.232)	-4.357*** (0.232)
<i>FDI</i>	2.434*** (0.122)	2.431*** (0.124)	2.438*** (0.122)	2.436*** (0.122)	2.467*** (0.120)	2.469*** (0.124)	2.470*** (0.126)
<i>Skill</i>	0.205*** (0.063)	0.223*** (0.063)	0.232*** (0.062)	0.256*** (0.062)	0.250*** (0.061)	0.225*** (0.062)	0.197*** (0.062)
<i>Eff</i>	2.651*** (0.368)	2.782*** (0.366)	2.673*** (0.368)	2.423*** (0.368)	2.445*** (0.368)	2.498*** (0.370)	2.465*** (0.368)
<i>Dummy</i>	0.875*** (0.069)	0.867*** (0.069)	0.883*** (0.068)	0.876*** (0.068)	0.875*** (0.068)	0.876*** (0.069)	0.875*** (0.069)
<i>Size</i>		0.486*** (0.082)					
<i>HHI</i>			0.022* (0.012)				
<i>Import</i>				0.168 (0.146)			
<i>Eff × HHI</i>					0.043* (0.024)		
<i>Eff × Size</i>						0.520*** (0.121)	
<i>Skill × Size</i>							0.287*** (0.088)
<i>n</i>	9964	9964	9964	9964	9964	9964	9964
<i>Pseudo R²</i>	0.074	0.074	0.074	0.075	0.078	0.076	0.076
<i>LR Chi² (4)</i>	713.50	715.89	718.43	710.80	719.25	712.25	714.60

Source: Authors' processed data.

Notes: The significance levels are; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors (SE) were in parentheses.

Only in the case of the beverages industry (i.e. Table 8), larger firms that employ highly skilled labour do not export more beverages to foreign markets.

To check the robustness of our estimate, we included a dummy variable for the food = 1 and beverage = 0 in the model of the F&B sector. Since the included dummy is for the food industry, the result for the dummy reported in Table 9 measures the extent to which the food industry enhances export performance in the F&B sector. Therefore, the parameters of the dummy variable for Models 1-7 are not significantly different in terms of size and magnitude. This implies that, regardless of the independent variables used, the average increase in exports for the beverages industry compared to the food industry is not significantly different.

Conclusion

This study examines the role of foreign direct investment, skilled labour, and technical efficiency, along with other key factors, in determining the export performance of the food and beverage sector in Indonesia. Unlike previous studies, this study utilised micro-level data from 2,491 firms, derived from a survey of the food and beverage industries, which has been rarely employed in existing studies analysing the food and beverage sector. The study has not only focused on the direct influence of these factors but also on their mediating role in determining export performance. This also signifies the unique aspect and significant contribution of this study. Studies that focused on technical efficiency mostly applied data envelopment analysis (DEA), which is less robust in estimating efficiency scores. In our case, we applied SFA, which is more robust for estimating efficiency, while the maximum likelihood estimation (MLE) technique and logistic model were used for the analysis. Our empirical strategies revealed an interesting finding about the F&B sector and its export determinants. The results show a relatively low level of technical efficiency in the F&B sector and the food and beverage industries. Although the beverages industry has shown improved efficiency, the analysed firms (in the F&B sector and food industry) not only recorded low technical efficiency but also exhibited a downward trend, with no improvement in their efficiency scores. Despite the low and declining efficiency, firms' efficiency has remained the primary factor influencing exports to foreign markets. This implies that technical efficiency contributes to increasing the probability of exporting more than any other variable incorporated.

However, *FDI* has proven to have a significant and increasing influence on firm exports across both sectors and industries. This indicates that enterprises

that accommodate *FDI* are more likely to experience increasing exports. Firms that employ highly skilled labour stand a better chance of exporting more to foreign markets. Except in the food industry, as firms increase in size, the tendency to export also tends to increase. Export concentration is closely linked to increasing the probability of exporting in the food and beverage (F&B) sector, specifically in the food industry, but not in the case of the beverages industry. Imported raw materials show an increasing impact, although it is not statistically significant and has no influence on the probability of exporting. Findings from the interaction of efficiency and export concentration revealed that firms with high levels of efficiency and concentrated export stand a better chance of exporting more than firms with low efficiency and export concentration. This applies to all analyses of the F&B sector, as well as to the food and beverage industries. Larger and more efficient enterprises tend to have a higher probability of exporting and penetrating foreign markets than larger and less efficient firms, as well as smaller and less efficient firms. Larger firms that employ highly skilled labour possess a greater tendency to export than smaller firms that employ skilled labour. This is only valid for the analysis of the F&B sector and the food industry, but not for the beverages industry.

These findings carry significant policy implications. The role of foreign capital in the food and beverage industries is crucial and should be a cornerstone of strategies aimed at boosting exports. This necessitates a more open policy on *FDI*. Enhancing *FDI* inflow into the food and beverage industries can be achieved by improving infrastructure quality and streamlining bureaucratic processes that hinder *FDI*. Given the positive impact of skilled labour on the industries' exports, there is a clear need to enhance access to formal education, a prerequisite for skill development. This can be achieved through substantial investment in education and the promotion of skill acquisition. The need for a concerted effort to improve the technical efficiency of the food and beverage sector, given its significant impact on export performance, is clear. This can be achieved by identifying the optimal input combination that produces high output at the lowest possible cost. Since imported raw materials do not significantly impact exports, the policy effort should be focused on promoting the use of local raw materials. The role of firm size must be taken into consideration in government policy for licensing new companies. Due to increased exports resulting from larger firm size, smaller firms should be encouraged to merge and form larger corporations to compete globally. However, to promote exports, F&B firms must simultaneously consider increasing technical efficiency and export concentration, as well as technical efficiency and firm size, and skilled labour employment and firm size.

It is essential to acknowledge that this study has its limitations. Some of these limitations are related to data, data coverage, and the study's context. Our sample period only covered 2010-2015 due to the survey's limited coverage, and there is no extension to this data coverage. The data is classified into different categories, and there is no unique identification code for each firm in the F&B sector, which limits the use of updated data for further research. The research focused solely on the F&B industry, yielding findings that are specific to the F&B industry and cannot be applied to other industries. Therefore, future research should extend the scope of this study by considering other industries to provide a comparative analysis of how the analysed factors affect the export performance of different industries in Indonesia and beyond.

Additionally, the study only considered a few determinants of F&B exports, as identified in the literature, which were not comprehensive. Therefore, future work should consider incorporating other factors influencing F&B exports. These limitations underscore the need for further research and the potential for new contributions to this field.

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Kabiru Hannafi Ibrahim

Department of Economics, Faculty of Social and Management Sciences, Federal University Birnin Kebbi, Kalgo-Bunza Street, Birnin Kebbi 860101, Nigeria

Email: kabiru.hannafi@fubk.edu.ng

He holds a Bachelor's degree in Economics (Bayero University Kano, 2009), a Master's degree in Economics (Lovely Professional University, Punjab, India, 2015), and a Ph.D. in Economics (Universitas Airlangga, Surabaya, Indonesia, 2021). He is presently a Senior Lecturer and the Head of the Economics Department, Federal University Birnin Kebbi, Nigeria. He is also an Adjunct Professor at the Department of Economics, Faculty of Economics and Business, Universitas Airlangga. His area of research includes: international economics, environmental and energy economics, infrastructural development, and applied econometrics, among others.

Rossanto Dwi Handoyo

Department of Economics, Faculty of Economics and Business, Universitas Airlangga, Jl. Airlangga Street, No. 4-6, Airlangga, Kec. Gubeng, Surabaya, Jawa Timur 60115, Indonesia

Email: rossanto_dh@fenb.unair.ac.id

He holds a Bachelor's degree in Development Economics (Universitas Gadjah Mada, 1999), a Master's degree in Development Economics (Universitas Gadjah Mada, 2002), and a Ph.D. in Economics (Universiti Kebangsaan Malaysia, 2015). He is presently a Professor and the Head of the Economics Department, Universitas Airlangga, Surabaya, Indonesia. He is also a researcher and consultant at the Ministry of Trade of the Republic of Indonesia. His research interests are in the field of international economics as well as development studies.

Nur Istifadah

Department of Management, Faculty of Economics and Business, Universitas Airlangga, Jl. Airlangga Street, No. 4-6, Airlangga, Kec. Gubeng, Surabaya, Jawa Timur 60115, Indonesia

Email: nur.istifadah-2024@feb.unair.ac.id

She holds a Bachelor's degree in Management (Universitas Brawijaya, Malang, Indonesia, 2014) and a Master's degree in Management (Universitas Islam Negeri, Syekh Wasil Kediri, Indonesia, 2023). She is presently a Ph.D. Candidate at the Department of Management, Universitas Airlangga, Surabaya, Indonesia. Her research interest covers managerial studies and managerial economics, among many others.

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Competency and Social Capital's Influence on Farmer Welfare: The Moderating Role of Social Capital

Ida Bagus Made Agung Dwijatenaya^{*a}, Yonathan Palinggi^a,
Musmuliadi^a, Srikandini Narulita^a, Jumaidi Nur^a

^a Kutai Kartanegara tenggarong University, Indonesia

Abstract

This study analyzed the effect of competency and social capital on farmer welfare and the effect of competency on welfare with social capital as a moderating variable. The population was 1758 corn farmers in six districts of Kutai Kartanegara Regency, East Kalimantan Province, Indonesia. The sample size was 240 people determined using the Slovin formula. Primary data was collected using questionnaires distributed to respondents. Respondents were chosen by proportional randomization. The questionnaire consisted of variables and indicators measured using a Likert scale with the lowest score of one and the highest score of five. The questionnaire used has been tested for validity and reliability. Data were analyzed using SEM PartPLS. The results showed that the effect of competence on farmer welfare was positive and significant. The effect of social capital on the welfare of farmers was positive and significant. The effect of competence on welfare with social capital as a moderating variable was negative and significant.

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* *Corresponding author:* Ida Bagus Made Agung Dwijatenaya - Kutai Kartanegara Tenggarong University - Jalan Arwana No F12 Timbau, Tenggarong, East Kalimantan, Indonesia. E-mail: tenaya@unikarta.ac.id.

Introduction

In essence, welfare is the right of all humans, for this reason, the Indonesian government has made various efforts to realize sustainable community welfare. The welfare of farmers needs to be improved due to the extreme climate change conditions and unsustainable agricultural practices in Kutai Kartanegara. Other challenges identified in the area include infrastructure as well as access to the market and agricultural resources. However, farmers are motivated to be profitable, improve their quality of life, and keep ancestral heritage, such as *betulungan etam bisa*. This trend shows that the sustainable welfare is not expected to be confined to urban areas (Khan *et al.*, 2020). Human Development Index (HDI) is a measure of welfare level in several ways, including education, health and income. However, the data from Central Bureau of Statistics (BPS) showed that the HDI of East Kalimantan Province was 77.44 in 2022 and Kutai Kartanegara Regency had 74.67 (Central Bureau of Statistics, 2022a). These values provide a clear picture of the welfare conditions in the two areas. The relatively high overall HDI of East Kalimantan and the low value recorded for Kutai Kartanegara show inequality in development. The trend is further identified by Gini ratio of 0.334 for East Kalimantan and 0.283 for Kutai Kartanegara.

The farmer's exchange can measure the welfare level of farmers. Based on data from the Central Bureau of Statistics in November 2022, the farmer's exchange rate for the plantation farmers in East Kalimantan province was 91.82 and for Kutai Kartanegara district was 95.97 (Central Bureau of Statistics, 2022b). Based on this data, it can be summarized that the welfare level of food plantation farmers remains low. The main factor influencing the level of welfare for corn farmers is competence in terms of farming, experience, knowledge of modern agricultural methods, and motivation to work in agriculture. Previous research also reported the significant influence of farmer competence on welfare (Fauzie *et al.*, 2020). Moreover, the concept of social capital is another important factor and it is explained as trust between individuals and farmer groups, the existence of networks that facilitate cooperation, and the upholding of positive norms developed. Various efforts have been conducted by the government of Kutai Kartanegara Regency to improve the competence of maize farmers, including through the maize revival program. The goal of the maize revival program is to improve farmers' welfare. Welfare has many dimensions, including material living standards (income, consumption, and wealth), health, education, individual activities including work, political voice and governance, social relationships and kinship, the environment, and insecurity (Stiglitz *et al.*, 2011).

Welfare will be better achieved if individuals can optimize their competence and potential. The potential will run maximized if farmers have the awareness to improve welfare, both as individuals and farmer groups. The awareness to “*Betulungan Etam Bisa*” which generally means mutual Cooperative which is an ancestral heritage should be maintained, which has recently begun to diminish. Research has been widely conducted on social capital in several aspects of life. Furthermore, social capital and competence have been examined in different regions but limited attention is placed on Kutai Kartanegara Regency, East Kalimantan Province. For example, Grootaert (Yunus & Fadli, 2020) focused more on other areas. Social capital has also been examined in an economic context without a clear consensus on the effective measurement of the concept among farmers. (Markowska-Przybyła & Ramsey, 2018) and (Muringani & Fitjar, 2021) reported the influence of social capital on economic growth but did not comprehensively explain the measurement and application in the context of farmer welfare. This trend is a representation that the interaction between social capital and competence in increasing farmer welfare has not been deeply examined by existing research. However, (Isralowitz *et al.*, 2022) reported the relationship between economic conditions and welfare but did not offer an adequate explanation as to how existing social networks could strengthen the competence of farmers. The second observation is that local wisdom, particularly, the idea of *betulungan etam bisa*, the value of cooperation, has not been discussed in terms of social capital and welfare of the farmers. It is important because local wisdom can be a good base for building social capital to increase farmer competence and welfare. The statement is based on the argument that the availability of social capital can help in the access to local resources. However, in Kutai Kartanegara Regency, East Kalimantan Province, the human capital aspect has not been made a priority, as observed by researchers. Therefore, it is important to conduct further research on the influence of social capital and competence on the farmers' welfare. Social capital that is strengthened by the existence of local wisdom (*betulungan etam bisa*) needs to be explored in depth. This needs to be done because social capital can increase the competence of farmers to improve their welfare. This study was conducted to analyze the effect of competence, the effect of social capital, and the effect of competence on farmers' welfare with social capital as a moderating variable.

1. Literature review

The Relationship Competence and Welfare

Competency is a person's fundamental characteristic, which determines the best and most effective work results following the specified criteria in a particular job or situation Spencer and Spencer (Ruky, 2006). Competence determines a person's behavior and work results in diverse situations and roles. The level of a person's competence can therefore be used to predict whether or not a person will be able to complete their work properly. Competency also determines how a person behaves or thinks, adjusts to various situations, and persists in the long term. Moreover, it is said that the components that makeup competencies are (a) motives, (b) traits, (c) self-concept, (d) knowledge, and (e) skills. Competency is a collection of interconnected personal characteristics, knowledge, and skills that affect the largest part of a job that has a relationship with performance (Ruky, 2006). In different parts of the business world and organizations, competence is very important. It is a determining factor of success from individual development to organizational performance. Research in several fields focuses mainly on the relationship between competence and various aspects of the business world and organizations (Berg *et al.*, 2020). The trend shows the importance of human resource competence in facing the increasingly rapid digital transformation. For example, (Alsabahi *et al.*, 2021) described how personal characteristics and workplace learning could affect the information technology competence of external auditors. (Batmomolin *et al.*, 2022) also focused on the relationship of intrapreneurship competence to training and development as well as employee innovative behavior. Moreover, (Barrientos-Báez *et al.*, 2022) reported that students with high entrepreneurial competence had more potential to start a business after graduation. Another research by (Kisubi *et al.*, 2022) stated that entrepreneurial competencies had a significant effect on the performance of small and medium enterprises (SMEs) in Uganda using company capabilities as a mediator. (Padi *et al.*, 2022) observed that the perceived innovative ability of employees and the attention to innovation by the company increased the possibility of engaging in entrepreneurial activities. The trend showed the need for companies to provide a supportive environment to ensure employees feel confident in using their competencies. Furthermore, (Sebestova *et al.*, 2022) compared competence models between business students and business owners in the Czech Republic and Romania. The research showed some core competencies were recognized as important in the two countries despite cultural and economic differences. (Škrinjarić, 2022) also stated the importance of a competence-based method in both organizational and individual contexts.

As discussed in the previous research, a significant relationship was established between competence and well-being. For instance, (Azhar, 2019) noted that teacher competence, for instance knowledge, skills and professional attitudes, directly influenced the psychological well-being of both teachers and those who were taught. (Fauzie *et al.*, 2020) also stated that good village development program management competence of village assistants could enhance the effectiveness of fund allocation. The research also showed that village assistant competence had a great influence on community welfare. Another research by (Musthofa, 2019) reported that professional and transparent zakat management was highly dependent on the competence of human resources (HR), with a subsequent greater impact on recipient welfare. It was further observed that HR competence had a positive and significant effect on welfare.

Competence is often associated with performance which subsequently influence welfare. Previous research by (Zainol *et al.*, 2018), (Purnamasari *et al.*, 2019), (Bektiarso, 2022), (Maulatuzulfa & Rokhmania, 2022), and (Kisubi *et al.*, 2022) reported that competence had a significant effect on performance. This trend showed the possibility of improving performance through competence. Increased performance could also influence the achievement of increased welfare. Meanwhile, (Esubalewa & Raghuramaba, 2020) reported that the relationship between competence and performance was not significant. Another research by (Jaya *et al.*, 2020) found a correlation between the quality of HR and product performance which was able to increase business competitiveness and later boost business actor welfare. The competence of corn farmers was determined based on skills obtainable from training, which further improved welfare through increased income. The trend was in line with the submission of (Wordofa & Sassi, 2017) that training had a positive and significant effect on income.

The Relationship Social Capital and Welfare

Social capital has been discussed by several experts, including Pierre Bourdieu, who emphasized the importance of resources related to group membership and social networks. James Coleman also argued that social capital was a productive element to achieve certain goals by focusing on the importance of social interaction. Moreover, Robert Putnam related the concept to social relations and the components included, trust, social norms, and social networks. Fukuyama also contended that social capital had a major influence on macro-level economic and political space. This was evident in the fact that the lack of social capital in a group led group or individuals to seek outside support to overcome the challenges they faced. Nan Lin also discussed the role played by individual and group perspectives in the use

of social capital (Usman, 2018). Social capital has been considered to have a significant role in improving community welfare (quality of education, quality of health, and increasing income) and relates to various aspects of life. Welfare is a condition of satisfying material and immaterial needs.

Welfare conditions arise when human life is safe and happy because basic needs for nutrition, health, education, shelter, and income can be achieved (Suharto, 2006).

The social capital discussed is related to utilizing resources to gain economic benefits. Social capital is mutually reinforcing to the welfare of farmers. Increased farmer performance will affect the improvement of farmer welfare. The influence of social capital on performance was found to be positive and significant in previous research (Asmara *et al.*, 2018). This was observed from the ability of social capital to act as a driving factor in improving the performance of lobster fishermen. Moreover, (Warmana & Widnyana, 2018) reported that businesses with strong social capital, through community networks and collaboration with other business actors, increase competitiveness and product innovation. This confirmed that social capital had a positive and significant effect on business performance. (Analia *et al.*, 2019) also showed how social networks assist SMEs accessing better market information and resources. Another research by (Lyu *et al.*, 2022) discussed the effect of social capital on the innovation performance of digital companies. It was observed that social capital of digital companies significantly and positively affected innovation performance during the pandemic.

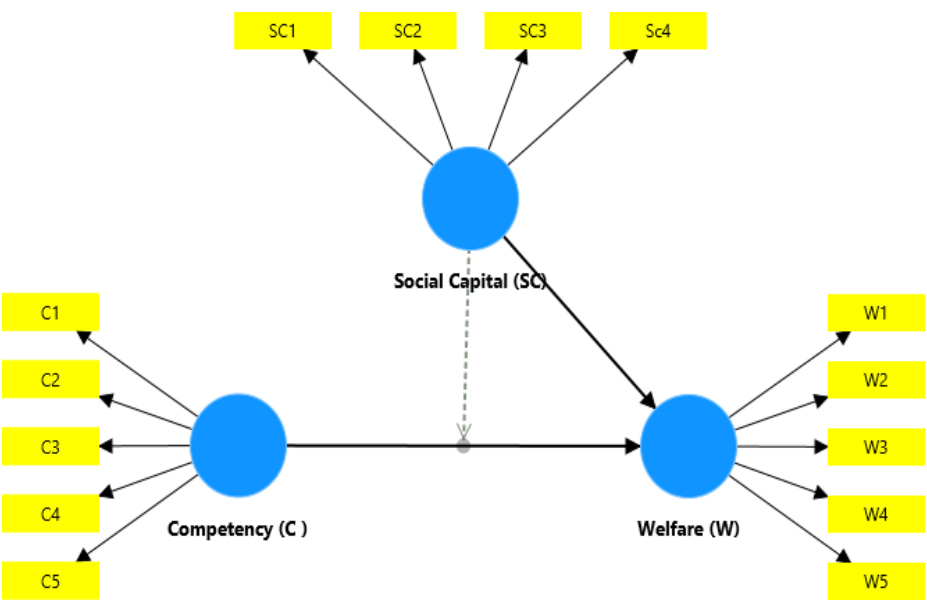
The success of development is indicated by the improvement in welfare of the community. Social capital therefore has a very important role in agricultural development. Thus, social capital plays a role in farmer groups in improving welfare (Cahyono & Adhiatma, 2012), (Harahap & Agusta, 2018), (Lestari & Yuliarmi, 2021), (Setiyawan, 2019), (Yunus & Fadli, 2020), (Antou *et al.*, 2022), and (Azis *et al.*, 2022). Social capital has a positive and significant effect on welfare (Yuliarmi *et al.*, 2020), (Mubarak *et al.*, 2020), and (Sidiq *et al.*, 2021). The increase in income is an indicator of a welfare measure. The results of the research show that social capital has a significant effect on improving welfare in terms of increasing income (Lulun *et al.*, 2019), (Puspita *et al.*, 2020), and (Bakri *et al.*, 2021). Social capital affects decision-making to take up entrepreneurship (Utomo *et al.*, 2022). Social capital is also said to be a reinforcing factor as found in the research on the importance of social capital in promoting financial Inclusion: an international perspective (Cuéllar, 2024). On the contrary, there are research results that show social capital has no significant effect on welfare such as the research results (Gandhiadi *et al.*, 2018) and (Kayadoe *et al.*, 2019). The existence of social capital can reduce poverty as a result of research (Kharisma *et al.*, 2020).

Social capital is a resource possessed by farmers as individuals and groups that can be utilized to improve their competencies. The trust that arises between farmers and farmer groups, the construction of social networks, acting based on cooperation (*Betulungan Etam Bisa*), and always working based on community norms will form individual capabilities that can support the competency of farmers to improve their welfare. Farmers' social capital if used properly, will be a reinforcing variable that improves their competencies to increase their welfare. Vice versa, if the social capital of farmers is not used optimally or not utilized at all, it will not affect welfare, and social capital can be said not to be a variable reinforcing competence in influencing the welfare of farmers. Farmers' social capital is formed from social values that have developed over generations. Social capital is the form of mutual trust, reciprocal relationships between individuals, networks, norms, and values. local wisdom values such as *Betulungan Etam Bisa*. Farmers act on *betulungan etam bisa*, an expression that is identified as the basis of the farming community in doing agricultural activities. This attitude of cooperation is a value of togetherness, mutual assistance and strong collaboration among farmers in social and economic contexts. The system of mutual cooperation in the world of agriculture ensures individual is working to achieve a common goal and this is an important concept in overcoming the problems of farmers. From the economic point of view, it is related to the reduction of production costs. But there is not always mutual cooperation between farmers, because opinions and interests differ. *Betulungan etam bisa* is a key element that can support the success of farmers in conducting agricultural businesses. It helps to solve problems, improve production efficiency and strengthen social relationships in the community through collaboration. In addition, the values are understood and applied by farmers to enhance agricultural output and a better future for themselves and future generations. It points out the significance of continuous support and promotion of cooperation among farmers and in all other aspects of life in the present world which is becoming increasingly complex.

It is argued that social capital has a very important relationship and role to competence, meaning that social capital can be a reinforcing variable or vice versa. Some research findings showed that social capital has had a positive and significant effect on competency as reported by (Yaméogo *et al.*, 2018), (Haris, 2019), (Al- Omousha *et al.*, 2020), (Ghahtarani *et al.*, 2020), (Ginting *et al.*, 2020), (Mubarak *et al.*, 2020), and (Budiarti, 2021). Social capital as a moderating variable has a positive and reinforcing effect on improving welfare as a research result (Yuliarmi *et al.*, 2020). The social capital variable is not a moderating variable that strengthens the influence of the independent variable on the dependent variable (Ravitasari & Larassaty, 2024). Based on the reviewed literature and empirical studies that have been described, the proposed hypothesis is:

- H1: Competence has a significant effect on farmer welfare.
- H2: Social capital has a significant effect on farmer welfare.
- H3: Competence has a significant effect on the welfare of farmers with social capital as a moderating variable.

Figure 1 - Research conceptual framework



Source: Data Analysis (2025).

