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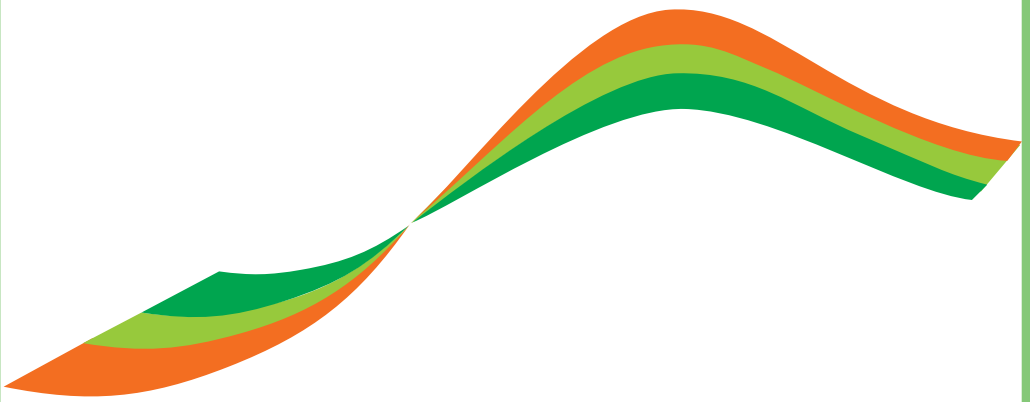

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ECONOMIA AGRO-ALIMENTARE
Food Economy

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Sommario

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Farewell Editorial for the Issue 3/2024

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The work published in Issue 3/2024 of *Economia agro-alimentare / Food Economy* highlights both the journal's enduring relevance and its growing global impact. Issue 3/2024 is special for several reasons. It not only showcases the cutting-edge research published in the journal but also highlights the vital role of **digital and environmental innovations** in advancing sustainability in the agri-food sector. The contributions featured in this issue stem from the **XXXI SIEA Conference**, held in **Venice** on **June 15-16, 2023**, and were edited by **Christine Mauracher**, **Vladi Finotto**, and **Chiara Rinaldi**. These papers focus on how **digital tools** and **sustainability measures** can reshape food production, supply chains, and consumption patterns. Their **Guest Editorial** introduces these contributions, providing insights into how the agri-food sector can evolve by integrating digital and environmental innovations into its business models.

Also featured in this issue is an article by **Ferry Syarifuddin**, titled *"Islamic Macroprudential Policy to Support Staple Agricultural Sector Financing."* This work examines how **Islamic financial instruments** can help finance staple crop production in Indonesia. Syarifuddin uses **Delphi-ANP analysis** to propose Islamic agricultural lending models, providing a sustainable alternative for financing large agricultural sectors in emerging

economies like Indonesia. His study offers a promising approach to financing agriculture while respecting local cultural and economic contexts.

As we close **Issue 3/2024** of *Economia agro-alimentare / Food Economy*, we are not only celebrating the achievements of this current issue but also reflecting on a transformative journey that began in 2011, under the editorial leadership of **Prof. Gervasio Antonelli** (2011-2016), whose new vision shaped the journal's mission and its focus on promoting high-quality academic research in the field of agro-food economics. The article **"The Scientific and Editorial History of the Journal Economia agro-alimentare"** (Antonelli *et al*., 2016), laid the foundation for what *Economia agro-alimentare* would become – a leading academic journal that contributes to discussions on the economic aspects of agriculture, food systems, sustainability, and related policy issues. Antonelli's guidance helped establish the journal as a critical player in academic discourse, both within Italy and internationally.

In June 2016, I took on the role of Editor-in-Chief. The journey was filled with challenges – moments of stress and uncertainty balanced with excitement and pride over the journal's progress. But as I reflect on the milestones we've achieved, I do so with immense pride, knowing that we've grown into an internationally recognized journal with a global influence. This issue marks the final one under my leadership, and it serves as an opportunity to reflect on the journal's journey, its impact, and the work of our contributors.

Looking back on the journal's trajectory, it is clear that we've made significant progress. One of the key milestones was being included in **Scopus** in 2018, which marked the beginning of our international recognition. The year 2024 also brought a major achievement: our inclusion in **Web of Science**, alongside our listing in the **Master's Journal List of Clarivate Analytics**. This will allow us to receive our first **Journal Impact Factor** next year, a landmark achievement for any academic journal. These accomplishments solidify *Economia agro-alimentare* as a key player in global academic discourse, reflecting the growing quality and relevance of the research we publish.