Based on the literature review on the relationship between social capital and welfare, the relationship between social capital and competency, and the relationship between competency and welfare, a research conceptual framework can be drawn in Figure 1.

This research consists of variables: 1) competency (C) with indicators of skill (C1), knowledge (C2), motive (C3), traits (C4), and self-concept (C5); 2) social capital (SC) with indicators of trust (SC1), network (SC2), norms (SC3), and social responsibility (SC4), and 3) variable welfare (W) with indicators of health status (W1), education status (W2), asset ownership (W3), family income (W4), and social life (W5).

2. Research Methods

Research Designed

This study employed a quantitative research design with an inferential statistical approach. Inferential statistics are statistical techniques designed to analyze sample data and the results are applied to the population (Sugiyono, 2012). The inferential statistical technique is the drawing of conclusions from several samples of the population and the conclusions are expressed in a hypothesis (Ahmad, 2015). The research sample was maize farmers in Kutai Kartanegara Regency, Indonesia. Sampling for maize farmers was conducted using a multi-stage sampling design with two stages. The first stage was to determine the research areas using purposive sampling. Purposive sampling was used in the first stage to determine the research area. This method was applied through the clear rationale of selecting districts with the largest land area and the highest level of corn production compared to others in Kutai Kartanegara. The process led to the selection of six districts, including Samboja, Tenggarong, Sebulu, Tenggarong Seberang, Muara Badak, and Marang Kayu. Each was observed to have unique characteristics supporting the growth of corn such as soil type, climate, and weather patterns. For example, Samboja District is known for its fertile soil and good irrigation system which leads to the tendency of having higher corn production than other areas. Tenggarong District also has good access to the market which ensures easiness for farmers to sell their crops. The consideration of these factors ensures the samples used are truly representative and relevant. Moreover, the use of purposive sampling ensured the focus was on districts with the best potential to produce accurate and useful data for the development of the corn farming sector in the research area. After determining the area, the second stage was to determine the number of samples using the probability method, specifically proportional stratified sampling. This method led to the division of the population into relevant strata and each stratum was represented proportionally in the sample. The purpose was to increase the accuracy of the research results as well as provide a clearer picture of the conditions and challenges faced by corn farmers in each district (Sekaran, 2006).

Data Collection

The types of data employed were primary data and secondary data. Primary data is sourced from direct research collected through questionnaire tools and interview results in selected sub-districts using questionnaires that have been tested for validity and reliability. A validity test was conducted

using Convergent Validity and Average Variance Extracted (AVE) criteria. A discriminant validity test was further applied using the Heterotrait-Monotrait Ratio (HTMT) value. Meanwhile, the reliability test used Cronbach's Alpha and Composite Reliability criteria (Yamin, 2023). Secondary data was obtained from data available at related institutions or agencies through other documentation, and articles. The total population was 1758 people. The number of samples was determined using the Slovin formula (Sedarmayanti & Hidayat, 2002) as follows.

$$n = \frac{N}{1+Ne^2} \dots\dots\dots (1),$$

Notes:

n = number of samples

N = population

e = sampling error rate

Based on equation (1), a sample size of 240 people was obtained. Furthermore, to determine respondents in each sub-district, proportional random sampling was conducted. Proportional random sampling was used to ensure each member of farmer group in the selected districts had an equal opportunity to be selected as part of the sample. The first step was to identify the population and the second was to divide the population into subgroups or strata which were farmer groups in this case. The next step was to take random samples from each farmer group using the lottery method without replacement which ensured each member of the population had the same opportunity to be sampled only once.

Questionnaires

Primary data was collected using questionnaires. The questionnaire consisted of a description of the characteristics of respondents (see Table 1) and questions in the form of indicators of each variable. The questionnaire distributed to 240 selected respondents was in the form of structured interviews with a focus on different research variables. Competence (C) is based on Spencer & Spencer's theory which defines the variable as an underlying characteristic of an individual causally related to criterion-referenced effective or superior performance in a job or situation (Ruky, 2006). This definition is very relevant, specifically when the superior performance expected to be possessed by farmers to increase productivity and achieve prosperity are considered. The explanation includes important aspects that can be applied in different contexts and this shows there is no

need for updates. Competence is a relevant fundamental characteristic that is capable of influencing performance irrespective of the specific context faced by farmers in Indonesia. This shows the basic principles of understanding competence are applicable even though there is a need to adapt some elements.

Another variable was social capital (SC) which was based on the opinions of Putnam and Fukuyama (Usman, 2018). According to Putnam, social capital is integrated into social relations and developed through social networks with the components identified to include trust, social norms, and networks. The concept is also defined by Fukuyama as a series of informal values or norms shared among members of a group to enable cooperation. This led to the evaluation of informal norms in the form of *betulungan etam bisa* implemented as social responsibility. The definition of Fukuyama adds a new dimension to the understanding of social capital by showing the concept extends beyond relationships between individuals to values that bind cooperation. In Indonesian context, a relevant example is the concept of *betulungan etam bisa* which shows how informal norms can be implemented as social responsibility.

The adjustments to the original definition of social capital are not necessary in the Indonesian context. This is because the values and norms existing in Indonesian community have proven effective in building cooperation and solidarity. The trend shows that social capital is an important element in building cooperation and solidarity.

Both Putnam and Fukuyama make significant contributions to understanding this concept through the emphasis on trust, social norms, and networks. This is associated with the fact that values such as cooperation reflect existing informal norms and show how Indonesian community can unite in facing challenges. The application of social capital in the local context remains relevant and does not require significant adjustments despite the existence of several different definitions.

Welfare (W) is another variable in this research developed based on the opinion of Stiglitz. Community welfare was formed based on several dimensions, including material living standards in the form of income, consumption, and wealth. The others are health, education, individual activities such as work, political and government voice in addition to social relationships and kinship, environment, and insecurity (Stiglitz *et al.*, 2011). The variable is a complex and multidimensional concept that covers several aspects of community life. In Indonesian context, a deep understanding of the dimensions proposed by Stiglitz is essential to formulate effective policies. This is possible because the consideration of factors such as health, education, employment, political participation, social

relationships, environment, and insecurity can allow the development of a more comprehensive strategy to improve individual welfare. Therefore, the original definition is considered relevant and there is no need for significant adjustments or adaptations.

The variables are measured through the measurement of the indicators of each variable with the size of an ordinal scale using a score developed by Rensis Likert (Sugiyono, 2012). Each questionnaire item containing statements or questions about the indicators of each variable is given a lowest score of one (1) and a highest score of five (5) (see Table 2).

Table 1 - Description of Respondent Characteristics

No	Respondent characteristics	Score and Criteria					Total
		1	2	3	4	5	
1.	Age (Years)	< 25	25-34	35-44	45-54	> 55	
	Frequency (f)	1	19	59	76	85	240
	Percent (%)	0.42	7.92	24.58	31.67	35.42	100
2.	Education	Not finished elementary school	Elementary school	Junior High School Equivalent	High School Equivalent	Bachelor, Master, Doctor	
	Frequency (f)	15	111	56	53	5	240
	Percent (%)	6.25	46.25	23.33	22.08	2.08	100
3.	Number of family dependents (people)	≤ 1	1-2	3-4	5-6	≥ 7	
	Frequency (f)	10	64	124	35	7	240
	Percent (%)	4.17	26.67	51.67	14.58	2.92	100
4.	Length of farming (years)	≤ 1	2-4	5-7	8-10	≥ 11	
	Frequency (f)	41	131	28	13	27	240
	Percent (%)	17.08	54.58	11.67	5.42	11.25	100

Source: Data Analysis (2025).

Table 2 - Variable Description

Code	Variable and indicators		Scores					
			1	2	3	4	5	Total
Competency								
C1	Skill	Frequency (f)	1	27	154	45	13	240
		Percent (%)	0.42	11.25	64.17	18.75	5.42	100
C2	Knowledge	Frequency (f)	3	22	157	45	13	240
		Percent (%)	1.25	9.17	65.42	18.75	5.42	100
C3	Motive	Frequency (f)	2	44	117	56	21	240
		Percent (%)	0.83	18.33	48.75	23.33	8.75	100
C4	Traits	Frequency (f)	7	14	77	91	51	240
		Percent (%)	2.92	5.83	32.08	37.92	21.25	100
C5	Self concept	Frequency (f)	0	24	83	118	15	240
		Percent (%)	0	10.0	34.58	49.17	6.,5	100
Social Capital (SC)								
SC1	Trust	Frequency (f)	1	65	94	53	27	240
		Percent (%)	0.42	27.08	39.17	22.08	11.25	100
SC2	Network	Frequency (f)	2	57	120	29	32	240
		Percent (%)	0.83	23.75	50.0	12.08	13.33	100
SC3	Norms	Frequency (f)	5	67	93	48	27	240
		Percent (%)	2.08	27.92	38.75	20.0	11.25	100
SC4	Social responsibility (Betulunga n etam bisa)	Frequency (f)	4	59	92	68	17	240
		Percent (%)	1.67	24.58	38.33	28.33	7.08	100
Farmer Welfare (W)								
W1	Degree of health	Frequency (f)	18	29	25	105	63	240
		Percent (%)	7.5	12.08	10.42	43.75	26.25	100
W2	Education degree	Frequency (f)	10	36	28	123	43	240
		Percent (%)	4.17	15.0	11.67	51.25	17.92	100
W3	Asset ownership	Frequency (f)	10	34	42	117	37	240
		Percent (%)	4.17	14.17	17.5	48.75	15.42	100
W4	Household income	Frequency (f)	9	41	14	129	47	240
		Percent (%)	3.75	17.08	5.83	53.75	19.58	100
W5	Social life improves	Frequency (f)	24	27	19	96	74	240
		Percent (%)	10.0	11.25	7.92	40.0	30.83	100

Source: Data Analysis (2025).

Analysis Approach

Data analysis was done by SmartPLS version 4.0. This research, in the social and economic fields, has been widely used by the SmartPLS statistical approach. Researchers chose SmartPLS, because SmartPLS has advantages, for example, compared to regression analysis, SmartPLS can estimate the model simultaneously (Sholihin & Ratmono, 2013). The use of SmartPLS follows several requirements, namely; (1) The loading factor (LF) value is above 0.7 ($LF > 0.7$), (2) composite reliability ≥ 0.70 , (3) $\rho A \geq 0.70$, Cronbach's $\alpha \geq 0.70$, AVE ≥ 0.50 , cross-loadings, Fornel-Lacker criterion, HTMT < 0.90 (Hair *et al.*, 2022). In turn, (a) if the weight of the measurement item was not significant but had an $LF \geq 0.50$, it was still included in the model, (b) if the weight of the measurement item was not significant and the $LF < 0.50$ but the LF was significant, then the indicator was removed from the model, and (c) if the weight of the measurement item was not significant and the $LF < 0.50$ and the LF was not significant, the indicator was removed from the model (Yamin, 2023).

3. Results

3.1. Evaluation of measurement model

The measures used to assess all the variables were evaluated and the variations identified in the items applied to construct validity and reliability tests were explained. The focus was on loading factor (LF), composite reliability through Cronbach's Alpha and Rho A values, AVE, Fornell Lacker Criterion, and HTMT.

Loading Faktor (LF)

The Loading Factor (LF) or outer loading is the correlation between each measurement item and the variable. LF was used to assess the level of good or bad associated with an item adopted to measure a variable. The assessment criteria or rule of thumb according to Hair *et al.* (2022) is $LF \geq 0.70$. (Yamin, 2023) further stated that LF value ≥ 0.50 could be included in the model and the criterion was used in this research. The results obtained from the application of SmartPLS version 4.0 are presented in Table 1.

Table 3 - Loading Factor (LF)

Indicator	Competency (C)	Social Capital (SC)	Welfare (W)	SCxC
C1	0,627			
C2	0,690			
C3	0,790			
C4	0,745			
C.5	0,622			
SC1		0,682		
SC2		0,774		
SC3		0,847		
SC4		0,857		
W1			0,955	
W2			0,936	
W3			0,921	
W4			0,951	
W5			0,945	
SCxC				1,000

Source: Data Analysis (2025).

Composite reliability and Average variance extracted (AVE)

The measures that describe the level of reliability or internal consistency of reliability are Cronbach's Alpha and Rho A. The Cronbach's alpha value will provide a lower/too conservative reliability value while the Composite Reliability value is considered too high. Therefore, the Rho A reliability level can be used as an alternative, whose value lies between Cronbach's Alpha and Composite Reliability (Hair *et al.*, 2022).

AVE is a measure that describes the average variation of each measurement item in a variable. It also shows how well the variable can explain the variation of the measurement items. Moreover, AVE reflects the convergent validity of the variable and the criterion used in this research is values > 0.5 (Yamin, 2023). The statistical results with SmartPLS showed that the statistical measures of variable reliability and convergent validity were acceptable, as shown in Table 4.

Table 4 - Construct Reliability and Validity

Variable	Cronbach' s Alpha	rho_ A	Composite Reliability	Average Variance Extracted (AVE)
Competency (C)	0,752	0,798	0,825	0,487
Social Capital (SC)	0,824	0,878	0,871	0,629
Welfare (W)	0,968	0,969	0,975	0,886

Source: Data Analysis (2025).

Discriminant Validity

The discriminant validity evaluation was conducted using the Fornell-Lacker Criterion approach. The results of the study are shown in Table 5. Based on the Fornell Lacker Criterion, the root AVE of competency was (0.698) higher than its correlation with social capital (0.097) and welfare (0.629). Similar to the root AVE of social capital was higher than the correlation of the welfare variable. Thus the evaluation of discriminant validity based on Fornell and Lacker criteria was accepted. Based on the HTMT assessment presented in Table 6, the HTMT value of the variable pair is less than 0.90. This indicated that the variables had good discriminant validity.

Table 5 - Discriminant Validity (Fornell-Lacker)

Variable	Competency (C)	Social Capital (SC)	Welfare (W)
Competency (C)	0,698		
Social Capital (SC)	0,097	0,793	
Welfare (W)	0,629	0,164	0,942

Source: Data Analysis (2025).

Table 6 - Heterotrait-Monotrait Ratio (HTMT)

Variable	Competency (C)	Social Capital SC	Welfare (W)	Moderating Variable (SCxC)
Competency (C)				
Social Capital (SC)	0,157			
Welfare (W)	0,654	0,154		
Moderating Variable (SCxC)	0,279	0,057	0,269	

Source: Data Analysis (2025).

3.2. Hypothesis Test

The hypothesis testing of this study was done by bootstrapping with a sub-sample = 5000. PLS SEM did not assume that the data was normally distributed, therefore the hypothesis testing procedure used a non-parametric procedural approach, namely bootstrapping. This procedure is an alternative to hypothesis testing from exact methods when the sampling distribution of the data is unknown, done by taking samples and returning samples (resampling) as many as p times (generally 5000), which is useful for creating standard errors and parameter estimates. The t-test results seen from the t-values for the two-tailed test were 1.96 (significant level = 5%). The test conducted in this research was at a 95% confidence level ($\alpha = 5\%$). The preference for the level is based on the consideration that social research generally uses $\alpha = 5\%$. SmartPLS generated a p-value for each evaluation and compared it with the pre-determined alpha (0.05). If the p-value < 0.05 then there is an influence between significant variables. The Bootstrap method was selected using Bias Corrected and Accelerated (BCA) (Yamin, 2023). The next step was looking at the path coefficient and T value to test the proposed hypothesis. According to Hartono, the hypothesis can be supported by comparing T-table and T-statistic values. This is based on the rule that the hypothesis is supported when T-statistic is greater than T-table value (Abdillah & Jogiyo, 2015). The results of calculations by SmartPLS are presented in Table 7.

Table 7 - Path Coefficient and T-Statistics (Mean, STDEV, T-Values, P-Values)

Variable	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values	Decesion
Competency (C) -> Welfare (W)	0.588	0.591	0.040	14.866	0.000	Significant
Social Capital (SC) -> Welfare (W)	0.109	0.119	0.053	2.070	0.038	Significant
Moderating variable (SCxC) -> Welfare (W)	-0.125	-0.127	0.055	2.261	0.024	Significant

Source: Data Analysis (2024).

The findings of this study indicated that competency and social capital had a significant effect on farmers' welfare. Social capital was a moderator variable that significantly affects welfare but had a negative relationship. This meant that social capital was not a variable that strengthened the influence of competency on welfare

4. Discussion

The Effect of Competency on Welfare

Competency is a characteristic that underlies a person's ability to achieve high performance in their work. These characteristics appear as skills, knowledge, motives, traits, and self-concept to achieve the set goals, namely increased welfare. The result of this study was that competency had a positive and significant effect on welfare. This was indicated by a T statistic of 15.165 which was greater than the T table of 1.96 and a significance value at the confidence level or $\alpha = 0.05$ of 0.000 (presented in Table 7). The results provided strong evidence that competence development could be an effective strategy to improve individual welfare, specifically in the context of corn farmers. The observation was in line with previous research conducted by (Azhar, 2019) and (Fauzie *et al.*, 2020) who also reported a significant

positive relationship between competence and welfare. The evidence provided showed that individuals with better competence tended to have a higher quality of life. Moreover, (Musthofa, 2019) confirmed that HR competence positively affected welfare. The research reported that appropriate and skilled HR could accelerate performance with subsequent improvement in welfare (Zainol *et al.*, 2018), (Purnamasari *et al.*, 2019), (Bektiarso, 2022), and (Kisubi *et al.*, 2022) also found a positive and significant relationship between competence and performance. In this context, entrepreneurial competence was the key to improving business performance and later increased income and welfare. The results are similar to the present research but there are differences in context and focus. The variation is based on the fact that the focus is on the impact of competence on individual welfare in the context of corn farming. The context provides a more specific and relevant perspective for farmers facing unique challenges in the agricultural sector. The understanding of this context shows how competence can be optimized to improve agricultural yields and general farmer welfare. The ability to manage a good farm in the sense that farmers have high competency, and thus welfare will be easier to achieve. The findings of this study were confirmed by the results of respondents' answers about competency (skills, knowledge, motive, traits, and self-concept) respondents tended to answer positively (see Table 2). Maize farmers' skills were obtained from technical guidance and counseling by agricultural extension workers. Knowledge is in the form of profit-oriented farmer experience and farming knowledge that has been owned. Farmers always have the motivation to increase farm productivity. Traits of farmers developed consistently in farming. Self-concept is a set of attitudes farmers possess to strive to increase farm productivity. The competency of maize farmers, as described, contributes to welfare. Thus, the analysis of each competency element in supporting the findings of this study was more detailed compared to other studies that usually only looked at competencies in general.

The Effect of Social Capital on Welfare

Researchers used social capital indicators of trust, network, norm, and social responsibility. The results showed that social capital had a positive and significantly influenced the welfare of farmers. This was indicated by the value of T statistic (2.039) greater than T Table (1.96) at a significance level of 0.041 ($\alpha = 5\%$) (Table 7). Social capital owned by corn farmers in Kutai Kartanegara is quite good because the answers provided tend to be positive as presented in Table 2. Corn farmers relatively trust the leaders of farmer groups and this further increases productivity to achieve welfare. There is also a sense of togetherness manifested in *betulungan etam bisa* which

is relatively good to further advance farming businesses. The concept of *betulungan etam bisa* reflects a strong collaborative spirit among farmers in land management, planting, and harvesting. This was in line with the opinion of (Yuliarmi et al., 2020) who emphasized the importance of members' trust in leaders to increase social capital. The research also emphatically stated that social capital had a positive and significant effect on community welfare. This was observed from the fact that farmers had more propensity to contribute actively to activities designed for increasing agricultural yields when there was high trust in the leaders of the groups. (Sidiq et al., 2021) supported the trend by emphasizing that social capital, consisting of participation, reciprocity, trust, social norms, values, and proactive activities contributed positively to community welfare. Meanwhile, (Gandhiadi et al., 2018) and (Kayadoe et al., 2019) had different results by showing that social capital did not have a significant effect on welfare. This difference can be interpreted through the variation in social and cultural contexts in each area. The trend is observed from the fact that areas with a strong tradition of cooperation tend to show a positive impact of social capital on welfare, while others without the same social structure present different results.

Trust developed between members and leaders of farmer groups is essential in increasing social capital. This extends beyond interpersonal relationships to the development of a collaborative climate that allows farmers to share information, resources, and experiences. The aspect of increasing social networks to motivate an enhancement in farmer income cannot be ignored. These social networks are often developed through joint activities, such as regular meetings, training, or even social events for all community members. An actively networked community can facilitate access to better market information, more efficient agricultural technology, and wider marketing opportunities. Moreover, social norms often used as the basis for farming are important in shaping the behavior and attitudes of community members. The norms are mostly passed down for generations to influence how farmers interact with each other and conduct agricultural activities. Social responsibility realized from community togetherness and reflected in the culture of *betulungan etam bisa* can ensure an increase in farmer welfare. This culture covers the physical aspect of working together and also reflects the moral and ethical values associated with social interaction. In several cases, when one member of the community experiences difficulties, others often attempt to help without expecting returns. This provides a climate of mutual trust and strengthens the sense of belonging to the community. For example, in a situation where a farmer experiences a crop failure, other community members often help by donating part of their harvest or offering labor to assist in the replanting process. The culture of *betulungan etam bisa* (cooperation) is an ancestral heritage that exists in the present time. It is a

cultural identity that also functions as an important social capital to increase farmer productivity and achieve prosperity. In a modern context, the culture can be integrated into more innovative agricultural practices. An example is for farmer groups to hold joint training related to learning new sustainable agricultural methods. This ensures cultural heritage is preserved and updated to meet the challenges of the times. The trend showed that social capital owned by farmers, both individually and in groups, had a positive influence on efforts to improve prosperity.

This research analyzed the effect of social capital on farmer welfare based on the assumption that other variables such as access to credit, weather conditions, and agricultural policies were control variables and had a constant effect (*ceteris paribus*). Access to credit is very important because it allows farmers to make the necessary investments to increase productivity. Lack of adequate access can force farmers to use traditional, less efficient farming methods, which are capable of hindering the growth of agricultural output. Weather conditions are also important to farmer welfare because extreme climate change, such as increasing temperatures and rainfall patterns, has a direct impact on agricultural output. Social capital is capable of functioning as an adaptation mechanism in these situations. For example, members of farmer groups are able to share information on how to deal with unpredictable weather conditions, such as more efficient irrigation methods or crop varieties considered to be better resistant to drought. Agricultural policies implemented by the government also have a significant effect on farmer welfare. This is because policies that support access to credit, training, and extension for farmers can strengthen social capital and improve welfare.

Social capital owned by farmers, both individually and in groups, had a positive effect on efforts to improve welfare, as respondents' answers to each element of social capital had a positive value (Table 2). Social capital has a significant effect on farmer welfare but the effect cannot be separated from control variables such as access to credit, weather conditions, and agricultural policies. This is because social capital functions as a bridge connecting farmers with the resources and information needed to increase productivity and resilience. Therefore, efforts to improve farmer welfare need to include strengthening social capital as well as ensuring access to credit and agricultural policies are provided to support the development of mutually beneficial social networks. This holistic method is expected to ensure a significant increase in farmer welfare in the future. The trend shows that social capital, consisting of trust, networks, norms, and social responsibility built among farmers, is a key element in increasing productivity and welfare. This research adds empirical evidence to support the theory of social capital and also provides new insights into how social and cultural

contexts can affect agricultural outcomes. The contribution is important to the development of more inclusive and sustainable agricultural policies in Indonesia.

The Effect of Competency on Welfare with Social Capital as a Moderating Variable

The effect of competence on farmer welfare through the application of social capital as a moderating variable was significant with a negative coefficient, as presented in Table 7. This result showed that social capital was unable to moderate the effect of competence on farmer welfare. The observation was in line with the report of (Ravitasari & Larassaty, 2024) that social capital could not moderate the effect of individual characteristics on performance. An important inference is that performance has an impact on productivity and cause an increase in welfare. Meanwhile, this research differed from the position of (Yuliarmi *et al.*, 2020) that social capital strengthened the positive effect of cooperative empowerment on public welfare in Denpasar City.

The development strategy of Kutai Kartanegara Regency, namely the prosperous people development movement through its maize revolution program, was aimed at improving the competency of maize farmers. Farmer competencies were measured; (a) based on skills, (b) knowledge, (c) a farmer's behavior that constantly improved competency (motives), (d) a farmer's consistent response to a situation or information to improve competency (traits), and (e) self-concept (attitude or self-image of the farmer that constantly improved competency). All of these elements of the farmer's competency could be built on the existence of social capital. Based on this description, it can be said that the social capital of maize farmers can strengthen the influence of competency on improving farmers' welfare. However, after research and analysis, this was not the case. The finding of this study was that social capital had a negative effect as a variable that moderated the effect of competence on welfare. This meant that social capital was not able to act as a moderating variable that strengthened the effect of competency on welfare. The trend showed that social capital was not maintained and managed properly to strengthen the existing local culture.

The trust aspect is the primary element of social capital, and networks and norms will not work well if trust between farmers, farmer groups, extension workers, and the government is not maintained. Based on observations in the field, the trust aspect of maize farmers was saturated because the maize revolution program was seen as a 'project'. Betulungan etam bisa failed to work well because, for instance, it was influenced by the development of time/technology. The importance of social capital cannot be separated from

the cultural context. This is necessary because the culture of social context where the initiative is implemented has a significant impact on success or failure. Moreover, (Cuéllar, 2024) stated that the cultural characteristics of a country had a great effect on the dynamics of social interaction. This shows that a culture of mutual cooperation and strong social norms in Indonesia, specifically in rural areas, can be used to support the development of social capital. However, the inability of the local culture to strengthen social networks is capable of leading to inadequate functioning of social capital.

Conclusions

This study investigated the effect of competence and social capital on the welfare of farmers and examined social capital as a moderator variable of the effect of competence on welfare. The results showed that the effect of competency on the welfare of farmers was positive and significant. Competencies that consist of aspects of skills, knowledge, motive, traits, and self-concept had a positive and significant effect on the welfare of the farmers. In conclusion, competence was an important factor affecting farmer welfare, specifically in the context of corn farming. The existence of good skills, knowledge, motivation, character, and self-concept could assist farmers to optimize their agricultural output and subsequently increase income and welfare. The results were in line with the report of previous research by (Azhar, 2019) and (Fauzie *et al.*, 2020) that there was a significant positive relationship between competence and welfare. Both research provided evidence that individuals with better competence tended to have a higher quality of life. However, it was important to consider the local context and external factors affecting outcomes despite the similarities in the results. More effective strategies could also be developed to improve farmer welfare in Indonesia and around the world by understanding the elements of competence and the interaction with other factors.

Social capital had a positive and significant effect on welfare. The main element of social capital is trust. The trust would encourage farmers to improve social networks based on local norms and culture (*betulungan etam bisa*). The results of respondents' answers to social capital tended to be dominantly positive. Trust between members and leaders of farmer groups provided a conducive environment for collaboration. In this context, the sense of togetherness manifested in the practice of mutual cooperation, known as *betulungan etam bisa*, showed a strong collaborative spirit among farmers. The activity was identified in different forms of corn farming activities, from land preparation, and planting, to harvesting. This was consistent with the result of (Sidiq *et al.*, 2021) that social capital, consisting of participation,

reciprocity, trust, social norms, values, and proactive activities, contributed positively to public welfare. The observation was an important contribution to the development of more inclusive and sustainable agricultural policies in Indonesia. The knowledge gained could be used by policymakers to design programs to support the strengthening of social capital among farmers. The results added empirical evidence to support the theory of social capital and provided new insights into how social and cultural contexts affected agricultural output.

The impact of potential on welfare with social capital as a moderating variable is negative and significant. The trust of corn farmers who were members of the Corn Revolution program was saturated. The local culture of '*betulungan etam bisa*' had been eroded by the influence of modernization and the development of advanced technology. However, (Yuliarmi *et al.*, 2020) provided a different report by showing that social capital strengthened the effect of cooperative empowerment on public welfare in Denpasar City. This difference was probably due to some conditions capable of influencing the results. For example, in the context of Denpasar, there was a stronger social structure and community network which allowed social capital to function effectively in strengthening relationships between individuals and groups. The local factors in Kutai Kartanegara such as culture, tradition, and ways of interacting did not support the development of effective social capital. This showed the importance of effective social capital in improving welfare in addition to farmer competence. The trend was associated with the observation that inadequate maintenance and management of social capital had a negative impact on efforts to improve farmer welfare. Therefore, to achieve better development goals, all parties including the government, non-governmental organizations, and the local community should collaborate in developing an environment to support the development of positive and sustainable social capital. The suggestion was considered important for improving farmer welfare in the future.

This research provided an important contribution to the development of more inclusive and sustainable agricultural policies in Indonesia. The knowledge gained could also be used by policymakers to design programs needed to support the strengthening of social capital among farmers. This was considered important to ensure effective management and optimal functioning of social capital to improve farmer welfare. Moreover, the contribution added to empirical evidence to support the theory of social capital and provided new insights into how social and cultural contexts affected agricultural output.

Some of the limitations identified included the focus only on corn farmers in Kutai Kartanegara Regency which showed the inability of the results to be effective in several other areas in Indonesia. The generalization is difficult because the variations in social and cultural contexts in each area

can produce different results. It is necessary to understand that each farming community is influenced by economic factors as well as the traditions, norms, and values of the community. For example, farmers have better access to education and training in rural areas in Java than in eastern Indonesia. This suggests that the results in an area cannot be fully applied to others without considering the unique local context. The limitations show the need for a more holistic and contextual method to understand the relationship between competence, social capital, and farmer welfare. The inclusion of multiple perspectives and research methods can ensure a deeper and more relevant understanding of how the factors interact across different social and cultural environments. This is necessary to enrich the existing literature and provide practical guidance for policymakers and practitioners in designing more effective interventions to improve farmer welfare across Indonesia.

This research recommends that farmers need to maintain trust well and optimally. Moreover, there is a need to implement the local culture of *betulungan etam bisa* seriously compared to serving as only a slogan. This is necessary because the local culture reflects the spirit of mutual cooperation that has become an integral part of the lives in Kutai Kartanegara. The implementation of the inherent principles can allow farmers to strengthen relationships between individuals and develop positive synergy in farming community. Farmers also need to continue building networks, specifically with corn associations, to improve their competence. These networks serve as a forum to share knowledge, experiences, and resources to increase productivity. For example, regular meetings or discussion forums held by the associations are necessary to exchange information on the latest cultivation methods, how to overcome pests, or even more effective marketing strategies. This shows that the networks strengthen solidarity among farmers and increase their competitiveness in the market. Furthermore, training and development programs conducted by all stakeholders are capable of empowering farmers to understand the importance of social capital and its effective management to increase welfare sustainably.

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Ida Bagus Made Agung Dwijatenaya

Program Study of Agribusiness, Faculty of Agriculture, Kutai Kartanegara
Tenggarong University, Tenggarong, Indonesia
Jalan Gunung Kombeng No. 27, Postal code 75512, Tenggarong East Kalimantan,
Indonesia

E-mail: tenaya@unikarta.ac.id

He is a doctoral graduate of economics from Udayana University, Denpasar, majoring in Development Economics. Associate Professor at the Agribusiness Study Program, Kutai Kartanegara Tenggarong University, since 2006. Current research interests: studies related to quantitative analysis methods, particularly in the field of development economics.

Yonathan Palinggi

Program Study of Public Administration, Postgraduate Program, Kutai Kartanegara
Tenggarong University Tenggarong, Indonesia
Jalan Gunung Kombeng No. 27, Postal code 75512, Tenggarong East Kalimantan,
Indonesia

E-mail: yonathan_palinggi@unikarta.ac.id

Professor at the Program Study of Public Administration Postgraduate Program
Kutai Kartanegara Tenggarong University Tenggarong. Current research interests:
fields of economics and management.

Musmuliadi

Program Study of Public Administration, Postgraduate Program, Kutai Kartanegara
Tenggarong University Tenggarong, Indonesia
Jalan Gunung Kombeng No. 27, Postal code 75512, Tenggarong East Kalimantan,
Indonesia

E-mail: musmuliadi@unikarta.ac.id

Assistant Professor at the Program Study of Public Administration Postgraduate
Program Kutai Kartanegara Tenggarong University Tenggarong. He is currently
interested in the fields of public policy research and policy economics.

Srikandini Narulita

Program Study of English Language, Faculty of Teacher Training and Education,
Kutai Kartanegara Tenggarong University Tenggarong, Indonesia
Jalan Gunung Kombeng No. 27, Postal code 75512, Tenggarong East Kalimantan,
Indonesia

E-mail: srikandini@unikarta.ac.id

Assistant Professor at the Program Study of English Language, Faculty of Teacher
Training and Education, Kutai Kartanegara Tenggarong University Tenggarong, her
current research interests include studies using quantitative and qualitative methods
(social, cultural, linguistic analysis)

Jumaidi Nur

Program Study of Educational Technology, Faculty of Teacher Training and Education, Kutai Kartanegara Tenggarong University Tenggarong, Indonesia
Jalan Gunung Kombeng No. 27, Postal code 75512, Tenggarong East Kalimantan, Indonesia

E-mail: jumaidinur@unikarta.ac.id

Associate Professor at the Program Study of Educational Technology, Faculty of Teacher Training and Education, Kutai Kartanegara Tenggarong University Tenggarong, Indonesia, since 2006.

His current research interests include educational management studies using quantitative and qualitative methods.



Environmental, Social, and Governance initiatives important for the economic performance of food and beverage companies in developed and emerging countries

Rodolfo Nussio Lumasini^a, Vinicius Cambaúva^b, Eli Hadad Junior^c,
Leonardo Fernando Cruz Basso^c, David Ferreira Lopes Santos^{*a}

^a São Paulo State University, Brazil

^b Harven Agribusiness School, Brazil

^c Mackenzie Presbyterian University, Brazil

Abstract

This study analyzes the impact of environmental, social, and governance (ESG) initiatives on the financial and economic performance of food and beverage companies operating in developed and emerging markets. The research seeks to clarify the role of ESG practices in corporate profitability and market valuation, addressing the gap in empirical studies that link firm-level ESG indicators to performance metrics. A panel data regression analysis was conducted on 159 companies from 30 countries between 2017 and 2021, using Bloomberg ESG scores and financial indicators. Results indicate that social and governance practices have a positive influence on financial performance, while environmental initiatives exhibit a negative impact. The study highlights the need for cautious evaluation of environmental investments due to their potential adverse financial effects. The research contributes to the ongoing ESG discourse by providing insights for businesses, policymakers, and investors regarding sustainable corporate practices. Future studies should explore sector-specific ESG impacts and broader datasets to refine these findings.

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* *Corresponding author:* David Ferreira Lopes Santos - São Paulo State University (Unesp), School of Agricultural and Veterinarian Sciences - Via de Acesso Professor Paulo Donato Castellane s/n, 14.884-900, Jaboticabal, São Paulo, Brazil. E-mail: david.lopes@unesp.br.

Introduction

Environmental, social, and governance (ESG) practices refer to company strategies and actions aimed at minimizing environmental harm, promoting social responsibility, and ensuring ethical and transparent governance (Martins, 2022). In recent years, ESG has become central to corporate strategy due to growing regulatory requirements, evolving investor expectations, and heightened societal awareness (Naffa & Fain, 2020; Raghunandan & Rajgopal, 2022). However, the relationship between ESG practices and corporate financial performance remains contested (Chouaibi *et al.*, 2022; Friede *et al.*, 2015; Lu *et al.*, 2026; Zhao *et al.*, 2018). This research aims to clarify this relationship by examining the food and beverage sector – a global, high-impact industry – through the lens of ESG practices and financial outcomes.

Prior studies point to the growing adoption of ESG frameworks, but their effectiveness, especially regarding financial returns, is still debated (Aich *et al.*, 2021; Chen *et al.*, 2025; Zhang & Xiong, 2024). Talan & Sharma (2019) identify gaps in assessing ESG as a determinant of investment value, while (Costantini *et al.*, 2017) and Zhong *et al.* (2022) call for more empirical research using firm-level data. Much of the existing literature relies on proxies like sustainability reports or index memberships, which may not reflect actual ESG engagement (Broadstock *et al.*, 2021; Yao *et al.*, 2023). This study builds on these discussions by applying a structured, quantitative analysis at the firm level, contributing new insights into the ESG performance debate.

The food and beverage industry was selected due to its significant environmental footprint, complex supply chains, and high exposure to social and governance scrutiny (Lanzalonga *et al.*, 2025; Nirino *et al.*, 2019). As a global industry with strong local roots, it operates across national and regional boundaries, making it a relevant context to assess ESG impacts at multiple scales – local (e.g., sourcing and labor practices), national (e.g., regulatory compliance), and global (e.g., climate goals and investor pressure) (Partalidou *et al.*, 2020). Moreover, shifting consumer demands and supply chain disruptions have pushed ESG to the forefront of sectoral strategy (Khanchel & Lassoued, 2022).

Emerging markets such as Brazil, China, and India are increasingly important suppliers to developed economies and are expected to shape the global ESG landscape (Barson *et al.*, 2024; Dayanandan *et al.*, 2024; Martins, 2022). Firms in these markets often face different regulatory and institutional pressures compared to their counterparts in developed economies, which may influence their ESG (Lanzalonga *et al.*, 2025; Martins, 2022; Yao *et al.*, 2023). In this study, “Global companies” are

defined as firms that operate across multiple national jurisdictions, with international supply chains, investor bases, or product markets. Understanding ESG in these settings enables a more nuanced view of how context influences motivation and outcomes.

Regulatory environments vary considerably between countries, influencing both ESG disclosure standards and enforcement (Chouaibi *et al.*, 2022; Gega *et al.*, 2025). While developed markets may impose stricter ESG reporting requirements, emerging markets often operate under looser or fragmented frameworks (Barson *et al.*, 2024). This divergence affects how ESG is implemented and perceived by stakeholders, adding another layer of complexity to assessing its financial impact (Chen *et al.*, 2025; Dayanandan *et al.*, 2024). Exploring these differences is critical to informing both corporate strategy and policy design.

This study examines whether ESG investments contribute to financial and economic success or if external factors, such as regulation, market maturity, or institutional quality, are more decisive. It focuses on two core hypotheses:

- (H1) ESG practices positively influence food and beverage companies' financial and economic performance.
- (H2) The impact of ESG practices differs between companies in developed and emerging markets.

The study analyzes panel data from 159 companies across 30 countries using firm-level ESG indicators to test these hypotheses. The results aim to inform corporate decision-making, guide investor strategy, and support policymaking in emerging and developed contexts.

1. Background

This work was constructed to identify the scientific foundations that underpin ESG and to develop empirical studies on the subject. In doing so, the Scopus platform was utilized, focusing on the time interval from 2017 to July 2022, but not limited to this period, considering classic references and other databases whose relationship closely aligned with the scope and purpose of this research.

Based on the literature, the ESG classification refers to a more objective approach for measuring a company's sustainable performance, distinguishing true differences between samples (Friede *et al.*, 2015; Xu *et al.*, 2021; Zhang & Xiong, 2024).

The challenges in implementing and increasing interest in ESG practices by companies worldwide are related to the lack of standardized metrics for companies to base their reports and practices (Dayanandan *et al.*, 2024; Naffa & Fain, 2020). The lack of standardization in terms of disclosure was

also highlighted by Lanza Longa *et al.* (2025), Lopes Santos *et al.* (2019) and Ismail *et al.* (2019), representing a difficulty in obtaining data from companies' sustainability reports.

According to market research conducted by KPMG (2020) A broad sample of food and beverage sector companies reported on sustainability at a rate of 73%. Compared to the mining sector (84%), the food and beverage sector still needs to enhance the statements in its sustainability reports. However, this does not imply that companies in the food and beverage sector are not working to better demonstrate their sustainability results. In 2017, 50% of sector companies reported on carbon reduction goals, compared to 69% in 2020 within the same segment. In the study proposed by Lanza Longa *et al.* (2025), high levels of ESG performance in the food and beverage sector are associated with lower levels of intangible assets in intellectual capital in a global sample of companies.

In 2018, the Chief Executive Officer (CEO), Larry Fink, of investment management firm BlackRock, published a letter to the CEOs of companies that receive investments from the company, urging the invested companies to recognize and quantify the impacts of environmental and social risks and opportunities through public disclosure (BLACKROCK, 2018). In addition, they were encouraged to detail any strategic actions taken or planned in response to evolving environmental and regulatory landscapes (Pawliczek *et al.*, 2021). Larry emphasized the firm's focus on the impacts of its actions on the world and noted that companies failing to meet their obligations to stakeholders would be abandoned (BLACKROCK, 2018).

In the annual letter published by the BlackRock CEO in 2020, Larry Fink reiterated the firm's commitment to generating long-term value for its investors. He says sustainability and deeper connections with stakeholders generate better company returns (BLACKROCK, 2020).

A study conducted by the authors Pawliczek *et al.* (2021), companies exhibited more alignment with the issues highlighted in the letter in the post-letter period, particularly when companies shared political preferences with BlackRock.

Essays by Henisz *et al.* (2019) indicated that an ESG-related proposition can create value for a company through sustainable growth, attracting customers with more sustainable products, gaining better access to resources through government relations, cost reduction by reducing energy and water consumption, increased productivity through greater employee motivation, and talent attraction due to enhanced company credibility in society. These practices contribute to increased customer loyalty, sales, productivity, and company value (Ismail *et al.*, 2019; Naffa & Fain, 2020).

Hence, the importance of these practices for evaluating businesses and making investment decisions is evident, particularly when evaluating long-

term company performance and exposure to risk (Lopes Santos *et al.*, 2019; Zhang & Xiong, 2024)

Friede *et al.* (2015) highlighted the development of numerous studies linking ESG factors to corporate financial performance. They collected evidence from over 2,000 publications spanning the period from 1970 to 2015. They concluded that there is a positive correlation between ESG strategies and strong financial performance, with 62.6% of the studies revealing a positive relationship and only 10% a negative one.

Zhang & Xiong (2024) found in their study of a sample of Chinese agricultural and agro-industrial companies that the relationship between ESG practices and financial performance can be U-shaped, indicating that high investment expenses and costs for ESG implementation do not directly translate into financial improvement until a certain threshold is reached.

A study conducted by Peiris & Evans (2010) demonstrated a positive relationship between ESG practices, operational performance, and company market valuation, resulting in higher profit expectations. Thus, the potential for return due to environmental and governance factors has been a key focus, recognizing the material influence of these issues on company performance.

According to Talan & Sharma (2019) investment strategies incorporating ESG criteria constitute the second largest sustainable investment strategy in the world, with the largest being in the United States and continents like Oceania and Asia. Furthermore, they are the fastest-growing sustainable investment strategy globally.

A study conducted by Dunn *et al.* (2018) examined the risk and return implications of including ESG aspects in an investment strategy, where ESG exposures can inform about the risks of individual companies. The researchers empirically demonstrated that stocks with poorer ESG exposures have volatility up to 15% higher than stocks with better ESG exposures. Moreover, the ESG score can contribute to predicting future changes in risk estimates from a traditional risk model.

Nirino *et al.* (2019) Investigated the impact of corporate social responsibility on the financial performance of companies in the food and beverage sector. Their research suggested that future studies should aim to understand how specific corporate strategies can benefit companies, communities, and the natural environment. This highlights the importance of assessing the impact of ESG practices, as key criteria for corporate strategy, on the economic and financial performance of companies in the food and beverage sector.

The difficulty in assessing the impact of ESG on the financial performance of companies in the food sector was also identified Gega *et al.* (2025), they found that investor-owned companies outperform family and cooperative companies in terms of ESG performance, with risk-taking and time

horizon being positively and negatively associated with ESG performance, respectively.

The importance of the performance of companies in the food sector in different countries and the degree of ESG was verified in the study de Chen *et al.* (2025) which showed that international diversification and ESG performance have a positive impact on financial performance metrics at the company level for a sample in Taiwan. However, the effect of extending or international markets was not explored, and the authors indicated the relevance of discussing the impact under different market conditions.

In recent decades, the role of corporate governance has been continually studied by administrators, researchers, and educators (Lu *et al.*, 2026). However, few of these studies have focused on the relationship between corporate governance, financial sustainability, and shareholder value (Sulimany *et al.*, 2021). According to the authors, studies in developed markets suggest that well-governed companies tend to have higher valuations, profits, and dividend distributions to shareholders, as well as lower bankruptcy risks.

The study conducted by Sun & Li (2021) concluded that publicly listed Chinese companies that adopt responsible practices mitigated the negative effects of the COVID-19 pandemic on financial performance. Broadstock *et al.* (2021) created portfolios of Chinese companies with high and low levels of ESG and found that the group of companies with a higher level of ESG has lower financial risk than the portfolio with companies with lower financial risk, indicating that ESG practices can contribute positively to investment decisions in the market.

The impact of the COVID-19 pandemic also affected the ESG performance of companies in different countries, as identified in the study by Al Amosh & Khatib (2023), also highlighting differences in ESG results between emerging and developed countries, but with varying effects on the environmental and social dimensions. The authors showed that emerging countries performed better in the environmental aspect, while developed countries performed better in the social area.

Based on the existing studies, a gap in the literature remains to be explored regarding the impact of ESG practices on the economic and financial performance of companies in the food and beverage sector. Overall, these studies do not consider regional and national effects where companies are located, failing to analyze important variables such as legal differences and consumer expectations (Manrique & Martí-Ballester, 2017). Moreover, few studies have jointly evaluated the effects of ESG practices on economic and financial company performance (Dayanandan *et al.*, 2024; Friede *et al.*, 2015; Madison & Schiehl, 2021; Park & Jang, 2021; Yoon *et al.*, 2018; Zhang & Xiong, 2024; Zhao *et al.*, 2018).

2. Materials and methods

This investigation constitutes an empirical study encompassing ESG practices within globally listed food and beverage companies. This choice is based on the need for company-level information that is both dependable and audited. The identification of companies was achieved through data accessed from the Bloomberg terminal, resulting in a sample size of 157 companies.

The temporal scope of this study spans from 2017 to 2021, ensuring that it includes current and relevant data while allowing for a five-year analysis period to yield more reliable results. This period also covers events both before and after the onset of the COVID-19 pandemic, along with the publication of the letter by BlackRock's CEO, Larry Fink, in 2018 (BLACKROCK, 2018).

As a preparatory step, financial, economic, and ESG indicators, as well as control variables, were collected for each company using available data, as mapped in the Bloomberg terminal. The objective was to gather data for a comparative analysis of companies with different ESG practices.

The analytical method employed was panel data regression using the Gretl software. This method was selected because it facilitates the evaluation of ESG variables across all 159 companies identified in the Bloomberg database from 2017 to 2021. Similar techniques have been employed in prior studies (Chelawat & Trivedi, 2016; Ismail *et al.*, 2019; Lopes Santos *et al.*, 2019). This approach allowed for the control of unobservable individual heterogeneity (firm effect) and the endogeneity of explanatory variables.

It should be noted that 167 companies were identified in the initial survey, with eight companies excluded due to a lack of information on economic performance and/or negative net equity that could lead to losses, which would impact the analysis.

The study initially involved an extensive range of 74 variables, encompassing independent ESG, dependent, and control variables. However, some companies do not provide data for all analyzed variables as corporate practices evolve.

Due to limited data availability, a selection process was undertaken, focusing on variables with higher frequency of information to ensure greater representativeness and a higher number of valid observations. Guided by Bloomberg's criteria, benchmark variables were identified using the "ESG Metrics Calculation Methodology" from MSCI and Standard & Poor's reports (MSCI, 2023). This yielded a selection of 27 variables with available data for 159 companies based in 30 different countries across America, Europe, and Asia. Table 1 shows the distribution of companies by continent, sectors, and characteristics related to size.

Table 1 - Aggregated sample information. (Asset values in US\$ million)

Continent	N%	Food				N%	Beverage			
		Average Asset	Minor Asset	Biggest Asset	Average Employee		Average Asset	Minor Asset	Biggest Asset	Average Employee
America	25	13,073	156	93,394	2,205	22	18,877	226	94,354	56,885
Ásia	–	–	–	–	–	22	12,683	1,398	40,145	22,413
Europa	19	13,099	354	134,084	35,452	12	34,200	640	217,627	39.942

Source: Authors' compilation.

The sample appears to comprise large corporations, as indicated by the average number of employees and size of assets. The company with the lowest valuation had assets valued at \$354 million. Despite being large companies, a high dispersion in company sizes is evident, and the food sector in Asia is represented in the consulted database.

2.1. Construction of the empirical model

To verify the hypotheses and achieve the objective of this study, the regression model with panel (pooled) data defined in Equation 1 was used, given its ability to aggregate cross-sectional data with time, at the company level, which allows working with the extension of the database and, equally, analyzing the results respecting the individual characteristics of the companies within the period:

$$Y_{it} = \alpha_i + b_1Environmental_{it} + b_2Social_{it} + b_3Governance_{it} + b_4Size_{it} + b_5Control_{it} + b_6COVID_{it} + u_{it} \quad (01)$$

Where:

Y: dependent variables (P/E, P/BV, dividend yield, ROA, ROE, and adjusted EBITDA Margin).

Environmental: average performance, at the company level, in selected environmental indicators.

Social: Average performance, at the company level, in selected social indicators.

Governance: Average performance, at the company level, in governance indicators.

Size: Company size, measured by the natural logarithm of total assets.

Control: dummy variable to control for emerging or developed countries, individual companies.

COVID: dummy variable to control the years with COVID-19 pandemic.

t: each year within the analyzed period (2017-2021).

α : model constant; β : partial coefficients of each independent variable in the model.

To construct the independent variables related to ESG initiatives, it was necessary to examine the results of each company individually and standardize them. Since the research aimed to verify best practices, priority was given to standardization following a ranking.