Another important achievement is the increase in our citation rates. According to **Scopus**, the following papers have been the most-cited in the years 2016-2024, underscoring the growing academic interest in our journal:

1. **"Food Loss and Waste, a Global Responsibility?!"** (Adamashvili *et al*., 2019) – This paper has been cited extensively for its analysis of the global food loss and waste problem, a key theme in sustainability discussions worldwide.
2. **"Lessons of Innovation in the Agrifood Sector: Drivers of Innovativeness Performances"** (Finco *et al*., 2018) – This study offers

valuable insights into the factors driving innovation in the agri-food sector, an increasingly important area of research as the industry faces new challenges and opportunities.

3. **"The Potential of Urban Agriculture Towards a More Sustainable Urban Food System in Food-Insecure Neighbourhoods in Cape Town and Maputo"** (Paganini *et al.*, 2018) – This paper highlights the role of urban agriculture in addressing food insecurity, providing a critical framework for sustainable urban food systems.

These papers reflect the journal's focus on key themes like sustainability, innovation, food security, and urban agriculture, all of which have had significant impacts on the academic and policy-making communities.

In the period 2017-2024 the journal has published 210 articles (including Notes and Editorials).

The journal's geographical scope has always been broad, addressing global issues while considering regional challenges. As we examine the geographical areas covered in the journal, it becomes clear that *Economia agro-alimentare* has provided valuable insights into the unique dynamics of food systems around the world. Our coverage includes research from several continents, each presenting its own challenges and opportunities in the context of food economics.

1. **Europe.** Europe has long been a focal point of our journal, with much of the research examining the **Common Agricultural Policy (CAP)**, **EU subsidies**, and the sustainability of farming practices in the region (Briamonte *et al.*, 2023). Studies have also explored rural development and the challenges faced by Mediterranean countries like **Italy**, **Spain**, and **Greece**, where agriculture is under pressure from climate change, land degradation, and evolving market demands (Cisilino & Vanni, 2019). For example, studies from **Italy** have provided important insights into the sustainability of **organic farming** and the role of **agriculture in regional development** in areas like **Basilicata** (D'Oronzio & Sica, 2021).
2. **Asia.** Asia, with its rapidly growing population and diverse agricultural sectors, has featured heavily in our journal. Countries such as **China**, **India**, **Kazakhstan**, and **Indonesia** have been central to studies examining the role of innovation in agriculture, including the use of **digital tools** and **precision farming technologies** to increase productivity and sustainability. Research on **agricultural trade, agricultural finance**, **food security**, and **contract farming** has also been key, particularly in countries like **India** and **Vietnam**, where agriculture plays a crucial role in livelihoods (Pomfret, 2017).
3. **Africa.** Africa's agricultural landscape has been a key area of focus, particularly in the context of **smallholder farmers** and **climate resilience**. Studies have explored how **small-scale farmers** can be supported through

better market access, policy reforms, and the integration of sustainable agricultural practices. Countries like **Kenya**, **Nigeria**, and **South Africa** have been the focus of research on food security, climate change adaptation, and the need for innovation in agricultural practices.

4. **North America.** Research from the **United States** and **Canada** has largely focused on **consumer behavior**, **food safety**, and the role of **agribusinesses** in sustainable agriculture. Research has also examined the impact of **precision agriculture** on improving productivity and reducing environmental impact.
5. **Latin America.** Latin America, with its rich agricultural resources, has contributed significantly to research on **agricultural exports**, **land use**, and the impact of **global trade agreements** on food systems (García Arancibia, 2019). **Brazil, Colombia** (Mendez Nobles *et al*., 2023) and **Mexico** (Alzate Gómez & Thomé-Ortiz, 2024) have been featured in studies on **agribusinesses**, **sustainable farming**, and the **role of trade agreements** in shaping local agricultural practices and food systems.

The journal's international scope highlights the diverse ways in which food systems operate globally, with each region facing unique challenges but also contributing solutions to common problems.

Over the years, *Economia agro-alimentare* has addressed a wide range of themes, many of which have become increasingly important as the challenges facing global food systems intensify. The journal's thematic focus reflects both the complexity of food systems and the urgent need for innovative solutions.

1. **Innovation and Technology in Agriculture.** One of the key themes in the journal is **innovation in agriculture**. Papers have focused on how **new technologies**, such as **AI**, **robotics**, and **precision farming**, are transforming the agri-food sector (Finco *et al*., 2018; Medici *et al*., 2020). These technologies have the potential to significantly enhance agricultural productivity and sustainability, reducing the sector's environmental footprint while meeting the growing global demand for food. A recent example examines **urban agriculture** and its role in sustainable food systems in food-insecure areas of **Cape Town** and **Maputo** (Paganini *et al*., 2018).
2. **Sustainability and Environmental Impact. Sustainability** has been at the heart of much of the journal's research. Our studies have covered various aspects of **sustainable farming**, including organic practices, **climate change resilience**, and the integration of **environmental technologies** into food production. These discussions are increasingly relevant as the agri-food sector is expected to contribute to global climate change mitigation efforts (Medici *et al*., 2020).