ESG variables, scores ranging from 1 to 10, were assigned based on percentiles within each of the 19 variables. This approach was taken to mitigate the effects of outliers. The criteria and independent variables subjected to each of these criteria are detailed in Charts 1, 2, 3, and 4, respectively:

Chart 1 - Applied Scores for Independent ESG Variables When HIGHER Value = Better

Percentiles	Scores
HIGHER value found	10
$\geq 0,95$ (among the top 5%)	9
$\geq 0,80$ (between 5,1% - 20% highest)	8
$\geq 0,70$ (between 20,1% - 30% highest)	7
$\geq 0,60$ (between 30,1% - 40% highest)	6
$\geq 0,50$ (between 40,1% - 50% highest)	5
$\geq 0,40$ (between 50,1% - 60% highest)	4
$\geq 0,30$ (between 60,1% - 70% highest)	3
$\geq 0,05$ (between 70,1% - 95% highest)	2
$< 0,05$ (among the bottom 5%)	1
No valid observations (empty cells)	0

Source: Authors' compilation.

The ESG independent variables, which were assigned scores based on the criteria outlined in Chart 1, are presented in Chart 2:

Chart 2 - Independent ESG Variables: When HIGHER Value = Better

Independent Variable (ESG)	Representation
ENVIRONMENTAL	
RENEW_ENERGY	Percentage of renewable energy consumed
ENERGY_USAGE	Total renewable energy consumption
RECYCLING	Percentage of waste recycled
SOCIAL	
EMPLOYEE_COST	Average total cost per employee
WOMEN_TOTAL	Percentage of female employees
WOMEN_MANAGEMENT	Percentage of female employees in managerial positions
WOMEN_EXECUTIVES	Percentage of female executives
SOCIAL_ACTIONS	Total resources invested in the community
GOVERNANCE	
IND_BOARD	Percentage of independent directors on the board
NON_EXEC_BOARD	Percentage of non-executive directors on the board
BOARD_ENGAGEMENT	Frequency of board members' participation in meetings
WOMEN_BOARD	Percentage of female directors on the board
ESG_SCORE	Score achieved in ESG initiatives disclosure

Source: Authors' compilation.

Chart 3 - Applied Scores for Independent ESG Variables When LOWER Value = Better

Percentiles	Scores
LOWER value found	10
<= 0,05 (among the bottom 5%)	9
<= 0,30 (between 5,1% - 30% lowest)	8
<= 0,40 (between 30,1% - 40% lowest)	7
<= 0,50 (between 40,1% - 50% lowest)	6
<= 0,60 (between 50,1% - 60% lowest)	5
<= 0,70 (between 60,1% - 70% lowest)	4
<= 0,80 (between 70,1% - 80% lowest)	3
<= 0,95 (between 80,1% - 95% lowest)	2
> 0,95 (between 4.9% - highest)	1
No valid observations (empty cells)	0

Source: Authors' compilation.

The ESG independent variables that were assigned scores based on the criteria elucidated in Chart 3 are presented in Chart 4:

Chart 4 - Independent ESG Variables: When LOWER Value = Better

Independent Variable (ESG)	Representation
ENVIRONMENTAL	
GHG	Total greenhouse gases emitted per sale
WASTE_GEN	Total waste generated
WATER_USAGE	Total water consumed per sale
SOCIAL	
TSWA	Percentage of total time spent on work accidents
TURNOVER	Total number of employees leaving
UNION_EMPLOYEES	Percentage of unionized employees

Source: Authors' compilation.

Based on this, the E, S, and G indicators (given by the average scores of the respective dimensions' independent variables) were derived, and subsequently, the Overall ESG Average (average of the E, S, and G indicator scores) for analysis. Some variables were not identified in the literature scan; however, they were selected for this study because they address sensitive topics that could potentially have financial or economic impacts on organizations.

Next, in Charts 5, 6, and 7, the independent variables selected to constitute the analyzed Environmental (E), Social (S), and Governance (G) indices are presented, along with their calculation methods and studies in which they have been utilized. These variables serve the purpose of explaining the financial-economic impact:

Chart 5 - Bloomberg Independent Variables Selected for Environmental (E) Index

ESG Initiatives	Calculation Method	Utilized by Authors
GHG	Emitted GHG (MT) ÷ total sales (millions)	Lopes Santos <i>et al.</i> (2019); Aich <i>et al.</i> (2021); Madison & Schiehl (2021)
RENEW_ENERGY	Renewable energy usage ÷ Total energy	Sharma <i>et al.</i> (2020)
WASTE_GEN	Total waste generated (000s metric tons)	Sharma <i>et al.</i> (2020)
RECYCLING	Total recycled waste ÷ total waste generated	Lokuwaduge & de Silva (2020)
WATER_USAGE	Total water usage (m3) ÷ total sales (thousand)	Park & Jang (2021)

Source: Authors' compilation, based on data obtained via Bloomberg.

Chart 6 - Bloomberg Independent Variables Selected for Social (S) Index

ESG Initiatives	Calculation Method	Utilized by Authors
TSWA	Time spent on work accidents ÷ total time spent on business activities	Lokuwaduge & de Silva (2020)
TURNOVER	Total employees left	Lokuwaduge & de Silva (2020)
EMPLOYEE_COST	Total employee costs ÷ total company employees	J. Zheng <i>et al.</i> (2022)
UNION_EMPLOYEES	Total unionized employees ÷ total company employees	Research proposition
WOMEN_TOTAL	Total female employees ÷ total company employees	Sharma <i>et al.</i> (2020)
WOMEN_MANAGEMENT	Total female managers ÷ total company managers	Sharma <i>et al.</i> (2020)
WOMEN_EXECUTIVES	Total female executives ÷ total executives	Sharma <i>et al.</i> (2020)
SOCIAL_ACTIONS	Total community spending (millions of euros)	Park & Jang (2021)

Source: Authors' compilation, based on data obtained via Bloomberg.

Chart 7 - Bloomberg Independent Variables Selected for Governance (G) Index

ESG Initiatives	Calculation Method	Utilized by Authors
IND_BOARD	Total independent directors ÷ total directors	(Iatridis, 2013); Ismail <i>et al.</i> (2019); Forte <i>et al.</i> (2021); Tleubayev <i>et al.</i> (2021); Gangi <i>et al.</i> (2020); Villiers & Dimes (2021)
NON_EXEC_BOARD	Total non-executive directors ÷ total directors	(Iatridis, 2013); Ismail <i>et al.</i> (2019); Forte <i>et al.</i> (2021); Tleubayev <i>et al.</i> (2021); Gangi <i>et al.</i> (2020); Villiers & Dimes (2021)
BOARD_ENGAGEMENT	Average (frequency of board member participation)	Sharma <i>et al.</i> (2020); Zhao <i>et al.</i> (2018)
WOMEN_BOARD	Total female board members ÷ total board members	Forte <i>et al.</i> (2021); Tleubayev <i>et al.</i> (2021); Shakil (2021)
ESG_SCORE	Score obtained in the ESG initiative disclosure	Iatridis (2013)

Source: Authors' compilation, based on data obtained via Bloomberg.

The Overall ESG Average indicator was derived from calculating the average of the E, S, and G indicators for each company and year within the study period (2017-2021).

Next, in Charts 8 and 9, the control variables and the dependent variables (financial and economic) used in this study are presented:

Chart 8 - Control Variables

Control Variables	Calculation Method	Utilized by Authors
SIZE	Log of total company assets (ln assets)	Shakil (2021)
CONTROL	Dummy variable = 1 if the company is headquartered in a developed country, and zero if in an emerging country	Manrique & Martí-Ballester (2017); Lopes Santos <i>et al.</i> (2019); Martins (2022); Al Amosh & Khatib (2023)
COVID-19	Dummy variable = 1 if pandemic year (2020 and 2021), and zero for others years (2017, 2018 and 2019)	Broadstock <i>et al.</i> (2021); Al Amosh & Khatib (2023)

Source: Authors' compilation, based on data obtained via Bloomberg

Chart 9 - Dependent Variables (Financial and Economic Scope)

Dependent Variables	Calculation Method	Utilized by Authors
ROE	$(\text{Net Income} \div \text{Shareholders' Equity}) \times 100$	Alshehhi <i>et al.</i> (2018); Nirino <i>et al.</i> (2019); J. Zheng <i>et al.</i> (2022)
ROI	$(\text{Net Revenue} - \text{Invested Capital}) \div \text{Invested Capital} \times 100$	Yoon <i>et al.</i> (2018)
ADJUSTED EBITDA MARGIN	$\text{EBITDA} \div \text{Company Revenue during the period}$	Alshehhi <i>et al.</i> (2018)
P/E	$\text{Current Stock Price} \div \text{Earnings Per Share}$	Alshehhi <i>et al.</i> (2018)
P/BV	$\text{Current Stock Price} \div \text{Book Value Per Share}$	Shakil (2021)
DY	$(\text{Total Dividends Paid in the Last 12 Months} \div \text{Current Stock Price}) \times 100$	Shakil (2021)

Source: Authors' compilation, based on data obtained via Bloomberg.

The variables ROE, ROI, and adjusted EBITDA margin were meticulously chosen for their ability to reflect distinct aspects of financial performance: return to shareholders, return on invested capital, and level of cash generation, respectively. These variables, widely acknowledged in the literature (Alshehhi *et al.*, 2018; Dayanandan *et al.*, 2024; Lopes Santos *et al.*, 2019) are instrumental in gauging a company's ability to manage its business, with or without ESG initiatives. It is important to note that these indicators are influenced by local accounting practices and reporting decisions, which is a limitation of multinational studies.

3. Results

In this chapter, we present and discuss the research findings based on the analyses conducted, highlighting the relevant descriptive statistics of the sample. Descriptive statistics encompass key metrics such as mean, median, standard deviation, minimum, and maximum for the selected variables.

Due to the lack of standardization information in the original dataset, we adopted the standardization methods outlined in Charts 1, 2, 3, and 4. Subsequently, to facilitate the incorporation of variables into the empirical model, the descriptive results are provided in Table 2.

Table 2

Variable	Mean	Median	SD	Min	Max	Kurtosis	P 5%	P 95%
Environmental	1.52	0.00	1.92	0.00	7.00	0.84	0.0	5.17
Social	1.74	1.67	1.39	0.00	6.00	0.68	0.0	4.53
Governance	3.12	3.40	2.48	0.00	9.40	0.06	0.0	7.00
Overall ESG Average	2.13	1.97	1.69	0.00	6.79	0.30	0.0	4.99
Size	8.42	8.33	1.56	3.22	12.41	-0.28	5.75	10.93
Control	0.73	1.00	0.44	0.00	1.00	-1.07	0.0	1.00
COVID-19	0.40	0.00	0.49		0.00	1.00	-1.83	0.0
ROE	0.14	0.11	0.25	-1.74	2.40	16.10	8.57	90.19
ROI	0.08	0.07	0.17	-3.63	0.67	4.04	0.69	15.11
Adj EBITDA Margin	13.96	14.34	9.27	-63.42	41.56	2.39	0.01	0.05
P/E	49.77	23.08	260.18	1.28	5,064	1.88	-0.08	0.44
P/BV	4.37	2.55	5.69	0.25	57.96	-14.57	-0.04	0.24
DY	0.02	0.02	0.02	0.00	0.15	-2.03	2.89	25.52

Source: Developed by the authors using Gretl software, based on data obtained via Bloomberg.

Note 1: Descriptive statistics, using observations 1:1 - 159:5 (missing values ignored). 2. SD - Standard Deviation. 3. P5% - Percentile 5%. 4. P95% - Percentile 95% 6. The variables individually do not have a normal distribution.

Upon observing the descriptive statistics of the variables utilized in the model presented in Table 2, it is evident that the scores, ranging from 1 to 10, yielded low results. The averages for the environmental and social variables were notably low, 1.52 and 1.74, respectively. A huge portion of this observation can be attributed to the lack of available information. The governance indicator exhibited an average of 3.12, signifying a higher score than the averages of the environmental and social indicators. This underscores the role of the governance indicator in bolstering the Overall ESG Average. The correlation matrix between the variables can be seen in the appendix.

These outcomes suggest that companies prioritize disclosing and presenting information expected by the financial market, possibly more than genuinely emphasizing social and environmental variables. This may also reflect the practicality of companies adopting sound governance practices rather than embarking on structural changes, such as integrating facilities for improved use of renewable energy.

The financial performance variables – ROE, ROI, and Adjusted EBITDA Margin – exhibited dispersed minimum and maximum values compared to their means. This outcome could be linked to the diverse array of companies within the sample, whose heterogeneity is further evident in the results presented by the control variables. Notably, these control variables offer insights into the company's characteristics in terms of size and country of origin (developed or emerging), which may influence its financial outcomes.

The examined companies demonstrate positive expectations for future economic performance growth. This is indicated by the positive average P/E ratio of 49.77, the average market price exceeding four times the book value, and the fact that these companies in the food and beverage sector, on average, offer a DY of 2.24% to their shareholders.

In the subsequent Table 3, the number of sample companies analyzed located in developed and emerging countries globally, as well as by continent, is presented:

Table 3 - Number of Sample Companies Analyzed Located in Developed and Emerging Countries

Variable	Developed	Emerging
Global	117	42
America	55	17
Europe	49	3
Asia	13	22

Source: Developed by the authors using Gretl software, based on data obtained via Bloomberg.

Based on Table 3, approximately 70% of the companies comprising the sample for this study are in developed countries, while around 30% are in emerging countries. Notably, among companies in developed countries, 94% are from Europe, 76% are from the Americas, and only 37% are from Asia. Companies of Asian origin primarily dominate the emerging country category.

Tables 4 and 5 present the empirical results from regression analyses conducted using the Gretl software. These analyses employed financial indicators (ROE, ROI, and Adjusted EBITDA Margin) and economic indicators (P/E, P/BV, and DY). The model employed aimed to understand the relationship between ESG initiatives and companies' financial and economic performance. The study period spanned from 2017 to 2021, encompassing market dynamics and shifts in organizations' market value in response to the disclosure of these practices.

Table 4 - Empirical Results Exploring Financial Performance of ESG Variables

Dependent Variable	ROE	ROI	Adjusted EBITDA Margin
	Coefficient	Coefficient	Coefficient
Constant	-0.011	0.051 ***	-2.957 ***
Environmental	-0.006 ***	-0.004 ***	1.061 ***
Social	0.012 ***	0.003 ***	-0.970 ***
Governance	0.002 **	0.004 ***	0.308 **
SIZE	0.013 ***	0.003 ***	1.663 ***
CONTROL	0.006	-0.019 ***	2.443 ***
COVID-19	-0.007 *	-0.007 ***	0.473
Statistics based on weighted data:			
R-squared	0.16	0.16	0.60
Adjusted R-squared	0.16	0.15	0.59
F	21,85	20.63	8720
P-value (F)	1.68e-23	3.02e-22	7.56e-66
Schwarz Criterion	1,872.69	1,945,15	1,022.08
Akaike Criterion	1,841.16	1,914.29	991.12
Cross-sectional companies	148	149	76
Observations	668	678	348

Source: Developed by the authors using Gretl software, based on data obtained via Bloomberg.

Note 1: Weighted Least Squares method, using weights based on unit error variances.

Note 2: *** > 99% significance; ** > 95% significance; * > 90% significance.

Table 5 - Empirical Results Exploring Economic Performance of ESG Variables

Dependent Variable	P/E	P/BV	DY
	Coefficient	Coefficient	Coefficient
Constant	3.875***	4.914***	0.001***
Environmental	-0.035***	-0.176***	-4.479
Social	0.016	0.355***	-0.001**
Governance	0.0183**	0.135*	0.000***
SIZE	-0.087***	-0.339***	0.000***
CONTROL	0.044.	0.903***	-0.000
COVID-19	0.039	0.2576***	0.001**
Statistics based on weighted data:			
R-squared	0.19	0.33	0.06
Adjusted R-squared	0.18	0.33	0.05
F	20.84	46.90	5.89
P-value (F)	5.56e-22	2.07e-46	5.66e-06
Schwarz Criterion	1,561.06	1,477.22	1,521.42
Akaike Criterion	1,531.06	1,446.98	1,491.27
Cross-sectional companies	123	125	122
Observations	537	556	549

Source: Developed by the authors using Gretl software, based on data obtained via Bloomberg.

Note 1: Weighted Least Squares method, using weights based on unit error variances.

Note 2: *** > 99% significance; ** > 95% significance; * > 90% significance.

As indicated in Tables 4 and 5, the goodness of fit of the regression models was assessed using the R-squared statistic, which yielded adequate fits for all models. The F-statistic, employed to test the model's overall significance, led to the rejection of the null hypothesis of misspecification ($p < 0.05$). All independent variables used in the model were statistically significant in explaining the dependent variable.

The regression model with panel data, incorporating weighted heteroscedasticity, addresses a problem identified when exploring panel models using fixed or random effects: heteroscedasticity. This limitation is common in studies with financial-economic data from companies, due to the amplitude, as verified in the results of Table 2. However, the exclusion or 'normalization' of 'abnormal' data must be done with caution, since results considered statistically 'abnormal' from companies can express very different strategies and operations of the sector, as expressed by the resource-

based theory (Chuang & Lin, 2017). Thus, only companies whose market conditions (negative equity and lack of economic performance information) were excluded from the sample. Furthermore, using different financial and economic indicators enables the evaluation of the persistence of the coefficients' results across the various models.

As shown in Table 4, the environmental indicator had a negative impact on profitability variables (ROE and ROI) and a positive effect on the Adjusted EBITDA Margin, with a 99% significance level. These findings align with Manrique & Martí-Ballester (2017), suggesting that companies often undertake measures to minimize environmental impacts, investing significantly in clean technologies and sustainable processes. Such investments lead to higher operational costs but yield gains for the company. Similarly, Nirino *et al.* (2019). Observed that environmental outcomes have insignificant or non-positive effects on financial performance, depending on various financial performance measures.

However, these results differ from the findings of Henisz *et al.* (2019), indicating cost reductions resulting from environmental practices, such as decreased energy and water consumption. Partalidou *et al.* (2020) Demonstrated that higher environmental performance has a positive impact on financial performance. In addition, Shakil (2021) ESG initiatives enable companies to reduce operational costs and enhance profitability.

The negative impact of environmental initiatives on financial performance for the investigated sector suggests that the market may not yet fully price or value these practices. Given the negative impact on profitability, investors may place less value on these initiatives. Conversely, positive impacts were observed for social and governance initiatives, indicating that investors appreciate and assign value to these practices, resulting in positive effects on companies' market valuations.

Regarding the social indicator, an opposite effect is observed compared to the impact caused by the environmental indicator, leading to a positive influence on ROE and ROI, while negatively affecting the Adjusted EBITDA Margin. These outcomes align with the findings of Yoon *et al.* (2018) asserting that effects related to the social dimension can enhance long-term profitability for companies. This alignment is also evident in the studies by Nirino *et al.* (2019) and F. Zheng *et al.* (2023), who provided evidence of the positive impact of social initiatives on the financial performance of firms.

The governance indicator had a positive impact on all financial variables (ROE, ROI, and Adjusted EBITDA Margin). These results align with the existing literature. According to Lopes Santos *et al.* (2019) robust corporate governance practices enhance stakeholder confidence, reduce risk, improve decision-making effectiveness, reduce costs, and enhance company

profitability. These findings reinforce the governance indicator's highest average among the scores in Table 2.

The results are consistent with Sulimany *et al.* (2021) this suggests that well-governed companies tend to have higher valuations, profits, and dividend distributions to shareholders, along with lower bankruptcy risks. Gangi *et al.* (2020) also, confirm that good governance practices, such as effective board involvement, drive corporate social and environmental responsibility. This becomes a positive predictor of higher profitability and lower corporate debt costs.

Company size was not significant for ROE and exhibited a positive impact on Adjusted EBITDA Margin. This could be attributed to economies of scale inherent in larger companies, allowing them to produce goods or services at a lower cost per unit than smaller firms, which reflects positively on profitability (Buitendag *et al.*, 2017). However, the results indicated a negative impact on ROI, suggesting that companies located in developed countries may take longer to realize returns on their investments.

The results support those of Iatridis (2013), indicating a positive relationship between certain company attributes, such as partly size, and the quality of environmental disclosure. Similarly, Buitendag *et al.* (2017) the quality of integrated reporting is influenced by industry type and other factors, including company size.

The control variable exhibited a positive impact on Adjusted EBITDA Margin, suggesting that companies located in developed countries tend to outperform operationally. However, this variable was insignificant for ROE and hurt ROI. The negative and significant impact on the ROI of companies established in developed countries signals the difficulty companies based in these regions face in transforming investments into positive financial results, especially if the temporal effect and risks involved are not moderated, as indicated in the study of Gega *et al.* (2025) for the food sector in Europe.

From the outcomes presented in Table 5, a negative impact of environmental initiatives on firms' economic performance is observed, suggesting that the market has yet to fully incorporate or assign value to these environmentally conscious practices. Given the adverse effect on profitability, these initiatives receive limited recognition from investors. Conversely, positive effects are discernible for both social and governance initiatives, indicating investor appreciation and valuation of these practices, which results in a favorable impact on market pricing of companies.

These findings are based on the conclusions drawn by Forte *et al.* (2021), who demonstrated that the proportion of independent directors on the Board positively influences the disclosure of environmental and social information. However, there is a divergence concerning the representation of women on the Board, which was not significant in the researchers' study.

Nevertheless, these findings do not entirely align with those of Aich *et al.* (2021), who suggest that good governance, human rights, employee relations, and corporate policy contribute to achieving investment impact through environmental means. Additionally, partial disparity exists in comparison to the results by Park & Jang (2021), who identified evidence indicating that institutional investors place greater importance on environmental and governance than on social factors.

Regarding firm size, the results indicate a positive impact on Dividend Yield (DY); in contrast, a negative influence is noted on P/E and P/BV ratios. As highlighted by Buitendag *et al.* (2017) larger companies can capitalize on economies of scale, producing goods or services at a lower unit cost than smaller enterprises. This leads to increased profitability and, consequently, higher dividend distributions to shareholders.

The impact of the effects of the COVID-19 pandemic on the profitability of companies is confirmed in the negative and significant coefficients for ROE and ROI. These results can be explained by the increase in investments in the working capital of companies, increased costs and reduced revenues (Liu *et al.*, 2024).

On the other hand, there is a positive effect on the economic variables P/BV and Dividend yield, which contrasts with previous results on the economic impact (Boumlik *et al.*, 2023). The effect on P/BV may be due to the reduction in financial results, which decreases the value of the company's equity and, consequently, increases the ratio. The positive effect on dividend distribution contrasts with previous studies that found a higher level of profit yield during the pandemic period, but contributes to the discussion of differing results in various contexts (Pettenuzzo *et al.*, 2023). It is possible that for the sector, the distribution of dividends is the result of a strategy by companies to signal to shareholders, with a view to balancing capital losses with financial returns (Gosain *et al.*, 2025).

Concerning the geographic location of firms, the results were not statistically significant for P/E and DY; however, they were important for the economic variable P/BV, with a positive impact. These outcomes partially substantiate the observations made by Martins (2022) affirming that companies in developed countries enjoy superior political-economic conditions for operating in the market, coupled with greater access to advanced technologies.

The findings presented in the panel data regression analyses confirm the impact of ESG indicators on companies' economic and financial performance. Furthermore, the varying impacts of these practices are evident between firms located in developed and emerging countries. Additionally, all proposed independent variables displayed significance in explaining the dependent variables.

As discussed in the preceding section, the social and governance indicators have a significant positive impact on the economic and financial performance of global food and beverage companies. Conversely, the environmental indicator signifies a significant negative impact on these firms' economic and financial performance, thereby partially validating H1.

Regarding H2, distinct effects emanate from ESG practices for certain dependent variables (financial and economic). However, ESG indicators did not exhibit significance for some variables when contextualized within the dichotomy of developed and emerging countries, thus partially confirming H2.

The partial confirmation of H2 may be subject to the sector, given that different emerging countries in the sample: Brazil, China, India, and Mexico, for example, are major food exporters worldwide. Therefore, their companies must present governance levels similar to those in developed countries. This fact was not identified in the study Lopes Santos *et al.* (2019) for example, due to the distinct characteristics of the sectors investigated, this requirement for adequacy, especially for governance in the presentation of results, was identified by Dayanandan *et al.* (2024) in India. Unfortunately, it was impossible to discriminate in the database for detailed information on the companies' internationalization level to include this condition as a discriminant eventually.

4. Conclusions

This research examined the impact of environmental, social, and governance (ESG) initiatives on the financial and economic performance of global companies in the food and beverage sector, using data from 159 companies between 2017 and 2021. The results confirm that the effects of the ESG pillars are distinct. While the social and governance dimensions have a positive and significant impact on indicators such as ROE, ROI, and P/BV, the environmental pillar has demonstrated a negative or insignificant impact, especially on profitability indicators.

These results indicate that, in practice, companies still face difficulties in converting environmental investments into measurable financial returns in the short term. This may be due to both high initial costs and the lack of immediate recognition by the market. On the other hand, practices focused on governance (e.g., board independence, effective member participation) and social responsibility (e.g., diversity, workplace safety) are valued by investors and are associated with creating corporate value.