3. **Food Security and Global Supply Chains**. As global food security becomes an ever-pressing issue, our journal has examined the vulnerabilities of food systems, including the **economic impacts of food shortages** and disruptions in **global supply chains**. We have also explored the role of policy frameworks in ensuring **food access** and **equitable food distribution** (Zecca & D'Errico, 2021).
4. **Consumer Behavior and Market Trends**. Understanding **consumer behavior** has been crucial in shaping food production and marketing strategies. Papers in this area have examined trends such as the demand for **organic foods**, **sustainability preferences**, and consumer attitudes toward **food safety** and **health-conscious eating** (De Devitiis *et al*., 2021; Kokthi *et al*., 2021).
5. **Policy Frameworks and Agricultural Support.** The role of policy in shaping the agricultural sector has been a consistent focus of the journal. Research has explored how **public policies**, such as subsidies and **agricultural support programs**, impact **sustainability** and **food security**. This includes a detailed examination of **EU agricultural policies** and their impact on rural development and **sustainable farming practices** (Briamonte *et al*., 2023).

The journal has always encouraged rigorous, evidence-based research, employing a variety of methods to address complex questions in agro-food economics. These methods have included:

1. **Quantitative Analysis.** Many studies published in *Economia agro-alimentare* have employed **quantitative techniques**, such as **econometric modeling**, **survey analysis**, and **statistical methods** to analyze **agricultural policies**, **consumer behavior**, and **economic performance** of food systems. For example, recent work on **food loss and waste** (Adamashvili *et al*., 2019) uses **quantitative methods** to assess global trends and policy implications.
2. **Case Studies.** Case studies have been essential in providing in-depth insights into how theories and policies are implemented in specific contexts. These papers offer valuable lessons for policymakers, practitioners, and researchers on how to address local challenges in food systems while considering global trends.
3. **Delphi and ANP Methods.** The use of **Delphi analysis** and **Analytic Network Process (ANP)** methods has been particularly valuable in assessing **agricultural financing systems** and the implementation of new technologies in agriculture.

The journals' impact

During the period 2017-2024, 505 documents cited the articles we published.

The Future of the Journal: Transition to New Leadership

I would also like to express my gratitude to the current members of the Editorial Board: **Sedef Akgüngör**, **Valeria Borsellino**, **Alessio Cavicchi**, **Catherine Chan-Halbrendt**, **Alessio Ishizaka**, **Simona Naspetti**, **Søren Marcus Pedersen**, and **Stefanella Stranieri**. Their contributions have shaped the journal into what it is today. I would also like to thank the earlier members of the Editorial Board: **John Stanton**, **Christine Mauracher**, **Martin Hingley**, and **Maro Vlachopoulou**.

As my time as Editor-in-Chief concludes, I am proud to hand over the leadership of *Economia agro-alimentare* to **Valeria Borsellino** (University of Palermo, Italy) and **Søren Marcus Pedersen** (Københavns Universitet, Denmark). Their deep expertise and vision for the journal will ensure its continued success.

The new editorial team, including **Giovanna Bertella** (UiT The Arctic University of Norway), **Luca Cacciolatti** (University of Westminster, UK), **Nicola Cantore** (UNIDO Vienna, Austria), **Alessandra Castellini** (Alma Mater Studiorum University of Bologna, Italy), **Alessio Cavicchi** (University of Pisa, Italy), and **Fabio A. Madau** (University of Sassari, Italy), will no doubt continue to guide the journal to new heights.

In closing, I would like to extend my deepest thanks to everyone involved in this journey – our readers, authors, reviewers, and the publisher, along with the SIEA Presidential Boards, who have supported the journal since its inception. It has been a privilege to serve as Editor-in-Chief, and I look forward to watching the journal thrive under its new leadership.

Warm regards,
Maurizio Canavari
Editor-in-Chief, *Economia agro-alimentare / Food Economy*

Note in memory of Prof. Maurizio Canavari

It is with great sadness that we inform you that Prof. Maurizio Canavari, Editor-in-Chief of the journal *Economia Agro-Alimentare / Food Economy*, has left us prematurely.

Maurizio tirelessly dedicated his work and passion to this journal until the last days of his life, leaving us a legacy of extraordinary commitment and vision.

His outstanding contribution has enriched not only this journal, but the entire scientific community.

Our thoughts go out to his family, friends, colleagues, and all those who had the privilege of knowing and working with him.

May his memory and work be an inspiration and stimulus to us.