The analyses also demonstrated that company size positively influences operating margin (adjusted EBITDA), indicating the presence of economies of scale. Larger companies are more efficient in transforming resources

into results, while smaller companies or those in emerging countries face additional challenges related to structure, capital, and transparency. From an applied perspective, the results offer important insights: (i) for managers, when prioritizing social and governance strategies as value levers; (ii) for investors, who should consider the disaggregation of ESG pillars in the analysis of risk and return; (iii) for public policy makers, who can act to promote the standardization of reports and incentives for environmental practices with long-term effects. Theoretically, this study contributes to deepening the understanding of the heterogeneity of ESG effects, partially corroborating the findings of Friede *et al.* (2015), Nirino *et al.* (2019), Lopes Santos *et al.* (2019) and Zhang & Xiong (2024), which suggests a positive relationship between ESG and performance, but with non-linear or homogeneous effects. The disaggregation of ESG pillars and the comparative analysis between companies from developed and emerging countries address gaps identified by Zhong *et al.* (2022) and Aich *et al.* (2021), while also reinforcing the central role of corporate governance in sustaining financial performance.

Limitations include the five-year time window, marked by the exceptional effects of the COVID-19 pandemic, during which we controlled for two years but not the entire period, and the use of self-reported data, which may be subject to disclosure bias. The number of companies between developed and emerging countries is imbalanced, which can influence the results. Future research suggests expanding the sectoral and temporal scope, as well as incorporating institutional and qualitative variables, to refine the understanding of the mechanisms by which ESG practices impact corporate performance. New studies can also advance the assessment of differences between economic subsectors or segments in the food and beverage industry value chain, as well as seek to expand the sample by integrating new databases and exploring data from companies in emerging countries that are not listed on the stock exchange.

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Appendix – Correlations Matrix of Variables

	Environ- mental	Social	Gover- nance	Size	Control	PE	P/ Book	DY	ROE	ROI	EBITDA Margin
Environ- mental	1,00	0,60	0,68	0,27	0,24	-0,08	0,20	0,04	0,26	0,13	0,33
Social		1,00	0,64	0,12	0,35	-0,10	0,24	-0,16	0,30	0,20	0,14
Governance			1,00	0,28	0,56	-0,15	0,25	0,13	0,25	0,10	0,36
Size				1,00	-0,03	0,05	0,15	-0,06	0,28	0,09	0,49
Control					1,00	-0,16	0,19	0,10	0,14	0,11	0,19
PE						1,00	-0,04	-0,16	-0,11	-0,03	-0,15
P/Book							1,00	-0,11	0,76	0,41	0,38
DY								1,00	-0,01	-0,26	0,11
ROE									1,00	0,63	0,47
ROI										1,00	0,34
EBITDA Margin											1,00

Rodolfo Nussio Lumasini

São Paulo State University (Unesp), School of Agricultural and Veterinarian Sciences, Brazil

Master in Administration and Agricultural Engineer graduated from the Unesp. He is currently a Life Planner, partner of Prudential of Brazil, focusing on financial protection, governance and legacy planning.

Vinicius Cambaúva

Harven Agribusiness School, Brazil

Master in Business Administration at the University of São Paulo (USP). Agricultural Engineer graduated from São Paulo State University (Unesp), School of Agricultural and Veterinarian Sciences. Associate at Markestrat Group and Professor at Harven Agribusiness School.

Eli Hadad Junior

Mackenzie Presbyterian University, School of Applied Social Sciences, Brazil

PhD in Business Administration from Mackenzie Presbyterian University. He works as a Professor at Mackenzie Presbyterian University. He was a Visiting Professor at New York University (2023).

Leonardo Fernando Cruz Basso

Mackenzie Presbyterian University, School of Applied Social Sciences, Brazil

PhD in Economics from the New School for Social Research. He works as a full professor at Mackenzie Presbyterian University.

David Ferreira Lopes Santos

São Paulo State University (Unesp), School of Agricultural and Veterinarian Sciences, Brazil

PhD in Business Administration from Mackenzie Presbyterian University. He works as a Professor Associate at São Paulo State University.

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The Hidden Harvest: An Efficiency Indicator for Agricultural Residues Production

Roberta Sisto^a, Naomi Di Santo^{*b}, Vincenzo D'Atteo^a, Edgardo Sica^a

^a University of Foggia, Italy

^b University of Bari Aldo Moro, Italy

Abstract

This study assesses the efficiency of agricultural residue production across regions within the framework of a circular economy. The objective is to identify the key factors driving performance and to provide insights for optimising resource use in line with the European Green Deal and the Common Agricultural Policy (2023-2030). We have integrated Data Envelopment Analysis (DEA) with Multi-Criteria Decision Analysis (MCDA-DEA), developing a composite efficiency indicator that enables the design of targeted policies based on the main determinants of regional performance. This indicator was applied to the Poland's NUTS-2 regions and incorporates variables such as irrigation, agricultural land, employment, machinery, and crop type, allowing for a more refined evaluation of efficiency. Our approach offers a robust tool to support evidence-based policymaking. The findings underscore Poland's potential to capitalise on significant agricultural residue surpluses for bioenergy and bio-based products, and advocate for tailored policy interventions, integrated evaluation methodologies, and enhanced support to address economic, environmental, and logistical challenges – thereby fostering a resilient circular economy.

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* *Corresponding author:* Naomi Di Santo - Department of Soil, Plant and Food Sciences, University of Bari Aldo Moro, Italy. E-mail: naomi.disanto@uniba.it.

Introduction

Large quantities of agricultural waste are produced daily to meet the demands of a rapidly growing population, with agriculture being a major cause of food loss due to its heavy reliance on the significant residues produced during the cultivation and harvesting stages (Koul *et al.*, 2022).

The issue of agricultural residues is particularly relevant in conventional farming systems, which primarily follow a linear resource consumption model of “produce, use, dispose” and are widely reported for their inherent unsustainability (Alan and Köker, 2023). This has prompted a proactive shift toward implementing a circular economy characterized by closed-loop systems, efficiently decreasing waste and aiming to reduce reliance on external inputs by valorising agricultural products (Carus and Dammer, 2018). Within this paradigm, challenges related to agricultural residues are often discussed using a range of overlapping terms – such as co-products, secondary products, and residues – which are frequently used interchangeably in the literature (Santana-Méridas *et al.*, 2012). This terminology reflects the ambitions of the European Green Deal, launched in 2019, which seeks to address the environmental externalities associated with harmful practices such as open burning – responsible for the release of pollutants and greenhouse gases – or the uncontrolled accumulation of residues in fields, which can impede crop growth, disrupt nutrient cycles, and promote pests and diseases (Pawłowski and Sołtysiak, 2024; Skjærseth, 2021). The overarching objective is to reframe these residues as a valuable resource for the production of renewable fuels, energy, and everyday goods such as bioplastics and other materials, all while avoiding competition with food production (Torres-León *et al.*, 2018; Medina *et al.*, 2015; Bentsen *et al.*, 2014). In a nutshell, this entails transforming agricultural residues from “bad outputs” into “good outputs”, shifting from linear to circular economic models in agricultural production and waste management systems to enhance sustainability (Skjærseth, 2021). This shift is strongly underscored by the European Union’s Common Agricultural Policy (CAP) for 2023-2030, which includes a 50% reduction in nutrient losses, a 20% reduction in fertilizer usage without compromising soil fertility, and a 50% reduction in chemical pesticide use (Skevas, 2025).

The transition towards a circular economy is based on rethinking the use of agricultural residues, prompting scientific literature to investigate their potential implications. Within this perspective, the generation of residues represents an intrinsic characteristic of crop production, since they emerge unavoidably alongside the principal outputs, both being derived from the same combination of inputs. This co-production implies that residues are not merely incidental, but constitute an inescapable component of the agricultural production process (Scarlat *et al.*, 2019).

The literature has extensively examined residue generation and proposed indicators for its quantification (Xu *et al.*, 2025; Sarkar *et al.*, 2020) also providing invaluable datasets (Smerald *et al.*, 2023) and methodological frameworks, often employing residue-to-product ratios (Skoutida *et al.*, 2025) and satellite-derived land use data to project theoretical, ecological, and technically recoverable potentials at national and global scales (Daioglou *et al.*, 2016).

Within this framework, the present study aims to assess the efficiency of residue production, treating residue quantities as a proxy for the technical potential of secondary biomass in accordance with circular economy principles, which prioritise recycling and reuse from both environmental and sustainability perspectives (Sherwood, 2020).

Building on this foundation, our study addresses the following research questions:

RQ1: *Which regions, given their quantified levels of residue production, are operating below optimal efficiency?*

RQ2: *Which specific policy or management measures could be implemented to improve their production efficiency?*

To achieve this objective, a multi-stage methodological approach was employed, integrating an input-oriented Data Envelopment Analysis (DEA) with Multi-Criteria Decision Analysis (MCDA). This combined framework supports the development of a more comprehensive efficiency indicator, providing a systemic perspective that highlights the complex interplay of factors influencing secondary biomass production at the regional level.

The indicator was tested using data from Polish regions. Poland was chosen due to its role as a key agricultural producer within the European Union, characterised by a diverse crop structure and strong regional variation in output. Agricultural residues represent a significant opportunity for advancing the country's circular economy agenda; however, this potential is unevenly distributed. Between 1999 and 2018, for example, Poland generated an average annual surplus of 12.5 million tonnes of straw – equivalent to 4.2 million tonnes of oil equivalent – yet the regional distribution of these surpluses varied substantially (Havrysh *et al.*, 2021). Nonetheless, several challenges persist. The environmental targets set by the European Green Deal risk lowering yields, particularly on small farms that lack access to modern technologies. Additional obstacles include economic constraints, fragmented land ownership, and ongoing soil contamination. Moreover, the efficient use of residues continues to be hampered by logistical barriers and limited policy support (Söderholm, 2020).

The paper is structured as follows: Section 1 provides the theoretical background. Section 2 presents the case study. Section 3 outlines the

methodological approach, while Section 4 shows the results, followed by a discussion in Section 5. Finally, the paper concludes with some final remarks.

1. Background

Agricultural residues encompass food loss and waste arising from both primary farming and industrial food processing, and can broadly be categorised into two groups: those generated on farms at harvest time, and those remaining after the processing of raw agricultural products (Awogbemi, 2022). The first group includes non-edible parts of crops – such as straw, stubble, stalks, leaves, roots, twigs, and pruning waste – typically left in the field after harvesting cereals, vegetables, fruits, and energy crops. The second group, known as agro-industrial residues, comprises by-products like fruit peels, bagasse, sawdust, husks, and pomace produced during food and wood processing. In some classifications, the term “tertiary materials” refers to waste generated after the processing of secondary materials (Santana-Méridas *et al.*, 2012).

Agricultural residues have been traditionally viewed as unwanted waste and typically removed through harmful practices like open-field burning (Prateep Na Talang *et al.*, 2024). This view reflected a linear approach to agriculture, focused on production and quick disposal of what was considered useless. Today, with the growing importance of sustainability, these residues are increasingly recognized as useful resources that can be transformed into valuable products such as biofuels and bioplastics. This change in perspective supports the integration of circular economy principles in agriculture, where waste is minimized, and materials are reused or recycled to create a more sustainable and efficient system (Rao *et al.*, 2024; Kapoor *et al.*, 2020).

In the context of biofuel production from agricultural residues, recent scientific research has focused on their valorisation as a promising feedstock for bioethanol, owing to their high lignocellulosic content and widespread availability (Melendez *et al.*, 2022). Two main pathways have emerged for the reuse of these residues, each with distinct characteristics and advantages. On one hand, biorefineries are capable of producing both liquid biofuels – such as bioethanol and biodiesel – and biochar, a carbon-rich by-product derived from biomass pyrolysis. Biochar has garnered attention for its agronomic benefits: it enhances soil structure, improves water retention, and supports beneficial microbial communities, thereby contributing to long-term soil fertility and carbon sequestration. Land application of biochar safely reduces heavy metals and pesticide residues in the soil, aiding in making agriculture safe and sustainable (Rajput *et al.*, 2022). On the other hand, bioethanol, biodiesel, and biohydrogen, among other liquid biofuels, come from items

that are left over after farming and treated either through fermentation or chemical methods (Kumar Sarangi *et al.*, 2023). As a renewable and safe option, biofuels help power many aspects of transportation and cut down on dangerous greenhouse gases. Several studies have looked into converting corn stover, rice straw, and bagasse into biogas to combat the current energy shortage (Alengebawy *et al.*, 2024; Guddaraddi *et al.*, 2023). Apart from providing energy, they impact agroecology by adding nutrients to the soil and directing how water flows on the farm. From this perspective, agricultural residues should not be seen as something to throw away, but should be utilized in a circular and bio-based economy (Bentsen *et al.*, 2014).

On the other hand, bioplastics – plastics derived from bio-based polymers – represent a promising avenue for supporting more sustainable plastic life cycles within the broader framework of a circular economy. This approach involves the use of renewable or recycled feedstocks for the production of virgin polymers, the adoption of carbon-neutral energy sources during manufacturing, and the design of products that are reused, recycled, or biodegraded at the end of their life (Rosenboom *et al.*, 2022). Compared to conventional fossil-based plastics, bio-based alternatives often have a smaller carbon footprint and offer favourable material properties. Many bioplastics can be integrated into existing recycling systems and, in certain cases, are capable of biodegrading under controlled or well-defined environmental conditions. The production of bioplastics from agricultural residues – such as straw, bagasse, and other lignocellulosic by-products – represents a particularly promising development (Kapoor *et al.*, 2020). These residues are indeed rich in cellulose, hemicellulose, and lignin, and can be converted into biodegradable polymers like polylactic acid (PLA) and polyhydroxyalkanoates (PHA) through biochemical fermentation or thermochemical conversion processes (Chan *et al.*, 2021), thus minimizing pollution and reducing greenhouse gas emissions (European Bioplastics, 2024). Moreover, the integration of bioplastic production into biorefineries – alongside the aforementioned biofuels – enhances resource efficiency and supports the development of sustainable agricultural systems (Saha *et al.*, 2019). By closing material loops and reducing dependence on fossil resources, bioplastics contribute to climate mitigation strategies and to the long-term sustainability of rural economies.

Although agricultural residues represent valuable feedstocks for bioenergy and bioplastic production, their practical utilisation is constrained by several limitations, including limited scalability and underdeveloped waste management infrastructure for compostable or biodegradable materials (Velasco-Muñoz *et al.*, 2022), as well as the high costs of collection, processing, and transportation, which disproportionately affect regions characterised by underdeveloped infrastructure and fragmented land holdings

(Gontard *et al.*, 2018; Guddaraddi *et al.*, 2023). Furthermore, complex logistics, shaped by the distance to processing facilities and the harvesting systems employed, pose significant environmental challenges (Suardi *et al.*, 2019).

From a social standpoint, the advantages of circular economy initiatives in agricultural residue management are not intrinsic. Although processors may benefit from intensive utilisation and smallholder farmers could access new markets, inequalities in access to technology, training, and capital can hinder equitable participation (Härri *et al.*, 2023).

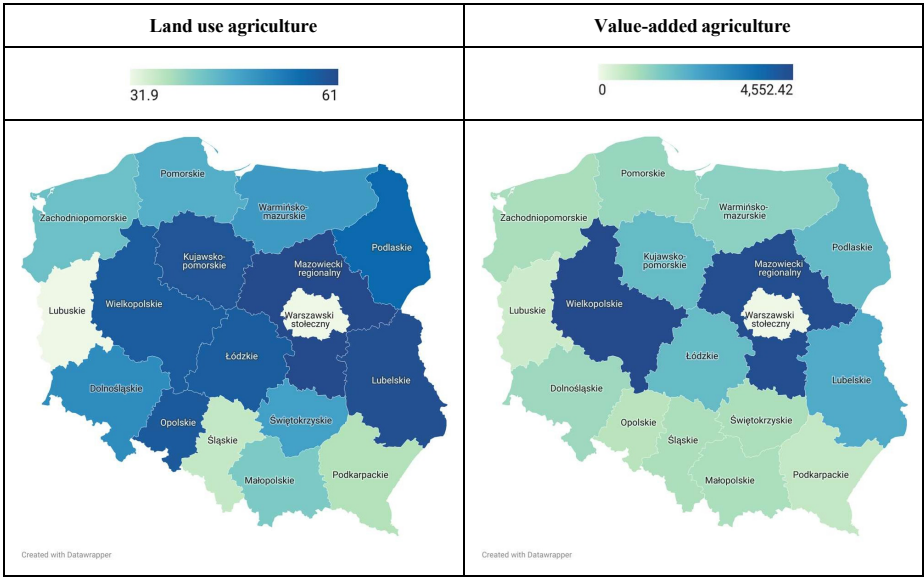
Overcoming these barriers will require coordinated efforts in policy support, technological innovation, and market development. Accordingly, this study enables the identification of regions operating below optimal efficiency, as well as the formulation of targeted policy and management recommendations, thereby providing evidence-based insights to support policymakers and promote territorial development.

2. Case study

Poland represents a key agricultural country within the EU, accounting for approximately 43% of its total agricultural output from plant production, and ranking second for arable land area (Sawinska *et al.*, 2020). Agricultural sector is a cornerstone of its economy, contributing significantly to the Polish gross value added, with agriculture, forestry, and fisheries being twice the EU average (European Commission, 2022). The country's diverse farm structure supports the cultivation of cereals such as wheat, triticale, rye, barley, and maize, alongside non-cereal crops like oilseed rape, sugar beet, and potatoes. The Wielkopolska Voivodeship, recognized as Poland's leading agricultural region, exemplifies high productivity due to its fertile soils and advanced farming practices (Pawłowski and Sołtysiak, 2024). However, regional disparities exist, with areas like Dolnośląskie and Lubelskie also showing significant crop yields, particularly in wheat and triticale, which account for nearly 50% of the national grain harvest (Havrysh *et al.*, 2021) (Figure 1).

Despite its strengths, Polish agriculture faces challenges in aligning with the European Green Deal's environmental objectives, which mandate a 50% reduction in plant protection products and a 20% reduction in fertilization. These requirements could reduce crop yields, particularly for small and medium-sized farms that lack the financial capacity to adopt precision agriculture technologies. Additionally, the sector struggles with structural issues, including fragmented land ownership and capital shortages, which limit modernization efforts (Pawłowski and Sołtysiak, 2024).

Figure 1 - Regional disparities in agricultural land use and value-added in Poland



Agricultural residues, including straw, stover, stalks, and animal husbandry waste, represent a significant resource for bioenergy production in Poland. Between 1999 and 2018, Poland generated an average annual surplus of 12.5 million tonnes of straw, corresponding to 4.2 million tonnes of oil, with notable surpluses in Dolnośląskie, Kujawsko-Pomorskie, Lubelskie, Wielkopolskie, and Zachodniopomorskie voivodeships (Havrysh *et al.*, 2021). Straw is the second most important biofuel in Poland after wood, capable of covering up to 15% of national power generation (Zabed *et al.*, 2017). Additionally, residues from the agri-food industry, such as maize silage, slurry, and distillery waste, are increasingly used as substrates for biogas production (Adamski *et al.*, 2009).

The management of these residues is critical to reducing environmental impacts. Inadequate handling of organic waste can lead to methane emissions from decomposing manure or soil degradation if residues are not returned to fields. However, the use of residues for bioenergy, such as co-firing straw with fossil fuels or anaerobic digestion for biogas, offers a sustainable alternative. For instance, in the Braniewo district of Warmia and Mazury, approximately 41,531 tonnes of straw are available annually for energy purposes, equivalent to 24,088 tonnes of coal (Marks-Bielska *et al.*, 2019). Despite this potential, logistical challenges, such as the lack of integrated methodologies

for assessing residue availability and spatial distribution, hinder efficient utilization.

Polish agriculture faces several challenges that impact residues management and overall sustainability. Economic factors are a primary concern, particularly for organic farming, where low yields and high production risks deter farmers. A study by Łuczka and Kalinowski (2020) revealed that over 80% perceive organic production as highly risky during the conversion period, with nearly 60% maintaining this view post-conversion, largely due to insufficient financial support. The European Green Deal's stringent environmental regulations exacerbate these concerns, as reduced pesticide and fertiliser use may lower productivity, particularly for smaller farms unable to invest in modern technologies (Pawłowski and Sołtysiak, 2024).

Environmental challenges also persist. Long-term studies in Bałcyny, Poland, detected DDT residues in soils five decades after its last use, highlighting the persistence of chemical contaminants (Łuczka and Kalinowski, 2020). Furthermore, the management of agricultural residues must balance energy production with soil conservation needs, as excessive removal of straw can deplete soil organic matter (Marks-Bielska, 2019). The lack of consumer awareness and limited policy support for sustainable practices further complicates the adoption of residue-based bioenergy systems (Bednarek *et al.*, 2023).

The aforementioned regional differences in residues availability and agricultural practices offer both challenges and opportunities. Beyond simple disparities in yields, Polish regions also display distinct patterns of productive specialisation. For instance, Wielkopolskie is strongly oriented toward cereals and oilseed rape, supported by mechanisation and large-scale farms. Lubelskie combines high wheat and triticale output with significant sugar beet cultivation, while Dolnośląskie maintains an important role in grain production, particularly triticale (Havrysh *et al.*, 2021). By contrast, Podlaskie and Podkarpackie are more specialised in livestock, generating larger quantities of manure and slurry residues rather than crop-based by-products. Other regions, such as Kujawsko-Pomorskie and Zachodniopomorskie, are characterised by significant straw surpluses, reflecting their cereal-oriented production systems (Stanek *et al.*, 2018). This productive specialisation shapes both the type and the volume of residues available, reinforcing the idea that residue management strategies must be tailored not only to economic and infrastructural disparities but also to regional agricultural profiles. Voivodeships like Wielkopolskie and Lubelskie, with high crop yields, have significant residue surpluses, making them ideal for biomass-based power generation (Havrysh *et al.*, 2021). In contrast, smaller farms in less productive regions struggle with the costs of residue collection and

transport, limiting their participation in bioenergy markets (Jezierska-Thöle *et al.*, 2016). Community-Supported Agriculture (CSA) models, with 13 active farms reaching 1,200 people as of 2023-2024, present a promising avenue for sustainable residue management by fostering local networks and reducing waste (Onyszkiewicz, 2024).

However, economic risks, environmental regulations, and logistical barriers continue to challenge the efficient management of agricultural residues. To fully unlock the potential of Poland's "hidden harvest", it is therefore essential to gain a deeper understanding of regional disparities in residue generation efficiency. These differences are shaped by a complex interplay of agronomic, infrastructural, and socio-economic factors which may vary significantly across regions.

Studying these regional dynamics is crucial for designing place-based policy interventions that reflect local realities and enhance the contribution of agricultural residues to a sustainable and resilient agri-food system. Regional disparities, in addition to the agronomic and structural factors mentioned above, are further reinforced by socio-economic conditions. In Poland, such disparities significantly influence the efficiency of agricultural residue management, reflecting economic and educational inequalities across Poland regions. Wealthier regions, such as Warszawski stołeczny (EUR 28,900 GDP per capita) and Dolnośląskie (EUR 15,600), stand in sharp contrast to less affluent regions like Lubelskie (EUR 10,100) and Podkarpackie (EUR 10,200). This economic divide enables more prosperous regions to invest in advanced technologies, including bioenergy generation from crop residues, while poorer areas face financial constraints, exacerbated by fragmented land ownership. Educational inequalities add to these challenges: in Podkarpackie (6.8%) and Lubelskie (6.5%), a higher share of the population has only primary education, compared with just 2.5% in Warszawski stołeczny. Such disparities limit the capacity of farmers in less-educated regions to adopt technical innovations. Together with marked differences in regional unemployment rates, these economic and educational gaps help explain the uneven efficiency of residue management across the country. Affluent and better-educated regions such as Wielkopolskie benefit from economies of scale and a skilled workforce, while less developed and more fragmented regions like Lubelskie face persistent logistical and technical barriers.

Poland's decentralised governance structure offers a framework for addressing these disparities through targeted regional policies. This autonomy allows wealthier regions such as Wielkopolskie to expand residue management initiatives, including the development of biogas plants, while less affluent regions such as Lubelskie and Podkarpackie can draw on EU funds to support small-scale farmers and mitigate land fragmentation (Zgut, 2022). By combining regional autonomy with EU funding, regions are able

to design tailored strategies, such as subsidies for technology adoption and training programmes aimed at enhancing technical skills in less-educated areas, in line with the EU's bioeconomy objectives (Ronzon and M'Barek, 2018). Such a decentralised approach ensures that policies are responsive to regional economic and educational contexts, thereby promoting more sustainable agricultural residue management across Poland.

3. Materials and methods

To answer our research question, we started by investigating whether the efficient production of agricultural residues in Poland results from economies of scale or from inefficient input use. For this purpose, we applied DEA (Charnes *et al.*, 1978), a non-parametric method used to assess the efficiency of production across decision-making units (DMUs), in this case, the Polish regions.

An important advantage of DEA is that it does not require a predefined production function, making it particularly suitable for identifying the specific sources of inefficiency across regions. Although DEA has been increasingly employed in recent years to develop indicators for assessing efficiency in agriculture (see, for instance, Wang *et al.*, 2025; Fusco *et al.*, 2023; Toma *et al.*, 2017), to the best of our knowledge, it has not yet been applied to evaluate the efficiency of agricultural residue production, treating residues as a good output within a circular economy perspective. The analysis considered land, labour, and capital as inputs, and agricultural residues as the output. To determine whether inefficiencies arose from scale or from poor input allocation, we considered both constant returns to scale (CRS) and variable returns to scale (VRS) (Banker *et al.*, 1984; Charnes *et al.*, 1978) models. Under CRS, all DMUs are assumed to operate at an optimal scale, whereas VRS allows efficiency to be separated into pure technical efficiency and scale efficiency components.

DEA can follow either an input-oriented or output-oriented approach. The first aims to minimize inputs while maintaining output levels, whereas the second focuses on maximizing outputs without increasing inputs. Given the aims of our study, we adopted an input-oriented approach, as it aligns more closely with sustainable agriculture practices. This orientation promotes indeed the efficient use of resources, helps reduce environmental impact, and supports strategies for agricultural waste valorisation (Zhang *et al.*, 2008).

It is important to elucidate the rationale for selecting the constant returns to scale (CRS-DEA), variable returns to scale (VRS-DEA), and multi-criteria decision analysis (MCDA-DEA) models, as well as their specific contributions to assessing the efficiency of agricultural residue production

in Polish regions. The CRS-DEA model assumes that all decision-making units operate at an optimal scale, providing a measure of overall technical efficiency (Charnes *et al.*, 1978). This model is valuable for benchmarking regions against an ideal production frontier, capturing inefficiencies arising from both suboptimal input use and scale effects (Coelli *et al.*, 2005). However, the CRS assumption may not fully reflect the diverse operational scales of Polish regions, where agricultural practices vary due to differences in land availability, labour, and capital endowments (Banker *et al.*, 1984).

This limitation necessitated the inclusion of the VRS-DEA model. The VRS-DEA model relaxes the CRS assumption, enabling the decomposition of efficiency into pure technical efficiency (PTE) and ES (Banker *et al.*, 1984). PTE measures the efficiency of input utilization, while ES indicates whether a region operates at an optimal scale. By calculating ES, we can pinpoint whether inefficiencies stem from poor input allocation or non-optimal scale (Cook, 2001). This distinction is critical for formulating targeted policy recommendations, as it differentiates between inefficiencies addressable through resource management improvements and those requiring scale adjustments (Fare *et al.*, 1994).

While CRS-DEA and VRS-DEA provide robust efficiency assessments, their flexibility in allowing DMUs to select individual weights can lead to multiple regions being classified as fully efficient ($\theta = 1$), reducing discriminatory power (Doyle and Green, 1994). To address this, we employed the MCDA-DEA model as a complementary approach. Unlike traditional DEA, MCDA-DEA uses a common set of weights across all DMUs, ensuring a fairer and more comparable evaluation (Hatefi & Torabi, 2010). By generating a composite indicator, MCDA-DEA enhances discriminatory power, reduces the number of fully efficient units, and provides a ranking of regions based on shared efficiency criteria (Gomes and Lins, 2008). This is particularly relevant in a circular economy context, where consistent efficiency metrics support resource allocation and waste valorisation strategies (Dyckhoff and Allen, 2001). The integration of CRS-DEA, VRS-DEA, and MCDA-DEA is justified by their complementary roles. CRS-DEA offers a baseline for overall efficiency, VRS-DEA disaggregates inefficiencies into technical and scale components, and MCDA-DEA provides a discriminative and comparable ranking of regions. Together, these models ensure a comprehensive analysis that informs both the sources of inefficiency and the prioritization of policy interventions for sustainable agricultural residue production.

Let us consider a set of n DMUs, each employing the same types of inputs to generate the same types of outputs. Let y_{ik} represent the quantity of output k produced by DMU i , and x_{ik} the quantity of input k used by DMU i . The weights assigned to each output and input – u_{ik} and v_{ik} , respectively – are

endogenously determined by the model and may vary across DMUs. The technical efficiency of DMU i under the CRS assumption is denoted by θ_i . The input-oriented CRS-DEA model can therefore be expressed as follows:

$$\left\{ \begin{array}{l} \max \theta_i = \sum_{k=1}^m u_{ik} y_{ik} \\ \text{s. t.} \\ \frac{\sum_{k=1}^m u_{ik} y_{ik}}{\sum_{k=1}^m v_{ik} x_{ik}} \leq 1, i = 1, 2, \dots, n \\ u_{ik} \geq 0, k = 1, 2, \dots, m \\ v_{ik} \geq 0, k = 1, 2, \dots, m \end{array} \right. \quad [1]$$

Model [1] determines the highest possible performance score for entity i , generating a set of efficiency scores $\theta_1, \theta_2, \dots, \theta_n$ by solving the model iteratively for each decision-making unit.

As before, let y_{ik} and x_{ik} represent the outputs and inputs, respectively. Now define w_{ik} as the variable weights assigned endogenously by the model to the inputs and outputs of each entity; x_{dk} as the input vector for the evaluated DMU d ; y_d as its output vector; and θ_i as the technical efficiency score of DMU i under VRS. The input-oriented VRS-DEA model for a single DMU can therefore be expressed as follows:

$$\left\{ \begin{array}{l} \min \theta_i = \sum_{k=1}^m u_{ik} y_{ik} \\ \text{s. t.} \\ \sum_{k=1}^m w_{ik} x_{ik} \leq \theta_d x_{dk}, i = 1, 2, \dots, n \\ \sum_{k=1}^m w_{ik} y_{ik} \geq y_d, i = 1, 2, \dots, n \\ \sum_{k=1}^m w_i = 1 \\ w_k \geq 0, k = 1, 2, \dots, m \end{array} \right. \quad [2]$$

The constraint $\sum_{k=1}^m w_i = 1$ introduces the VRS assumption, which distinguishes the VRS model from the CRS one. This condition allows for the identification of cases where DMUs operate under non-constant returns to scale. Alongside Models [1] and [2], we also calculated scale efficiency (SE),

defined as the ratio of CRS to VRS efficiency, to assess the extent to which deviations from optimal scale affect overall performance.

Models [1] and [2] can sometimes identify multiple entities as equally efficient, thereby failing to single out the top performer. To enhance the robustness of our results, we complemented the DEA analysis with a MCDA-DEA. Unlike the CRS-DEA, the MCDA-DEA derives a common set of weights simultaneously for all entities, preventing any individual entity from biasing the evaluation by selecting weights in its own favour. This method provides a fairer assessment based on composite indicators calculated using shared weights. Let I_{ik} denote the value of each sub-indicator k (including both inputs and outputs) for entity i , w_{ik} the weights assigned to these sub-indicators, and d_i the deviation of entity i 's efficiency from unity during evaluation. The MCDA-DEA model is then expressed as follows:

$$\left\{ \begin{array}{l} \min M \\ M - d_i \geq 0, i = 1, 2, \dots, n \\ s. t. \\ \sum_{k=1}^m w_{ik} I_{ik} + d_i = 1 \\ w_{ik} \geq \varepsilon, k = 1, 2, \dots, m \\ d_i \geq 0, i = 1, 2, \dots, n \end{array} \right. \quad [3]$$

The constraints $M - d_i \geq 0$, $\forall i$ assure that $M = \max \{d_i, i = 1, 2, \dots, m\}$.

Using this model, the composite indicator for the i -th entity is calculated as $CI_i = 1 - d_i$, $\forall i$. As highlighted by Hatefi and Torabi (2010), model [3] presents several advantages compared to models [1] and [2]. Notably, because all common weights are constrained to be strictly positive (i.e., $w_{ik} \geq \varepsilon$), the model incorporates the contribution of all sub-indicators when assessing production efficiency. Furthermore, model [3] offers greater discriminatory power by reducing the number of entities classified as fully efficient with a composite indicator equal to 1.

In models [1], [2], and [3], y_{ik} denotes the quantity of agricultural residues in each region, while x_{ik} refers to the percentage of land use, the number of agricultural machineries employed, and the percentage of agricultural labour, respectively, for each region.

We created radar charts for each Polish region to draw policy conclusions from our findings. These visual tools allowed us to clearly identify, for each region, the variables that were optimised – represented near the outer rim of the chart – while also highlighting those requiring further improvement, which appeared closer to the centre.

The empirical analysis draws on data from two main sources: Eurostat, which provides socio-economic, demographic, and infrastructural indicators, and the S2BIOM Tool, which supplies information on resource endowments. The dataset refers to the year 2020 and covers all 17 NUTS-2 regions of Poland. Table 1 offers a detailed description of the variables considered, alongside their descriptive statistics

Table 1 - Description of variables used and descriptive statistics

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
Agr res	Agricultural residues (ton/km ²)	17	70.77	39.86	.05	148.50
Agr land	% land use agriculture	17	48.43	10.33	31.9	61
Low edu	% low educated people (less than primary and secondary)	17	7.28	2.36	3.2	13.5
Empl agr	% workers in agriculture	17	10.38	5.68	2.22	19.33
Road	km/1000 km ²	11	8.82	4.64	1	19
Mach	No. of machinery	17	11.79	4.81	7.59	24.87
Colture type	% of high-residue crops in total production	17	14.15	4.99	7.01	25.45
Irrigation	Number of farms by size of irrigated area/km ²	15	4.52	2.61	1.30	9.42

4. Results

Figure 2 illustrates the efficiency of agricultural residues across Polish regions using DEA and MCDA-DEA, in map form.

Figure 2 - Results of the DEA and MCDA-DEA

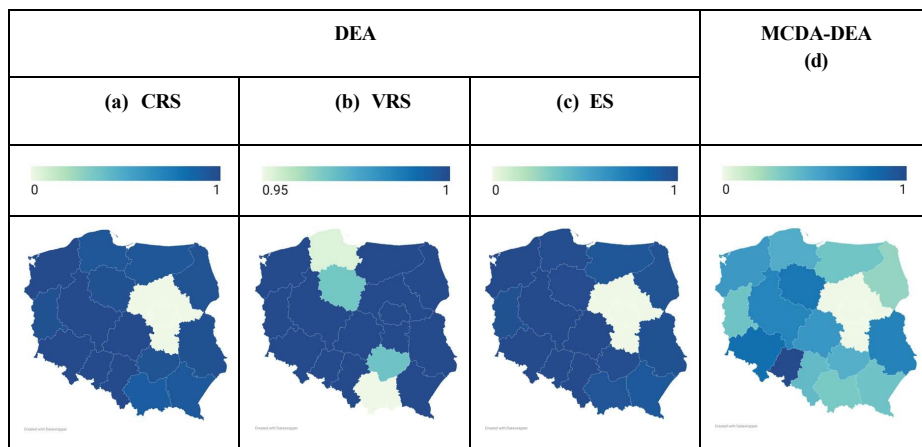


Table 2 - Results of the DEA and MCDA-DEA

NUTS code	Label	CRS	VRS	ES	MCDA-DEA
PL21	Małopolskie	0,89491916	0,9513711	0,94066256	0,32494081
PL22	Śląskie	1	1	1	0,4044935
PL41	Wielkopolskie	1	1	1	0,68664387
PL42	Zachodniopomorskie	1	1	1	0,57772987
PL43	Lubuskie	0,96428245	1	0,96428245	0,35328419
PL51	Dolnośląskie	1	1	1	0,80163992
PL52	Opolskie	1	1	1	1
PL61	Kujawsko-pomorskie	0,9604584	0,9679462	0,99226421	0,76227864
PL62	Warmińsko-mazurskie	0,93581212	1	0,93581212	0,34794989
PL63	Pomorskie	0,93635035	0,954132	0,98136359	0,47500998
PL71	Łódzkie	1	1	1	0,5893226
PL72	Świętokrzyskie	0,95230204	0,968658	0,98311478	0,46104932
PL81	Lubelskie	0,96404308	1	0,96404308	0,69957392
PL82	Podkarpackie	0,92468512	1	0,92468512	0,35743935
PL84	Podlaskie	0,95554751	1	0,95554751	0,25992817
PL91	Warszawski stołeczny	0,0003254	1	0,0003254	0,00033671
PL92	Mazowiecki regionalny	0,00024248	1	0,00024248	0,00033671

The CRS-DEA map shows a predominantly dark blue coloration, indicating high efficiency scores, with a notable white area in the central-east, likely Warmia-Mazury or Podlaskie, suggesting the lowest efficiency. The VRS-DEA map displays a similar dark blue pattern; however, it features a broader light green area in the centre – particularly in regions like Kujawsko-Pomorskie and Wielkopolskie – indicating a decline in efficiency when accounting for scale flexibility. The ES map confirms the results of CRS-DEA. The MCDA-DEA map displays varying efficiency levels, suggesting a more refined assessment when multiple criteria are integrated.

Figure 3 displays radar plots grouped into four clusters based on similar patterns, with respect to five key variables, thus illustrating the distinctive characteristics of the classified regions:

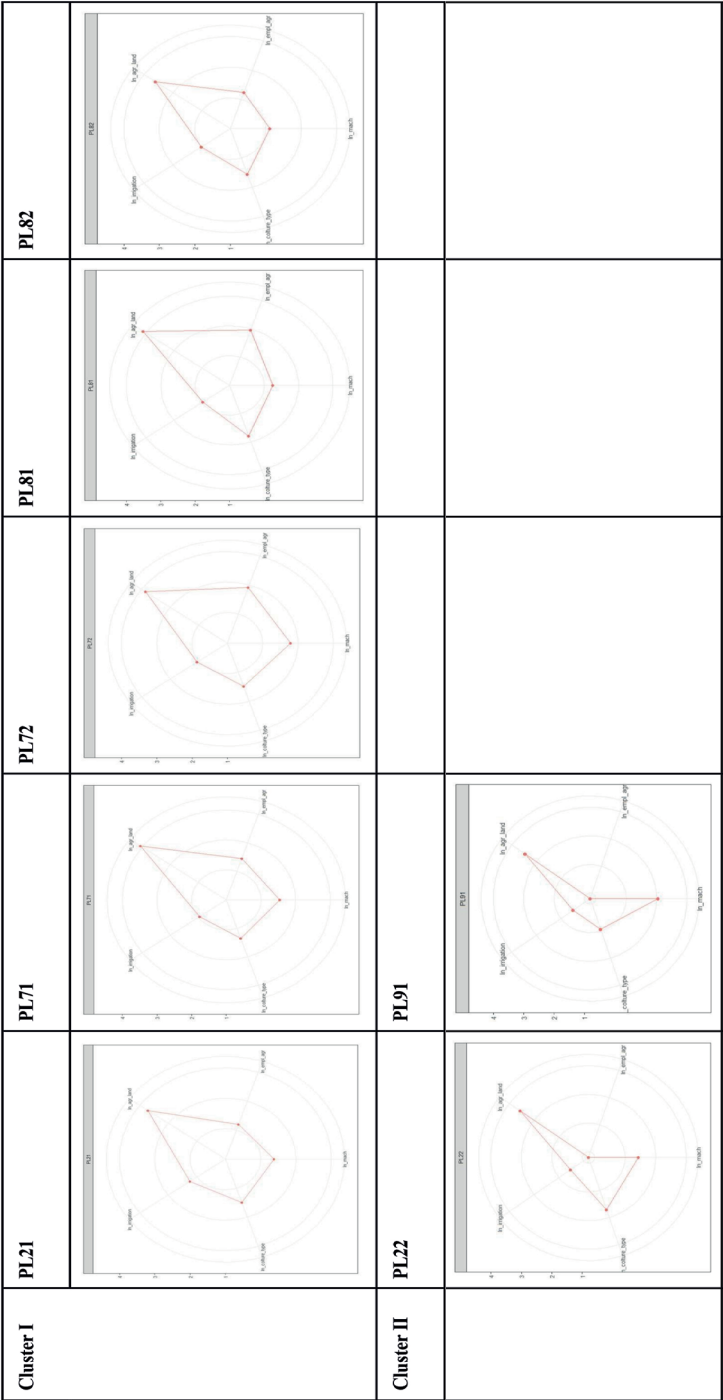
- irrigation: number of farms by size of irrigated area/km²;
- agricultural land: percentage of land use agriculture;
- agricultural employment: percentage of workers in agriculture;
- machinery: number of machineries employed in agriculture;
- crop type: percentage of high-residue crops in total production.

The results offer a comprehensive assessment of inefficiencies across clusters, providing an efficiency indicator that yields important insights into the performance of agricultural systems and underscores the need for region-specific policy interventions aimed at improving agricultural residue production.

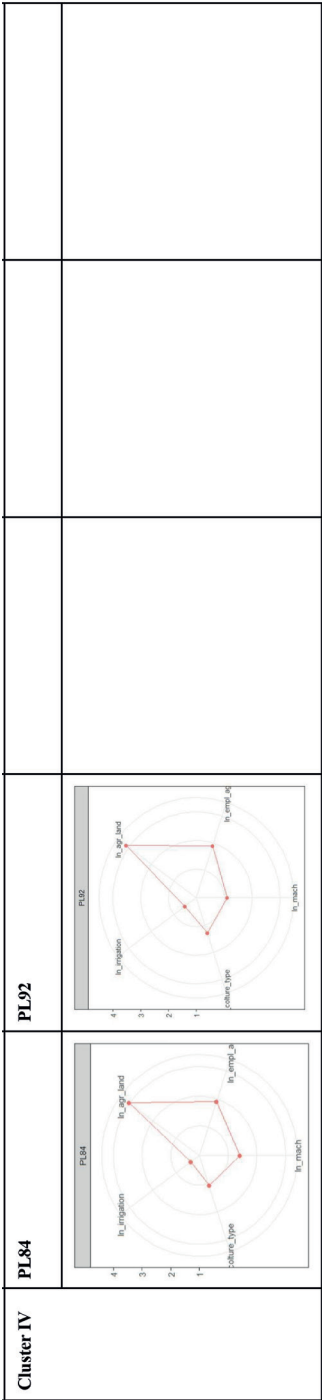
Agricultural land consistently emerges as the most efficient variable across all clusters, representing the least problematic input. This suggests that land allocation and utilization are relatively optimized, requiring only marginal adjustments in selected regions. By contrast, machinery and crop type display widespread inefficiencies, signalling persistent challenges in mechanization and crop selection that constrain residues production. Irrigation appears to be a major bottleneck, particularly in clusters III and IV, indicating notable deficiencies in water management infrastructure or practices. Agricultural employment exhibits variable performance: cluster II demonstrates the most significant inefficiency, pointing to structural problems in labour allocation or workforce skills that warrant immediate policy attention. These patterns reveal substantial heterogeneity in inefficiencies across clusters, underscoring the limitations of uniform policy approaches.

In cluster I, pervasive inefficiencies are observed in irrigation, agricultural employment, machinery, and crop type – necessitating a comprehensive policy response. Cluster II is marked by pronounced inefficiency in agricultural employment, coupled with low performance in irrigation, crop type, and machinery; here, labour and equipment constraints constitute the primary barriers. In cluster III, irrigation is the most critical issue, followed by agricultural employment, machinery, and crop type, reflecting challenges

Figure 3 - Radar plots



[illegible]



Note: The axes are arranged clockwise starting from the top-left: ln_irrigation (log-transformed irrigated area), ln_agr_land (log-transformed agricultural land), ln_empl_agr (log-transformed agricultural employment), ln_mach (log-transformed machinery intensity), and ln_culture_type (log-transformed crop diversity index). Each axis is scaled from 0 to 4, with higher values indicating greater relative intensity.

similar to those in cluster II. Cluster IV likewise identifies irrigation as the primary area of concern, followed by machinery and crop type, with comparatively better outcomes in agricultural employment and land use.

5. Discussion

The analysis of agricultural residue efficiency across Polish regions underscores the complexity of optimising agricultural systems within different regional contexts. The results provide a robust framework for identifying inefficiencies, offering a nuanced perspective on resource utilisation. These findings are particularly pertinent in the context of Poland's agricultural sector, which plays a pivotal role in the national economy, and advocate for tailored, cluster-specific interventions to effectively address the identified inefficiencies.

For cluster I, a comprehensive strategy is required, involving investment in irrigation infrastructure, workforce training, machinery modernization, and crop diversification to address the multifaceted inefficiencies. Specifically, policymakers could consider implementing integrated development programmes that combine public-private partnerships to fund irrigation infrastructure upgrades and provide subsidies for modern machinery. Additionally, targeted educational initiatives could enhance workforce skills, particularly in regions where agricultural employment inefficiencies are pronounced. Such interventions should be supported by rigorous monitoring and evaluation frameworks to ensure their effectiveness and adaptability to local conditions.

In cluster II, efforts should prioritize reforming agricultural employment through training schemes or labour reallocation, complemented by improvements in machinery and crop selection. For clusters III and IV, urgent investments in irrigation systems – such as advanced water management technologies or infrastructure enhancements – are essential, along with targeted upgrades in machinery and crop optimization. Moreover, the adoption of precision agriculture technologies, such as sensor-based irrigation systems and data-driven crop management tools, could address inefficiencies in irrigation and crop type, particularly in clusters III and IV. These technologies, while requiring initial investment, have the potential to yield long-term efficiency gains by optimising resource use and reducing environmental impacts. Collaborative research initiatives between academic institutions, agricultural extension services, and regional stakeholders could further drive innovation, ensuring that technological advancements are tailored to the specific needs of each cluster.

Across all clusters, the relative strength of agricultural land should be leveraged through policies that promote sustainable land management to

preserve its efficiency. Furthermore, cross-cluster knowledge exchange and pilot initiatives could facilitate the dissemination of best practices, particularly in machinery use and crop selection, where inefficiencies are most pervasive. Such targeted, evidence-based interventions, grounded in the specific characteristics of each cluster, will enable more effective resource allocation and improve agricultural residues production efficiency throughout Poland – aligning with the imperative for regionally differentiated strategies highlighted in the aforementioned analyses.

Conclusions

This study has undertaken a comprehensive analysis of agricultural residues production efficiency across Poland's NUTS-2 regions, employing an integrated framework combining DEA and MCDA-DEA to investigate the key determinants of residue supply efficiency. This study proposes an efficiency indicator designed to target the key determinants influencing the performance of agricultural residue supply. To achieve this, an integrated framework was adopted, combining Data Envelopment Analysis (DEA) with Multi-Criteria Decision Analysis (MCDA-DEA), and applied to the agricultural residue production across Poland's NUTS-2 regions.

The findings reveal substantial regional disparities in the performance of agricultural systems, shaped by varying levels of inefficiency in irrigation, agricultural employment, machinery, crop type, and – though to a lesser extent – agricultural land. The relatively higher efficiency of agricultural land across all clusters suggests the importance of maintaining sustainable land management practices.

By contrast, widespread inefficiencies in machinery and crop type, along with critical shortcomings in irrigation – particularly in clusters III and IV – and agricultural employment, especially in cluster II, point to structural constraints that hinder the full exploitation of agricultural residues within a circular economy paradigm. These challenges indicate a need for regionally tailored policy responses to improve performance and promote the efficient use of agricultural resources.

For cluster I, a comprehensive strategy is required, involving coordinated investments in irrigation systems, workforce development, machinery upgrades, and diversification of crop choices to address the diverse sources of inefficiency. In cluster II, immediate interventions in agricultural employment are essential, including targeted training initiatives and potential labour reallocation, alongside enhancements in machinery and crop selection. Clusters III and IV necessitate urgent investment in modern irrigation technologies, supported by improvements in mechanization and crop

optimization. Across all clusters, cross-regional knowledge sharing and pilot schemes could accelerate the dissemination of effective practices, particularly in areas of universal concern such as machinery use and crop selection.

These insights are closely aligned with the objectives of the European Green Deal and the CAP 2023-2030, that prioritize sustainable resource use, waste reduction, and the advancement of circular economic principles in agriculture.

Poland's considerable residues' potential presents a valuable opportunity to convert agricultural by-products into bioenergy and bio-based goods. However, economic uncertainties, stringent environmental regulations, and logistical constraints, including fragmented land ownership and underdeveloped infrastructure, continue to present barriers to efficient residues management. Overcoming these obstacles will require the integration of robust evaluation methods, technological innovation, and strengthened policy support to enable Poland's "hidden harvest" to contribute meaningfully to a sustainable and resilient agricultural sector.

While the current study provides valuable insights into regional inefficiencies, it is not without limitations. The reliance on DEA and MCDA-DEA assumes a certain level of data homogeneity, which may not fully capture micro-level variations within regions.

Future research should pursue longitudinal studies to assess the impact of policy measures over time and examine a broader set of socio-economic and environmental factors influencing residue efficiency indicators. Such efforts will be vital in supporting transition towards a fully realized circular economy framework. Furthermore, future research could incorporate finer-grained data, such as farm-level surveys, to validate these findings and explore additional variables, such as soil quality or climate impacts, that may influence efficiency. Such research would complement the current findings, offering a more comprehensive understanding of agricultural residue efficiency dynamics across Poland.

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Roberta Sisto

Department of Social Sciences - University of Foggia, Italy

Via Alberto da Zara, 11 – 71121 Foggia FG

E-mail: roberta.sisto@unifg.it

She is Full Professor of Methods and Policies for Rural Development at the University of Foggia, Italy. Her research focuses on sustainability transitions, rural development, and social capital. She is the author of over 100 publications and has presented more than 70 papers at international conferences. She also serves on the editorial boards of several international journals and acts as a reviewer for leading journals in the fields of sustainability and rural studies.