Valeria Borsellino and Søren Marcus Pedersen
Co-Editor-in-Chief

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Islamic Macroprudential Policy to Support Staple Agricultural Sector Financing

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Abstract

The study aims to recommend Islamic macroprudential policy instruments to support Indonesia's staple agricultural sector financing. Delphi-ANP analysis method is used to determine the optimal Islamic macroprudential instruments, which result is supported by meta-analysis and optimum method findings. The results show that Islamic Agricultural Lending to Sector (IALTS) is the optimal instrument to support agricultural sector financing. According to the ANP and optimum method findings, an Islamic macroprudential instrument should meet three criteria i.e., it should be able to increase financing for the agricultural sector, prevent speculative short-term transactions, and internalize systemic risk. Experts emphasized that IALTS have met the criteria to support sustainable growth and stability in the agricultural sector financing. Meta-analysis reveals a positive and significant correlation between agricultural financing and agricultural productivity across countries, which supports the instrument of macroprudential implementation. The government should adopt measures to boost agricultural production through macroprudential policy tools, financing for agriculture from Islamic banks, and policies that ensure inclusive agricultural financing for the benefit of all levels of farmers.

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Introduction

Indonesia's agricultural sector is crucial for economic development and growth, contributing about one-fifth of the country's GDP and employing over 30% of the workforce (ILO, 2021). However, the sector's growth rate has been inconsistent and significantly declined over the last ten years (OECD, 2020; Sudaryanto *et al.*, 2021) due to factors such as climate change (IPCC, 2022), limited agricultural infrastructure (Arizka *et al.*, 2022), land conversion (Azis *et al.*, 2022; Satria *et al.*, 2019), market access (Minten *et al.*, 2023), limited access to finance (Larasati *et al.*, 2017; Marita *et al.*, 2021), less favorable agricultural regulations, and suboptimal policies (Winoto & Siregar, 2008). Indonesia faces constraints in supporting agricultural production, ensuring food price stability, financial sector stability, access to financing, and environmental sustainability (Gumata & Ndou, 2021; Kahou & Lehar, 2017).

The intensification and commercialization of agriculture are crucial to guarantee food security due to the growing global population and urbanization (Kopittke *et al.*, 2019; Tilman *et al.*, 2011; Viana *et al.*, 2022). However, limited access to finance in the agricultural sector can hinder productivity, leading to a decrease in the supply of needed products. Imports can fill this gap, but they often result in higher prices for the public. Additionally, various constraints within the agricultural sector contribute to rising prices, and concerns about declining production have emerged due to worsening climate conditions and environmental degradation (Hiebert, 2022). Macroprudential policy plays a crucial role in supporting economic growth by providing sufficient and stable financing. Policymakers are prompted to formulate macroprudential policies and explore alternatives to support domestic food security, especially in the staple agricultural sector.

Macroprudential policy is also crucial for ensuring financial system stability and balanced financing in dual financial systems like Indonesia. It supports sustainable economic growth and maintains moral values. Since the global financial crisis, policymakers and academics have emphasized the importance of financial system regulation and supervision (Kahou & Lehar, 2017). Regulators focus on promoting stability and reducing imbalances, potentially leading to macroeconomic imbalances. On the other hand, the Islamic financial system has gained attention for its potential stability against crisis shocks, as it has been proven more resilient than conventional financial systems (Bilgin *et al.*, 2021; Syarifuddin, 2022).

The Islamic financial system is relatively stable because it applies intrinsic elements and moral values enshrined in Sharia principles (Galati & Moessner, 2012; Nachane & Islam, 2012). These elements include the prohibition of interest in lending and borrowing activities (*riba*), prohibition of excessive

debt (leverage), non-transparency in transactions (*gharar*), and excessive speculation (*maysir*) that trigger financial shocks. Islamic finance also promotes profit-loss sharing (PLS) tools, which are essential for the stability of the Islamic financial system (Adela, 2020). According to Chapra (2007), PLS contracts increase discipline by encouraging Islamic banks to be more cautious when making loans, while also raising depositors' awareness of the state of Islamic banks. In the end, this discipline increases the Islamic system's efficiency and stability.

Islamic finance, despite its moral values, still requires macroprudential regulation to achieve this goal (Hadian, 2016). Oseni (2015) advocates for using macroprudential policies in Islamic finance to prevent systemic risks. Zulkhibri *et al*. (2016) emphasize the need for Islamic macroprudential studies to develop a solid framework and effective instruments for such policies in a dual financial system. However, some groups doubt the use of macroprudential policies in the Islamic financial system due to its different structure and moral norms (Yoshida, 2016). Islamic finance is based on Islamic morality and social norms (Azmat *et al*., 2021), but it is often seen as irrelevant due to its different structure and moral norms. Macroprudential regulation, which does not regulate greed and profit, aims to ensure stability in the system. However, due to constraints and challenges, Islamic finance is seen as not based on true Islamic principles (Maurer, 2001). The current financial structure may fail if the primary motivation to seek profit dominates, potentially leading to the failure of a financial system based on Islamic principles. Concerning stability, sustainable economic growth is a crucial component that must be supported to promote prosperity. Political stability and social progress are based on economic growth (Cao & Ren, 2016; Ip & Law, 2011). As the economy grows, the government can make money from taxes, giving it the ability and resources to provide its citizens with public goods and services like healthcare, education, social protection, and other essential services (Sen, 2021).