Naomi Di Santo

Department of Soil, Plant and Food Sciences - University of Bari Aldo Moro, Italy

Via Giovanni Amendola, 165/a – 70126 Bari BA

E-mail: naomi.disanto@uniba.it

She is a Research Fellow at the University of Bari Aldo Moro, focusing on food policy. She holds a Ph.D. in Economics, Culture and Environment from the University of Foggia. Her research interests include agricultural economics, rural development, and sustainability transitions, with particular attention to policy mixes, participatory approaches, and consumer behaviour in the agri-food sector. She has contributed to several research projects and published in leading international journals.

Vincenzo D’Atteo

Department of Social Sciences - University of Foggia, Italy

Via Alberto da Zara, 11 – 71121 Foggia FG

E-mail: vincenzo.datteo@unifg.it

He holds a Master’s degree with honours in Banking, Finance, and Markets from the University of Foggia (Italy). He is currently a PhD candidate in Economic and Social Sciences at the University’s Department of Social Sciences, where he previously worked as a research fellow in the field of bioeconomy.

Edgardo Sica

Department of Social Sciences - University of Foggia, Italy

Via Alberto da Zara, 11 – 71121 Foggia FG

E-mail: edgardo.sica@unifg.it

He is Associate Professor of Economics at the University of Foggia, Italy. He holds an MA in “Economics and Finance” (Federico II University - Naples), an MA in “Development Economics” (Sussex University), a Ph.D. in “Sustainable Development” (University of Foggia) and a Ph.D. in “Technology and Innovation Management” (SPRU, UK). Author of over 80 publications, his research focuses – among others – on the economic analysis of sustainability transitions.

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Economic crises and organic food consumption: A Danish perspective

Jana Majerova^{*,a}, Sarka Cizkova^a

^a AMBIS University, Czech Republic

Abstract

The study aims to analyze the impact of the global economic crisis in 2008 and the COVID-19 crisis in 2020 on the consumption of organic food in Denmark, one of the largest markets for organic food in Europe. The Error Correction Model (ECM) has been implemented, with modifications applying the Markov Regime Switching (MRS) methodology to integrate breakpoint analysis. It has been confirmed a statistically significant dependency of organic food consumption on disposable income during both crisis and non-crisis periods. As the identified effect is positive during non-crisis periods and negative during crises, it has been confirmed that organic food consumption significantly increases when disposable income decreases during a crisis. The use of the Error Correction Model (ECM) with modifications incorporating the Markov Regime Switching (MRS) methodology allows the integration of breakpoint analysis and provides a more realistic description of the evolution of the variables under study. The study is designed to explore overall attitudes towards consumption and aims to measure the influence of disposable income on organic food consumption. It also seeks to analyze how this impact evolved over time and during the aforementioned crises.

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* *Corresponding author:* Jana Majerova - AMBIS University - Lindnerova 575/1, 180 00 Prague, Czech Republic. E-mail: jana.majerova@ambis.cz.

Introduction

Organic food is an issue that has become a subject of academic interest from an economic perspective as a logical consequence of its growing importance at the turn of the 20th and 21st centuries. Traditionally, it has been defined as the output of alternative agricultural production characterized by sustainability and by the absence of synthetic chemicals and genetically modified structures (Campos *et al.*, 2024). However, various legislations place stricter demands on organic food. In the context of European Union law, there is much more scope beyond the original definition of organic food. Producers wishing to obtain the certified organic food producer label must respect natural biological systems and implement sustainable management systems that respect natural resources and observe animal welfare standards (Sujanska & Nadanyiova, 2023).

Although European Union legislation is uniform, the EU market displays marked regional disparities in terms of organic farming development. Recent evidence underscores both the maturity and resilience of Denmark's organic market and the broader European context. Denmark remains a global leader by retail market share; official statistics report DKK 16.0 bn in retail turnover for organic foods in 2024, and industry syntheses report a 11.8% retail market share (value) in 2023, with signs of recovery into 2024 (Statistics Denmark, 2025; Organic Denmark, 2024). According to Eurostat (2023), Austria and Estonia record the highest proportions of organic farmland (more than 20% of their utilized agricultural area), while countries such as Bulgaria, Malta and Ireland maintain comparatively lower shares, below 5%. These differences reflect variations in national agricultural structures, consumer demand, and policy support. One of the sources of these disparities is the reluctant attitude of producers, who argue for a higher price level for organic food and fear competitive disqualification in national markets (Jankalova & Vartiak, 2017; Maasz *et al.*, 2024). It is precisely the short-termism of economic thinking that is identified by Staton *et al.* (2024) as a clear barrier to the development of the organic food market.

An important objective of national policies is to mitigate the regional disparities identified within the European Union. The new Common Agricultural Policy for 2023-2027 (European Commission, 2022) and the European Green Deal's "Farm to Fork" strategy aim to reduce such disparities by supporting a target of 25% of EU farmland under organic management by 2030. Direct payments, eco-schemes, and rural development funds provide financial incentives for conversion to and maintenance of organic practices, reinforcing market development across member states.

At the EU level, the EU Agricultural Outlook 2024-2035 highlights a sector adapting to climate and demand shifts, and projects continued

structural changes in consumption, with policy baselines relevant to organics (European Commission, DG AGRI, 2024). Complementing this, a USDA/FAS market brief documents a 10.5% increase in EU organic sales in 2023, after the 2022 downturn, and anticipates modest growth in 2024-2025, noting strong per-capita spending in countries (von Witzke *et al.*, 2025). Regarding crisis dynamics and consumer behavior, systematic reviews of COVID-19 era consumption report shifts toward products perceived as healthier and more sustainable (Cramarenco, 2023).

The aim of this paper is to identify the relationship between disposable income and organic food consumption. The results will be used as an argument in favor of an active policy by the European Union and its individual Member States aimed at levelling out the significant regional disparities in the development of organic food markets. The generalization of the conclusions thus proposed will be possible by referring to the conclusions of the research carried out by First and Brozina (2009) on the impact of cultural dimensions on organic food consumption. There, it was identified that cultural dimensions have only a partial influence on organic food consumption, and even then only in the case of the dimensions of individuality and assertiveness.

The conclusions of the research will also be useful in the practice of pricing policy of entities implementing their business activities on the organic food market. The knowledge of the influence of disposable income on the consumption of organic food is the basis for the implementation of a functional pricing policy based on reference price limits strictly defining the organic nature of food as a source of consumers' subjectively perceived value of the product and, by analogy, a competitive advantage. This is because previous research has strictly preferred a consumer-oriented approach and has lacked a macroeconomic conception of the issue, which would address the dilemma of the mechanisms of consumer-perceived and consumer-implemented purchasing behavior in the area under study.

1. Background

Pant *et al.* (2024) report, based on a content analysis of 783 papers published between 1991 and 2002 and contained in the Scopus database, that current themes in the field of organic food and its consumption are purchase motives, health consciousness, value schemas, theory of planned behavior, green marketing and environmental concerns. While individualistic motives such as improving individual health and quality of life dominated early research on this topic (Sampaio *et al.*, 2013), current trends suggest a significant shift towards altruistic motives related to sustainable principles

of organic food consumption (Buil & Mata, 2024; Martini *et al.*, 2024). It is true that the same mechanism is also present with respect to the economic development of countries. In this case, individualistic motives are dominant in less developed economies, while there is also a substantial shift towards altruistic motives of organic food consumption as national economies develop (Anand *et al.*, 2024). Ergonul and Ergonul (2015) stated that organic food is perceived by consumers as an expensive product whose quality parameters do not match the set price. These findings are corroborated by Dangi *et al.* (2020) who identify price as one of the key factors in purchase decision making in relation to organic food. However, these authors also point out that the importance of each factor varies depending on the development of the economy and the level of average income in that country. In the context of Lebanon's developing economy, Tleis *et al.* (2019) research identifying the key values of organic food consumption. Quality of life, enjoyment and peace of mind were identified by them. At the same time, purchase motives were found to vary in the context of consumption frequency. Frequent consumers of organic food were more concerned about the health of their family and the environment, but occasional consumers preferred their own pleasure and perceived organic food as a traditional product with nostalgic added value. Exploring the regional specificities of consumer perceptions of organic food is an important component of current scientific research in this area. Petrescu *et al.* (2017) found that in Romania, individual consumer affinity towards sustainable lifestyles is an important determinant of organic food consumption. Paradoxically, the status element of consumption was not identified. This means that the propensity to consume was not reinforced by the prospective acquisition of the status of so-called organic consumer. Similar conclusions are reached by Azzurra *et al.* (2019), according to whom environmentally conscious consumers tend to consume organic food to a greater extent, while the consumption of organic food alone does not evoke a more intense consumer contact with environmental issues and their active participation in their solution. Thus, in the context of the broader socio-economic context, it can be concluded that the consumption of organic food is a real manifestation of the existence of pro-environmentally oriented consumer values, while the consumption of organic food itself is not a prerequisite for the subsequent more intense presence of sustainability in consumer and civic behavior.

The above points in favor of examining organic food consumption not with a one-size-fits-all approach, but across different consumer groups. Such an approach has already been suggested by Baranauskas *et al.* (2015), who investigated organic food consumption in the case of athletes in Lithuania. However, their research only declares the positive impact of consumption on consumers' health, thus verifying one of the commonly used arguments in favor of purchasing this food category. Gustavsen and Hegnes (2020)

investigated the relationship between consumer personality type and propensity to consume organic food. Among other things, they found that consumers with high levels of conscientiousness as a personality trait are less willing to pay a higher price for organic food than for its non-organic alternatives. Chekima *et al.* (2017), however, draw attention to the fact that research oriented to ascertain consumer motives for buying organic food is biased by the recurrent phenomenon of respondent's insincerity towards themselves. Under the influence of this phenomenon, consumers answer as they think they should in order not to damage their self-image, but in a situation leading to a real purchase decision, completely different factors are relevant than those identified in motivation-oriented research. One of these factors is price (Sica & Franco, 2024). Bryla (2016) clearly describes the importance of price in the purchase decision of organic food in research conducted on Polish consumers. In their case, he states that the obstacle to the development of the organic food market is precisely its high price.

Kis *et al.* (2023) in the Hungarian context find that in the period confronted with the economic consequences of the COVID-19 pandemic (years 2020-2021), paradoxically, the consumption of organic food is increasing despite the decrease in the disposable income of the population. This finding can be justified by the attitudinal change of consumers related to the appeal of healthy lifestyles and health protection (Shenoy *et al.*, 2024). Such a post-COVID shift towards preference of healthier alimentation has been identified on the case study of honey consumption also by Murmura *et al.* (2024). However, Rutelione and Bhutto (2024) find that price does not have a significant impact on consumer's purchase decision in favor of organic food. On the other hand, however, they find the influence of the quality of organic food to be substantial. At the same time, however, they set boundaries on the applicability of these findings by considering the gender, education, age and income of the consumer. It is precisely in the case of consumers from higher income categories that the irrelevance of the price of organic food in the context of consumer purchasing decisions is valid. Barua *et al.* (2023), however, suggest that there is a relationship between income level and the extent of environmental awareness, and thus that the irrelevance of the financial aspect of buying organic food is related to the inherent positive affinity of consumers from higher income brackets towards socially responsible issues and sustainable consumption. Watanabe *et al.* (2023) find that consumers are generally willing to pay 5 to 10% more for organic food, with disposable income and organic label being significant predictors of their willingness to pay more. Guney and Giraldo (2019) do not generalize their research and focus on specific organic products. Using the example of organic eggs, they declare that Turkish consumers are willing to pay 0.76 monetary units more per egg if it is organic.

Disposable income, defined as the income available to individuals after taxes and other deductions, is a fundamental factor influencing consumer behavior. It determines the purchasing power of consumers. In the context of organic food, which is typically priced higher than conventional food, disposable income may play a vital role. From this perspective, consumers with higher disposable income possess the financial flexibility to opt for organic food despite its elevated cost. This viewpoint is corroborated by several studies (Mazur-Wlodarczyk *et al.*, 2024; Johansson *et al.*, 2014; Kuhar and Juvancic, 2005; Millock *et al.*, 2004). Conversely, it is frequently argued that disposable income is not a significant factor, as health consciousness and environmental awareness play more crucial roles in the organic food market (Azzurra *et al.*, 2018; Aschemann-Witzel and Zielke, 2015).

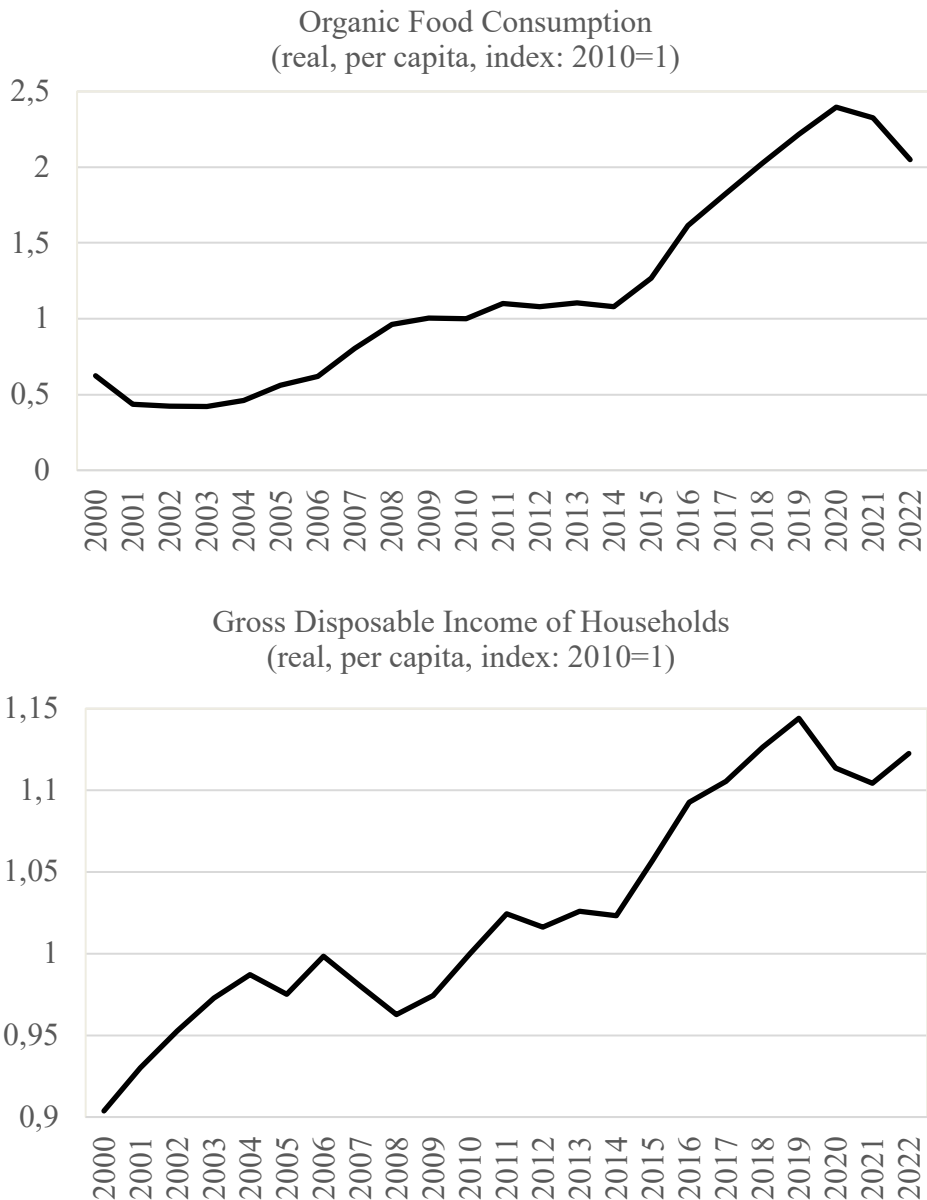
Therefore, the primary objective of this paper is to elucidate these contrasting attitudes by investigating the research question of how significant a factor disposable income is in the organic food markets. While the majority of empirical literature concentrates on microeconomic data, our research adopts a macroeconomic perspective, thereby contributing to the existing literature by applying a different viewpoint on this topic. The secondary research question explores how the relationship between organic food consumption and disposable income is influenced by severe economic crises.

2. Materials and methods

Data on total organic food consumption per capita in Denmark were sourced from the FiBL database, a research institute dealing with organic food at a European and global scale (<https://statistics.fibl.org/>). Real gross disposable income per capita was obtained from the Eurostat database (<https://ec.europa.eu/>). The time series of modelled variables for real organic food consumption per capita and real gross disposable income per capita were tested for stationarity using Perron's (1989) test designed for time series with a breakpoint, where the breakpoint was not fixed but detected by Perron's test. The development of the time series indicating a breakpoint during the onset of the global economic crisis in 2008 and in 2020 in connection with measures against the spread of COVID-19 is shown in the Figure 1.

The error correction model will be formulated in the logarithms of variables and in the absolute differences of the logarithmic values. Perron's test results of stationarity for the time series are therefore expressed for the logarithmic variables and their first differences. For the original variables, Perron's test used a trend and level constant, and for the differentiated data,

Figure 1 - Development of the time series indicating breakpoints in the years 2008 and 2020 and 2020



Source: Authors' own calculations.

only a level constant was used in the test. The null hypothesis is always that the respective time series contains a unit root. The results are summarized in Table 1.

Table 1 - Results of the Perron stationarity test with a breakpoint in the time series

Perron stationarity test		Logarithm of Real Consumption of Organic Food (per capita)	Logarithm of Real Disposable Income (per capita)
Undifferenced Data	Test Statistic	-3.600	-3.954
	P-value	0.629	0.400
First Difference of the Variables	Test Statistic	-4.929	-5.195
	P-value	0.011	<0.01

Source: Authors' own calculations.

The results in the table show that in all cases the undifferentiated data are non-stationary and also that their transformation using 1st differences has already ensured their stationarity. For this reason, an error correction model was chosen to model the dependence between the consumption of organic food and disposable income, both with the aim of eliminating the problem of spurious regression in non-stationary time series and for the purpose of describing both the long-term equilibrium relationship between the mentioned quantities and the short-term dynamics.

The formulated error correction model is not, however, econometrically estimated using the standard two-phase Engle, Granger (1987) method. The chosen methodology of the error correction model is modified and the assumption of time-invariant coefficients is replaced by parameters changing over time, using Hamilton's (1989) methodology of Markov Regime Switching (MRS) models. Abandoning the assumption of time-invariant coefficients allows for a much more realistic description of the development of modelled variables within the examined time interval 2000-2022, during which both the global economic crisis in 2008 and the crisis in 2020 caused by measures to prevent the spread of COVID-19 occurred. However, since the standard error correction model with constant parameters is the initial modelling framework that is subsequently modified, this standard model will first be briefly summarized and then the specific way of its modification will be shown.

Standard error correction model

The econometric estimate of the long-term equilibrium relationship between the consumption of organic food and disposable income is realized in the original Engle-Granger (1987) methodology on (undifferentiated) non-stationary time series using the Ordinary Least Squares (OLS) method in the classical linear regression model:

$$\ln(C_t) = \alpha_0 + \alpha_1 \cdot \ln(Y_t) + u_t, \quad (1)$$

where C_t denotes real organic food consumption per capita,
 Y_t represents real disposable income per capita,
 u_t is random error with white noise properties.

Because the time series $\ln(C_t)$ and $\ln(Y_t)$ are non-stationary, there is a problem of spurious regression in this econometric estimation of parameters. However, it is possible to use the OLS estimates of the parameters $\hat{\alpha}$ and $\hat{\beta}$ for the purpose of estimating the deviation from long-term equilibrium $\hat{u}_t$:

$$\hat{u}_t = \ln(C_t) - \hat{\alpha}_0 - \hat{\alpha}_1 \cdot \ln(Y_t). \quad (2)$$

The error correction model is formulated in the following form:

$$\Delta c_t = \beta_1 \cdot \Delta y_t + \beta_2 \cdot \hat{u}_{t-1} + \varepsilon_t, \quad (3)$$

where $\Delta c_t \equiv \ln(C_t) - \ln(C_{t-1})$ is the difference in consumption of organic food,
 $\Delta y_t \equiv \ln(Y_t) - \ln(Y_{t-1})$ represents the difference in real disposable income,
 $\hat{u}_{t-1}$ denotes the deviation from the long-term equilibrium relationship in the previous period,
 ε_t is the error term with white noise properties.

Given that the variables are in logarithms, their absolute difference approximates the relative difference of the original non-logarithmic variables: $\ln(X_t) - \ln(X_{t-1}) \cong \frac{X_t - X_{t-1}}{X_{t-1}}$. Therefore, the parameters β_1 , β_2 can be interpreted as coefficients of relative elasticity. The coefficient β_1 indicates by how many percent the consumption of organic food will change if the disposable income increases by 1%. Similarly, the parameter β_2 expresses by how many percent the consumption of organic food will change if this consumption in the previous period was 1% above its long-term equilibrium value.

Modification of the standard ECM model

The econometric estimation of the long-term equilibrium relationship between the consumption of organic food and disposable income in this study, as in the original Engle-Granger (1987) methodology, is carried out on (undifferentiated) non-stationary time series. However, it is not done using the OLS method, but using Hamilton's MRS methodology of Markov regime-switching models:

$$\ln(C_t) = \alpha_0(S_t) + \alpha_1(S_t) \cdot \ln(Y_t) + u_t, \quad (4)$$

where the time-varying coefficients $\alpha_0(S_t)$ and $\alpha_1(S_t)$ are functions of the unobservable state variable S_t :

$$\alpha_0(S_t) = \begin{cases} \alpha_{0,1}, & \text{for } S_t = 1, \\ \alpha_{0,2}, & \text{for } S_t = 2, \end{cases}$$

$$\alpha_1(S_t) = \begin{cases} \alpha_{1,1}, & \text{for } S_t = 1, \\ \alpha_{1,2}, & \text{for } S_t = 2, \end{cases}$$

The variable S_t is a discrete random quantity that can only take on two possible values $S_t = 1$ and $S_t = 2$, characterizing the state of the economy. Its evolution is determined by a Markov chain with transition probabilities given by:

$$P = \begin{bmatrix} p_{11} & 1 - p_{11} \\ 1 - p_{22} & p_{22} \end{bmatrix},$$

where $p_{ij} = P(S_t = j | S_{t-1} = i)$ is the conditional probability that the system will be in state j at time t , given that it was in state i at time $t - 1$.

The regression equation of long-term equilibrium (4) is only an auxiliary regression used exclusively for estimating the deviation from equilibrium, and not for estimating the parameters $\alpha_0(S_t)$, $\alpha_1(S_t)$, with the estimates of deviations from equilibrium being the obtained residuals.

The application of the error correction model requires that the used variables $\ln(C_t)$, $\ln(Y_t)$ are cointegrated of the first order, i.e., the deviation from long-term equilibrium must be stationary. Stationarity was again tested using the standard Augmented Dickey-Fuller (ADF) test and the results are summarized in the following table, where symbols *, ** and *** denotes that the null hypothesis was rejected at 10%, 5% and 1% level of significance, respectively.

Table 2 - Results of the stationarity ADF test for the estimate of deviation from long-term equilibrium

ADF Test for Stationarity	Deviation from Long-Term Equilibrium ($\hat{u}_t$)
Test Statistic	-4.103
P-value	0.005***

Source: Authors' own calculations.

The null hypothesis $H_0: \hat{u}_t$ has a unit root is rejected even at the 1% significance level. Therefore, the deviation from long-term equilibrium $\hat{u}_t$ is stationary and the error correction model can be applied.

The mentioned standard ECM model was further modified by abandoning the assumption of time-constant parameters not only in the long-term equilibrium equation (1), but also in equation (3). Specifically, for this purpose, the Markov regime-switching model will be used again in the following form:

$$\Delta c_t = \beta_1(S_t) \cdot \Delta y_t + \beta_2 \cdot \hat{u}_{t-1} + \varepsilon_t, \quad (5)$$

where the time-varying coefficient is again a function of the unobservable state variable S_t :

$$\beta_1(S_t) = \begin{cases} \beta_{1,1}, & \text{for } S_t = 1, \\ \beta_{1,2}, & \text{for } S_t = 2. \end{cases}$$

3. Results

Estimation of parameters and discussion

The econometric estimation of the parameters of the error correction model with time-varying parameters was performed using Hamilton's (1989) methodology. Since autocorrelation was detected using Q-statistics within the correlogram analysis, estimates of standard errors for estimated parameters were obtained using the HAC (Heteroscedasticity and Autocorrelation Consistent) methodology (White, 1980). The results are summarized in Table 3. In addition to the parameter estimates, the table also includes the P-value of the z-statistic for testing statistical significance for each estimate. Symbols *, ** and *** denotes that the null hypothesis was rejected at 10%, 5% and 1% level of significance, respectively.

Table 3 - Results of the econometric estimation of the ECM model using MRS methodology

Parameter Estimates (P-value of the z-Statistic)		
$\hat{\beta}_{1,1}$	$\hat{\beta}_{1,2}$	$\hat{\beta}_2$
4.398 (0.001)***	-6.550 (0.000)***	-0.339 (0.001)***

Source: Authors' own calculations.