Outlining the issues facing the agricultural industry reveals a lack of funding as well as regulations and policies that are unfavorable to farmers. Financial institutions, both conventional and Sharia, including banks and non-bank financial institutions, are reluctant to finance the agriculture sector because of the high-risk nature of the industry. There are several macroprudential laws and policies that affect financing, but until this point, no macroprudential law or policy has specifically supported financing in Indonesia's agricultural sector. Inadequate macroprudential policies can lead to financial system instability in a number of industries, including the agricultural industry, which will have a significant impact on the nation's food security (Laeven *et al*., 2022). A further implication of the problems in the agricultural sector is deagrarianization, where excessive modernization and

rapid development transform productive landscapes into unproductive ones such as real estate. According to Pujiriyani (2022), there are six key indicators which shows deagrarianization phenomenon in Indonesia, such as declining in: the agricultural sector's GDP, number of farming households, agricultural villages, rural population, agricultural labor participation, and agricultural area.

Since the global financial crisis, academics and policymakers have become increasingly interested in studying macroprudential policy. In general, conventional banking and financial institutions are primarily focus of the literature on macroprudential policy (Altunbas *et al.*, 2018; Bailliu *et al.*, 2015; Buncic & Melecky, 2013; Gauthier *et al.*, 2012; Kahou & Lehar, 2017). On the other hand, exploring macroprudential policy from an Islamic perspective has been attempted on numerous occasions (Wahyudi *et al.*, 2019; Zulkhibri, 2019). Nonetheless, limited research has been conducted to investigate the role of Islamic macroprudential policies in Islamic banking. There is a significant lack of Islamic macroprudential studies that endorse the provision of financing in the staple agricultural sector. Thus, this study aims to evaluate the most effective Islamic macroprudential policy instruments for bolstering financial support to the staple agricultural sector.

This study builds a conceptual framework to identify the most suitable Islamic macroprudential instrument to support Indonesia's agricultural sector financing by utilizing primary data. The Islamic macroprudential literature is extended by exploring Islamic macroprudential instruments for the agricultural sector through a systematic decision-making process, considering the perspectives of regulators, academics, and practitioners in Indonesia. To achieve this objective, the ANP method, which considers the interdependencies between the criteria, was utilized to determine the most suitable option. This model, which is designed based on the Delphi method, try to identify the most appropriate Islamic macroprudential instrument to support Indonesia's agricultural sector financing. To validates the findings; this study also conducted a meta-analysis as a form of robustness check. This paper also implements an optimal analysis approach by identifying criteria based on previous related literature.

This paper proceeds as follows. Section II discusses data and methodology. Discusses main findings and robustness check in Section III. Finally, Section IV concludes the paper.

1. Literature Review

1.1. *Key Aspects in Macroprudential Tools*

The key aspects of macroprudential refer to the various factors that affect overall financial stability. The main objective of macroprudential policy is to

prevent the occurence of financial crises that may harm the economy at the large. IMF (2013) underlines that macroprudential policy must aim at three objectives: (1) enhancing resilience, (2) limiting sectoral imbalances, and (3) limiting systemic liquidity risk.

To enhance resilience, the Basel Committee on Banking Supervision (2010) explains that it is important to increase banks' capital buffers during periods of elevated systemic risk. The additional capital raised during economic boom periods is expected to reduce banks' willingness to lend excessively (IMF, 2013). Conversely, during the downturns, macroprudential policies can avoid credit crunches by reducing the pressure on banks to deleverage to meet capital requirements. However, the extent to which macroprudential policy can effectively mitigate the fluctuations in credit, given the procyclical nature of credit, relies predominantly on the amount of capital maintained by banks beyond regulatory requirements. The issuance of new equity, which is relatively cheap during booms, may mitigate the impact of the demand for increased capital in the event of credit expansion (Adrian & Shin, 2010). Generally, the impact on overall credit and the real economy will depend on the extent to which non-financial firms can find substitute credit from unregulated financial intermediaries in the market.

In relation to limiting sectoral imbalances, instruments to address procyclical systemic risk can be selected and calibrated taking into account aggregate or sectoral variable conditions (International Monetary Fund, 2013). From a macroprudential viewpoint, aggregate instruments are meticulously calibrated to ensure adequate capital or liquidity in the entire financial system. On the other hand, sectoral instruments focus on assessing the relative risks associated with specific sectors, such as consumer loans, corporate exposures, or real estate markets. In situations where systemic risks are observed to accumulate within the financial system, employing aggregate instruments is deemed suitable. However, if risks permeate specific sectors individually, sectoral instruments are considered the apt mechanism to address such risks (Committee on the Global Financial System, 2012). Sectoral macroprudential instruments can affect either the demand side of credit (e.g., mortgage lending limits) or the supply side of credit (sectoral capital requirements). These instruments aim to restrain excessive credit growth in a sector, and may target specific types of loans, specific groups of borrowers, properties in high-potential regions, or loans denominated in specific currencies (Crowe *et al.*, 2013). These two policies can be applied separately or together.

A strong liquidity profile that can withstand unexpected funding shocks is pivotal for ensuring the effective functioning of any bank, given its transformative role. Yet, the recent financial crisis has underscored the essentiality of having sufficient liquidity to uphold financial stability.

Financial market imperfections characterized by asymmetric information cause financial institutions to fail to internalize risk when lending, thus encouraging excessive credit expansion. Excessive credit expansion is often funded by short-term wholesale funding, as stable deposits tend to increase slower than credit demand. Banks in small open economies (SOEs) rely on short-term wholesale funding, which is often denominated in foreign currency, leading to maturity and currency mismatches. The occurrence of such mechanisms can give rise to a significant increase in the influx of capital, followed by an abrupt halt. This situation frequently culminates in a dual crisis, wherein both the banking sector and the currency experience a mutually reinforcing downturn (IMF, 2011).

Hiebert (2022) highlights that appropriate macroprudential policies are necessary, as the agricultural sector is exposed to various risks, including climate change risks. Macroprudential policies are crucial in managing systemic risks related to the financial implications of climate change. They constitute a vital component of a comprehensive policy approach aimed at mitigating the financial repercussions. These risks encompass both the financial vulnerabilities stemming from climate change and the financial vulnerabilities that can impact economic entities across various sectors, such as the agricultural sector.

In proposing macroprudential tools, it is crucial to address the three essential aspects. This becomes especially significant when considering the risks that may arise from the agricultural sector's development, specifically in the staple sector. Moreover, this sector tends to be riskier than other sectors (Syed *et al.*, 2022). Therefore, fulfilling these aspects should lead to macroprudential policies.

2. Research Methodology

This study can be considered as frontier research, as Islamic macroprudential policy has never been directly applied in any country including countries with dual banking system. This analysis adopts three different research methodologies i.e., Delphi-ANP, meta-analysis, and optimum analysis.

2.1. *Data*

This study consists of primary and secondary data. Primary data obtained from focus group discussions (FGD) and ANP questionnaires distributed to seven academicians in several regions, such as Yogyakarta, East Java, North

Sumatra, West Sumatra, and South Sulawesi. On the other hand, secondary data is obtained through literature reviews. In-depth interviews are conducted with regulators and practitioners to gather information about the development of the agricultural sector. According to Sakti *et al*. (2019), mastery and competence in the relevant fields are the most important factors to consider in selecting respondents for the Delphi-ANP method. Furthermore, Reza & Vassilis (1988) pointed out that the number of experts as interviewee should not be too much, and in general, 5-15 persons are best suited. This means that the respondent in this study is appropriate. The following is a list of respondents in this study.

Table 1 - List of Experts Profile

No.	Job Title	Education	Institution	Expertise
1.	Academics	Master	Ahmad Dahlan University	Islamic economics
2.	Academics	PhD	North Sumatra State Islamic University, Medan	Islamic economics
3.	Academics	Master	Telkom University	Econometrics, monetary economics
4.	Academics	PhD	Alauddin Makassar State Islamic University	Macroeconomics
5.	Academics	PhD	Brawijaya University	Islamic economics
6.	Academics	Master	Sjech M. Djamil Djambek State Islamic University Bukittinggi	Islamic economics

Source: Author's own elaboration.