The statistical significance of all parameters was demonstrated by the z-statistic even at the 1% significance level. If the economy is in the first non-crisis state $S_t = 1$, the regressor Δy_t has a positive and statistically significant impact on the consumption of organic food. A year-on-year increase in disposable income per capita by 1% in this case leads to a year-on-year increase in total consumption of organic food per capita by 4.398%.

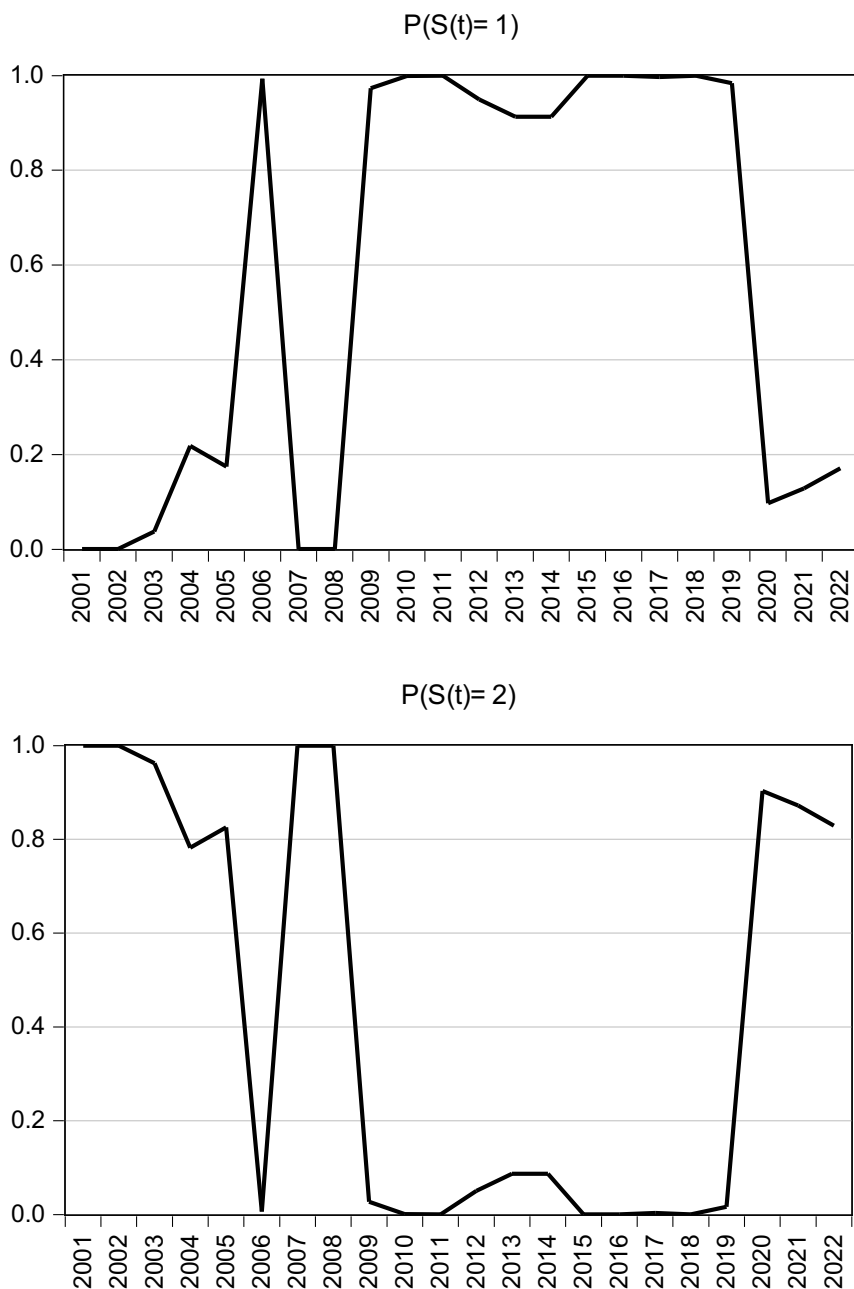
However, if the economy finds itself in its second crisis state $S_t = 2$, this statistical dependence of organic food consumption on disposable income reverses. A one percent decrease in disposable income per capita during a crisis period triggers a statistically significant and very high increase in organic food consumption per capita, amounting to 6.550%.

In terms of the coefficient β_2 , the a priori condition $\beta_2 \in (-1,0)$ is met. The fulfillment of this condition ensures that the consumption of organic food partially returns to its long-term equilibrium if it was deviated from equilibrium in the previous period. The statistical significance of this adjustment mechanism, which keeps the variables close to equilibrium, has been demonstrated even at the 1% level of statistical significance. Therefore, if the total consumption of organic food deviates above its equilibrium value by 1%, then in the following period, the total consumption of organic food will decrease by 0.339% year-on-year.

Regime probabilities estimation

The concept of a smoothed estimate is applied to the individual states $S_t = 1$ and $S_t = 2$. This technique uses all the information from the entire dataset to provide a more accurate estimate. The results of this process are visually depicted in the Figure 2.

Figure 2 - Smoothed Estimates of Regime Probabilities $P(S_t = 1)$ and $P(S_t = 2)$



Source: Authors' own calculations.

Figure 2 provides a clear and concise graphical interpretation of the data, facilitating a more straightforward understanding and analysis of the probabilities of the individual states. It offers valuable insights into the behaviour of the individual states under consideration, significantly contributing to our understanding of the dataset as a whole. Specifically, the provided graph unequivocally demonstrates that in the years 2007-2008, the market for organic food in Denmark was almost certainly (with 100% certainty) in a crisis state $S_t = 2$. This undoubtedly occurred in connection with the global financial crisis that broke out in 2007 and culminated in the following year 2008, escalating into a global economic crisis. The graph also shows that the market for organic food in Denmark was in this crisis regime $S_t = 2$ with a very high probability (over 80%) also in the years 2020-2022. This certainly occurred in connection with measures to prevent the spread of COVID-19 infection. The estimated MRS model was thus able to very reliably detect the effect of these two significant global events on the market for organic food in Denmark.

The graph also provides a clear visual representation of the impact of global events on the organic food market in Denmark. It highlights the resilience of this market in the face of significant global crises, demonstrating its ability to adapt and recover from the crisis state $S_t = 2$ at an accelerating rate. This is particularly evident in the years following the global financial crisis in 2007-2008, where despite the challenges, the market was able to return back immediately in 2009. This resilience is a testament to the robustness of the organic food market in Denmark and its ability to withstand severe external shocks. The MRS model's accurate detection of these effects underscores its utility as a tool for analysing and understanding market dynamics. This analysis contributes to our broader understanding of the factors influencing the organic food market, providing valuable insights for policymakers, stakeholders, and researchers alike.

Figure 2 also substantiates that with a very high probability (over 95%), the relationship between the consumption of organic food and disposable income was governed by the crisis regime $S_t = 2$ also in the years 2001-2003. However, in the subsequent years 2004-2006, the estimated probability $P(S_t = 2)$ gradually decreased, practically to zero by 2006. In Denmark, there was no crisis in the organic food market in the years 2001-2003. But the organic food market was in its early stages of development during this period and its development was very rapid and dynamic. Therefore, the transition from state $S_t = 2$ to state $S_t = 1$ in the period 2000-2006 can thus be explained by this fact. Rapid development of organic market in 2004-2006 was supported by government measures. The Danish government actively worked to make Denmark a leader in the field of organic farming, which included increasing the area of agricultural land under organic farming and supporting sustainable practices (Kaad-Hansen, 2022).

4. Discussion of the results and implications

The transition from state $S_t = 2$ to state $S_t = 1$ in the period 2000-2006 can also be viewed in a broader perspective, particularly in relation to the global food crisis that broke out in 2000. This global food crisis was characterized by a sharp increase in the prices of basic foods, which had very negative impacts mainly on developing economies, where hundreds of millions of people faced chronic hunger (Ivanic and Martin, 2008; Soekirman, 2001; Timmer and Cabot, 2010). The negative impacts were certainly not so significant on the advanced Danish economy, however, this significant global event naturally led to a global support for genetically modified foods having the potential to mitigate the negative consequences of such global food crises in developing economies. This is fully in accordance with the theory of Barua *et al.* (2023) who have identified that there is a relationship between income level and the extent of environmental awareness, and thus that the irrelevance of the financial aspect of buying organic food is related to the inherent positive affinity of consumers from higher income brackets towards socially responsible issues and sustainable consumption. On the other hand, it also confirms the importance of price as a substantial factor of buying behavior in favor of the organic food products as it has been stated by Dangi *et al.* (2020) and Sica and Franco (2024).

The production of genetically modified foods has expanded significantly already in the 1990s. After 2000, this significant increase continued and led to economic benefits and an increase in the production of agricultural crops (Brookes and Barfoot, 2013; Qaim and Kouser, 2013). However, the expansion of genetically modified foods inevitably brings concerns about their safety and health harmlessness, which can explain the significant development of the organic food market in Denmark observed in the years 2000-2006. In our estimated model, this was manifested by a gradual transition from state $S_t = 2$ to state $S_t = 21$, which is demonstrated in Figure 2 by an increase in the probability $P(S_t = 1)$, or a decrease in the probability $P(S_t = 2)$, during years 2000-2006.

These findings have several important implications in relation to the research questions: (1) significance of positive effect of disposable income during non-crisis periods, (2) economic resilience of organic food consumption during crisis periods.

The study confirms that disposable income exerts a significant influence on the consumption of organic food from a macroeconomic perspective. This finding is significant in light of research conducted by Chekima *et al.* (2017), who found that there is significant variation in consumer survey results and resulting consumer behavior in organic food consumption. It is by conducting research on the consumption of organic food at the macro level that it is

possible to provide relevant information on consumption patterns and their dependence on changes in disposable income in the category of consumers who, in real terms and not only declaratively for the purpose of improving their social perception, consider organic food product valuable and prefer it in their purchasing decisions.

During non-crisis periods, a surge in disposable income corresponds to an escalation in organic food consumption. This suggests that as individuals possess more disposable income, they are more likely to purchase organic food. This outcome, derived at a macroeconomic level, answers our first research question and complements the conclusions of other studies that reported similar results using microeconomic data (Johansson *et al.*, 2014; Kuhar and Juvancic, 2005; Millock *et al.*, 2004).

Extending the outcomes of the research led by Kis *et al.* (2023) in scope of the pandemic COVID-19 impact on organic food consumption, the results also suggest that the consumption of organic food is resilient to economic downturns. Even during economic crises, when disposable income decreases, the consumption of organic food increases. This reveals an intriguing phenomenon implying that such a high level of resilience in the organic food market that can provide a degree of stability for businesses in this sector during turbulent economic times. This resilience could be attributed to a variety of factors, such as increased health consciousness or a desire for higher quality food during uncertain times. Thus, it can be also stated that we have confirmed the research outcomes of Rutelione and Bhutto (2024) who have identified that price does not have a significant impact on consumer's purchase decision in favor of organic food.

This finding is closely related to our second research question. The relationship between disposable income and organic food consumption is reversed during a crisis. A decrease in disposable income leads to an increase in organic food consumption. This counterintuitive result suggests that during times of economic hardship, consumers may prioritize spending on organic food due to health consciousness and environmental awareness despite having less disposable income as is often argued in empirical studies (Azzurra *et al.*, 2018; Aschemann-Witzel and Zielke, 2015; Bazhan *et al.*, 2024).

Pandemic-era research consistently documents how COVID-19 reconfigured agri-food demand and strained supply chains: in the United States, local food systems in several countries showed adaptive capacity through rapid channel shifts and community-based logistics (Thilmany *et al.*, 2021). Italy's agri-food value chains faced pronounced shocks along production, HORECA, and export links, while retail partially offsetting losses, serving as evidence of simultaneous resilience and vulnerability (Borsetta *et al.*, 2023; Coluccia *et al.*, 2021). Sectorally, fisheries across Europe experienced measurable downturns in catch and prices under

COVID-19 restrictions (Seixas *et al.*, 2024). At the firm/plant level, preparedness and risk-management gaps in the food industry were widespread, highlighting the need for robust contingency planning and safety protocols (Nakat & Bou-Mitri, 2021). Together, these findings align with our regime-switching evidence for Denmark: crisis conditions can trigger shifts in purchasing and channel usage while exposing bottlenecks in upstream logistics.

Research findings also have significant additional implications in these areas: 1) strategic planning and crisis management; 2) marketing and consumer engagement; 3) supply chain management and 4) policy engagement.

Understanding this trend can aid businesses in the organic food sector in strategic planning and crisis management. Businesses can take comfort in the knowledge that demand for organic food is likely to remain stable, or even increase, during economic downturns. This can inform business strategies, investment decisions, and risk management plans.

The findings can also guide marketing strategies and consumer engagement efforts. If consumers are more likely to purchase organic food during economic crises, businesses can tailor their marketing campaigns to highlight the benefits of organic food, particularly during times of economic uncertainty. Moreover, the findings indicate a lower degree of demand sensitivity to the consumer's economic situation. However, this is not the case absolutely, but only for consumers who are intrinsically convinced of the value of organic food. For consumers who are not so attitudinally profiled, price remains a significant factor in their purchasing decisions. It is therefore appropriate to step up activities to systematically cultivate consumer awareness of the value of organic food across the motives and factors that have been defined as relevant in each consumer category. From a supply chain perspective, businesses in the organic food sector can use these results to ensure they are prepared to meet increased demand during economic crises. This could involve securing robust supply chains, increasing production capacity, or investing in storage and distribution infrastructure. These findings could also have implications for policy engagement. Businesses in the organic food sector could use this evidence to advocate for policies that even more support the organic food sector.

5. Summary of the main findings

The aim of the study was to analyze the impact of the global economic crisis in 2008 and the COVID-19 crisis in 2020 on the consumption of organic food in Denmark. Methodologically, an Error Correction Model (ECM) was implemented, with modifications applying the Markov

Regime Switching (MRS) methodology to integrate breakpoint analysis. Econometric estimation of the modified error correction model showed the following main quantitative results: (1) The adjustment mechanism toward the long-run equilibrium is statistically significant at the 1% level, with a speed-of-adjustment coefficient $\lambda = -0.339$. This implies that roughly 34% of any disequilibrium is corrected each year and the deviation's half-life is approximately 1.7 years. (2) Cointegration of the long-run relation is supported by an ADF test on the equilibrium error (ADF = -4.103 , $p = 0.005$). (3) The dependence of organic food consumption on disposable income is significant at the 1% level in both regimes, but with opposite signs: positive in non-crisis periods and negative in crisis periods. In the non-crisis regime, the income effect is positive as expected; by contrast, in the crisis regime the effect reverses sign and strengthens in magnitude – such that declines in disposable income are associated with increases in organic food consumption. (4) In the non-crisis regime, a +1% annual increase in real disposable income per capita is associated with a +4.398% annual increase in total per-capita organic consumption ($p = 0.001$). (5) In the crisis regime, a –1% year-on-year change in real disposable income per capita is associated with a +6.550% increase in total per-capita organic consumption ($p < 0.001$). These findings are summarized in the following Table 4.

Table 4 - Key ECM-MRS Estimates: Income Effects and Adjustment Dynamics (Denmark, 2000-2022)

Quantity	Shock definition	Estimated effect on organic consumption (y/y)	Significance	Interpretation
Income elasticity (non-crisis regime)	+1% in real disposable income (y/y)	+4.398%	1% level ($p = 0.001$)	Positive and significant outside crises
Income elasticity (crisis regime)	–1% in real disposable income (y/y)	+6.550%	1% level ($p < 0.001$)	Sign reversal in crises: lower income → higher organic consumption
Speed of adjustment (λ)	Deviation from long-run equilibrium in $t-1 = +1\%$	–0.339 pp	1% level ($p = 0.001$)	Consumption partially reverts to equilibrium each period

Source: Authors' own calculations.

6. Conclusions

Contribution to existing knowledge

The paper contributes to the literature on organic food consumption in several important ways. First, by employing a macroeconomic approach, it extends prior research that has largely been based on micro-level survey data. Whereas consumer surveys often suffer from attitudinal bias – where stated preferences do not always translate into actual behavior – our findings provide aggregate evidence that income dynamics shape organic food consumption in measurable and regime-dependent ways. This helps reconcile inconsistencies in earlier consumer-level studies (e.g., Chekima *et al.*, 2017; Johansson *et al.*, 2014), which reported considerable variation in the strength and direction of income effects.

Second, integrating the ECM-MRS methodology enabled analyzing breakpoint dynamics, delivering a more realistic depiction of regime changes while remaining interpretable.

Third, regime-probability evidence indicates near-certain crisis states in 2007-2008 (~100%), high crisis probabilities in 2020-2022 (>80%), and an earlier crisis episode in 2001-2003 (>95%), with transitions back to non-crisis around 2006 and after 2009. Overall, Denmark's organic market exhibits high resilience during macroeconomic stress, consistent with stable or countercyclical demand in this sector.

Fourth, we showed that Danish organic consumption is tightly linked to disposable income, with a positive elasticity outside crises and a sign-reversing, countercyclical elasticity in crises, both statistically strong. The discovery of a sign-switching income elasticity across regimes adds a novel dimension to the debate on affordability and resilience in sustainable food markets. While prior work has emphasized the price sensitivity of organic products (Dangi *et al.*, 2020; Azzurra *et al.*, 2018), our results show that during crises, demand for organic food may increase despite income contraction. This counterintuitive outcome underscores the role of heightened risk perceptions, health consciousness, and environmental salience in shaping consumer priorities. By capturing this effect at the macro level, our study provides evidence that organic demand is not only income-responsive but also context-sensitive, with different drivers prevailing in stable versus turbulent economic environments.

Fifth, the analysis demonstrates the resilience of the Danish organic market during two major crises (2008 and 2020), highlighting its stability relative to other food categories. This aligns with recent findings from Kis *et al.* (2023) on pandemic-era consumption, but adds historical depth and a methodological contribution by explicitly modeling regime transitions.

In doing so, the paper enriches the understanding of organic markets as potential stabilizers in food systems during periods of uncertainty, a perspective less emphasized in the existing literature.

Sixth, the results contribute to the policy debate on food equity and sustainability. Previous studies have called attention to the importance of certification credibility, consumer trust, and labeling coherence (Aschemann-Witzel & Zielke, 2015; Rutelione & Bhutto, 2024). Our findings substantiate these arguments by showing that demand for organic products persists, and even strengthens, when risks are perceived to be high. This underscores the importance of maintaining strong institutional frameworks – certification, enforcement, and communication systems – that support consumer confidence in organic markets.

Finally, this research situates Denmark's experience within broader discussions of market maturity and the extent to which findings derived from high-penetration markets can be generalized to other countries. Denmark represents a high-penetration case, and our results highlight both the opportunities and limitations of extrapolating from such a context. Thus, the study provides a baseline framework for future comparative work across countries with different levels of organic market development, certification regimes, and consumer income distributions.

Therefore, our contributions advance the field by demonstrating that organic food consumption is not only shaped by disposable income but is also contingent on broader macroeconomic conditions, institutional contexts, and shifts in consumer perceptions during crises. This opens new avenues for research on the resilience, equity, and sustainability of food systems.

Implications

Individually, these findings can be applied in strategic planning, marketing, supply chain management and policy formulation in the organic food sector. Let's first discuss implications for firms (managerial strategy). The regime-dependent income elasticity warrants dual-regime strategies. During non-crisis periods – when income effects are positive – firms should emphasize portfolio premiumization (higher value-added, products strongly defined by trust-based qualities), assortment breadth (greater variety across categories and price tiers), and experience-based differentiation (in-store education, traceability apps, and external validation of quality). In crisis periods – when the sign reverses and risk salience increases – firms should prioritize protection of core organic lines, credible signaling of safety and authenticity (well-recognized certification, residue testing transparency, narratives emphasizing product origin and supply chain journey), and affordability-oriented pricing schemes (smaller pack sizes, temporary price guarantees,

retailer-branded organic products). In both regimes, managers should integrate scenario planning those accounts for potential regime shifts into demand forecasting, and they should align promotion schedules, inventory targets, and working capital policies with the estimated transition probabilities.

Implications for policymakers (regulation and equity). The countercyclical nature of organic demand observed during economic crises indicates a need for policy interventions that safeguard equitable access to organic products at times when perceived health and environmental risks become more pronounced. Priorities include: (i) strict certification standards and effective enforcement mechanisms to maintain consumer confidence; (ii) interventions to enhance the quality of consumer information (establishment of public communication standards, mechanisms for rapid response to misinformation, and greater consistency between nutritional and sustainability labelling; and (iii) targeted affordability instruments that are time-limited and countercyclical (temporary reductions in value-added tax on certified organic products, vouchers for vulnerable households, or subsidies directed toward staple organic categories with significant health externalities). Policymakers should also consider privacy-preserving data-sharing frameworks to enable timely monitoring of regime shifts and to coordinate with industry on contingency supply measures.

Implications for supply-chain actors (operations and contracts). Countercyclical demand during downturns raises the risk of stock-outs precisely when producers and suppliers face reduced financial flexibility, making it more difficult to expand inventories and meet the heightened demand. Distributors and retailers can mitigate this through crisis-contingent contracts (e.g., flexible minimum-order quantities, option contracts with upper bounds on prices), inventory policies with service-level triggers linked to regime probabilities, supplier diversification across geographies and certification bodies in order to reduce dependency on any single region or certifying institution, and sourcing strategies aligned with established certification standards designed to minimize verification delays and reduce bottlenecks in compliance processes. Investments in traceability infrastructure (batch-level traceability, rapid certification verification) and expanded quality-assurance capacity improve both compliance and consumer confidence under heightened risk salience.

Limitations and directions for future research

While the ECM-MRS approach yields interpretable regime dynamics, several limitations constrain the strength of the inferences and motivate further work.

Aggregation and compositional masking. The macro series cannot disentangle category-specific or demographic heterogeneity (e.g., differences between fresh vs. processed organic food, or between households in different lifecycle stages). Future research might integrate product-level scanner data and household panel microdata to recover segment-specific elasticities and substitution patterns.

Price measurement and promotion dynamics. Future research might incorporate transaction-level price data, measures of price dispersion, and indicators of promotion intensity. Doing so would make it possible to distinguish income effects from price-driven mechanisms and to estimate both own- and cross-price elasticities for organic and conventional products.

Model specification and identification. Regime classification is probabilistic and may be sensitive to lag length, or transition rules. Robustness checks employing alternative regime specifications (e.g., threshold VAR/ECM or time-varying parameter models), as well as allowing for state-dependent error variances, would provide a useful test of the stability of our results.

External validity and market maturity. Denmark is among the countries with a very high market share of organic products. Consequently, our findings may not be directly transferable to contexts characterized by lower levels of organic market penetration or by generally lower consumer incomes. Comparative work across countries with different certification regimes, retail structures, and income distributions could help to identify contextual factors of regime-dependent elasticities. Methodologically, the ECM-MRS specification is not Denmark-specific. It can be applied to other geographical markets to study regime-dependent adjustments in organic consumption during economic crises, assuming adequate data coverage and comparability.

Temporal granularity and dynamics. Higher-frequency data (monthly/weekly) could reveal short-run adjustment, inventory hoarding, or panic-buying effects that annual data may smooth out. Future models might incorporate time-varying transition probabilities linked to macro indicators (unemployment, uncertainty indices) to improve early-warning properties.

Communication environment and trust. We do not observe the information ecosystem (media coverage, misinformation events) that plausibly shifts preferences in crises. Coupling demand data with media/online attention measures could quantify the mediating role of information and trust.

Future research agenda. We recommend: (i) estimating joint price-income-promotion models within an ECM-MRS or TVP framework; (ii) combining macro and micro (multi-level) data to reconcile aggregate resilience with household heterogeneity; (iii) exploiting policy experiments (labeling changes, VAT tweaks) for causal identification; (iv) conducting cross-country comparative analyses to assess institutional moderators; and (v) integrating uncertainty and risk-perception indices to test mechanisms underlying the

crisis-regime sign switch. Collectively, these extensions would sharpen causal claims, enhance forecast accuracy, and improve the translational value of regime-aware strategies for managers and policymakers.

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Jana Majerova

AMBIS University, Czech Republic

Lindnerova 575/1, 180 00 Prague, Czech Republic

E-mail: jana.majerova@ambis.cz

She is an associated professor in Business Economics and Management. In her scientific career she deals with branding and socially responsible marketing. So far, her papers have more than 2500 citations according to Google Scholar. She actively participates in organizational and editorial processes of various reputable international conferences resp. scientific journals. She also teaches various courses in marketing, marketing communication, marketing management and marketing dynamics.

Sarka Cizkova

AMBIS University, Czech Republic

Lindnerova 575/1, 180 00 Prague, Czech Republic

E-mail: sarka.cizkova@ambis.cz

She studied the Mathematical Methods in Economy at the Prague University of Economics and Business. She earned Ph.D. degree in econometrics and operational research in 2013. Her professional interest lies in building econometric models and optimization of economic policy. She is the author of a number of scientific papers and contributions to conferences. She also teaches various courses in econometrics, mathematical modeling, optimization, and mathematical foundations of informatics.

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