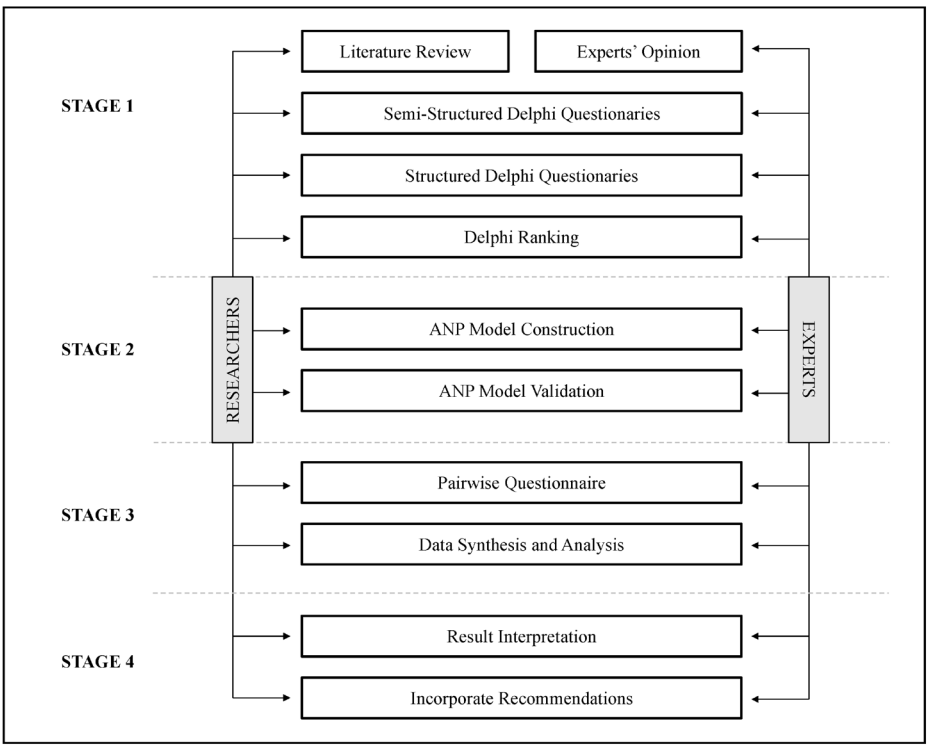
2.2. *Methods*

2.2.1. The Delphi-ANP Method

The Delphi-ANP method, as illustrated in Figure 1, is adopted to provide a decision-making framework to select the best Islamic macroprudential instruments to support the financing of the agricultural sector in a country. This study begins by reviewing literatures related to Islamic macroprudential instruments to identify the criteria of Islamic macroprudential instruments

that are suitable for the agricultural sector in Indonesia. The Delphi method is subsequently employed to examine the primary indicators for evaluating the impact of Islamic macroprudential instruments on the agricultural sector in Indonesia.

Figure 1 - Stages of Delphi-ANP Methodology



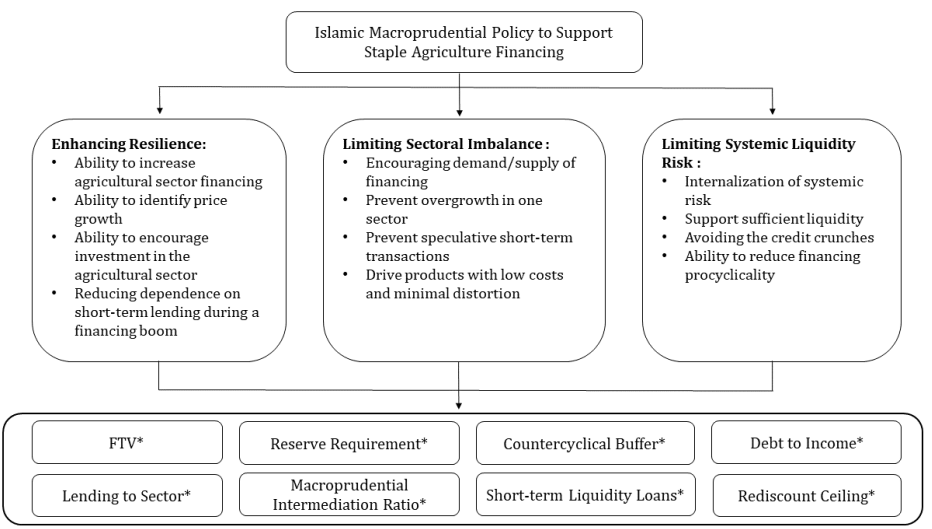
Source: Almashhour *et al.* (2023)

The Delphi procedure is a structured communication technique that relies on a panel of experts to solve complex problems (Landeta, 2006). Initially, Delphi was a decision-making approach to predict the impact of technology on warfare (Dalkey & Helmer, 1963), but now many studies use Delphi to decompose and structure ANP frameworks (Akhlagh *et al.*, 2013; García-Melón *et al.*, 2012; Kumar *et al.*, 2022; Sakti *et al.*, 2021). The Delphi method does not rely on statistical samples that aim to represent the population, but rather a group decision mechanism that requires competent

experts who have a deep understanding of the problem, hence the selection of experts is a fundamental aspect of this method (Okoli & Pawlowski, 2004). In this study, experts completed a questionnaire in more than one round, and the authors summarized their anonymous responses and justifications. To reduce disagreements and arrive at a consensus answer, experts were urged to modify their responses in response to those of others (Gamarra, 2009).

Following a comprehensive literature review and Delphi procedure, an analytic network process (ANP) model is constructed as presented in Figure 2. An ANP method is used to transform qualitative judgements from experts into quantitative data. ANP is a mathematical theory that examines the effects of using assumption-based techniques for problem solving (Saaty & Vargas, 2006). The integration of the Delphi into ANP method is expected to produce different assessments. By employing this approach allows the Delphi procedure to validate the evaluations provided by various respondents, unlike the conventional ANP method where the consensus among respondents may be less than optimal (García-Melón *et al*., 2012). This enables a better understanding of the discussed topics and the expectations of each respondent. The integration of these two methods facilitates further consensus-building among respondents.

Figure 2 - Delphi-ANP Model



*All alternatives are adjusted to Islamic principle and directed to agricultural (staple) sector

Source: Author's originality.

The ANP model as in Figure 2 will be transformed into questionnaire in the form of pairwise (comparison). This questionnaire will be administered to multiple experts. Finally, the data derived from the questionnaire is analysed using Super Decision 2.10, Microsoft Excel, and SPSS software. The sensitivity analysis for the robustness test will not be conducted in this study as the Delphi procedure serves as an analysis of expert judgment's robustness (García-Melón *et al.*, 2012). The primary aim of sensitivity analysis is to ascertain the reliability of the ratings. Through the utilization of Delphi, it is possible to reinforce the accuracy of experts' evaluations, implying their confidence in the conclusions and obviating the need for sensitivity analysis.

2.2.2. Meta-analysis

To enhance the credibility of the findings, a meta-analysis was performed concurrently to validate the outcomes. Meta-analysis is a statistical method that integrates several findings from individual studies (Glass, 1976). Meta-analysis aims to identify the facts of strong relationships from various literatures more accurately, although there may be bias in certain studies (Cook & Leviton, 1980). This can drive decision-making, both at the organizational and societal levels, as it is based on facts (Hunter *et al.*, 1986; Schmidt, 1984).

This analysis was conducted using the data obtained from related literature on Google Scholar as it is connected to various journal websites and indexing agencies. Google Scholar was employed with the aim of gathering an extensive pool of data to mitigate bias. The criteria of the studies collected for the meta-analysis were: 1) Articles using quantitative research methods; 2) The independent variable used relates to the agricultural financing by financial institution, while the dependent variable relates to agricultural productivity; 3) The article has a correlation coefficient. This method will be analyzed using JASP software.

The type of meta-analysis in this study is a correlation meta-analysis that shows the relationship between two variables by utilizing the results of previous correlation studies. The process consists of several stages (Berkhout *et al.*, 2024). First, transforming the r (correlation) value in each study into an effect size using a predetermined formula. Then, testing for heterogeneity and calculating summary effect. If there is no heterogeneity, the summary effect will be calculated using a Fixed Effect Model (FEM). However, if there is heterogeneity, the summary effect will be calculated using a Random Effect Model (REM). Finally, an evaluation of publication bias was conducted.

In this study, the scale proposed by Bhandari (2022) was utilized to interpret the effect size obtained from correlational studies. The classification of effect sizes is as follows:

Table 2 - Effect Size Classification

Effect Size	Pearson's r
Weak	.1 to .3 or –.1 to –.3
Moderate	.3 to .5 or –.3 to –.5
Strong	.5 or greater or –.5 or less

Source: Bhandari (2022).

The Pearson's r correlation coefficient provides insight into the magnitude of an effect size. Values nearing -1 or 1 suggest a significant effect, while values near 0 suggest a smaller effect. The positive or negative signs within the r Pearson coefficient indicate the direction of the relationship between variables. A positive sign indicates that both variables increase or decrease simultaneously, while a negative sign indicates that while one variable decreases, the other variable increases (and vice versa).

2.2.3. Optimum analysis

To fortify the results of this study and ensure greater validity, it becomes imperative to perform an evaluation that gauges the individual contribution or influence of each criterion outlined in the model. Optimum analysis is used to provide an assessment based on previous related literature. The assessment form can be seen in Table 3.

Table 3 - Optimum Analysis Score

	Increasing financing of the Staple agriculture sector	Limiting financing imbalances in the Staple agricultural sector	Limiting systemic liquidity risk in the staple agricultural sector
Yes	+1	+1	+1
Quasi Yes	+0.75	+0.75	+0.75
Depend	+0.5	+0.5	+0.5
Quasi No	+0.25	+0.25	+0.25
No	0	0	0

Source: Author's originality.

The scoring system utilizes a scale from –1 to +1, where positive values are assigned to statements that uphold the sub-criteria, and negative values are assigned to those that oppose it. A score of +1 or –1 signifies strong support for the optimum aspects based on the statements derived from existing literature. In contrast, a score of 0 indicates the absence of support for the optimum aspect.

In the initial phase, the first step entails describing the optimal aspects of each alternative of Islamic macroprudential policy instrument. If the criteria for these alternative instruments possess absolute attributes that are independent of other criteria, meaning they enhance the optimal aspects, they will receive a positive evaluation denoted by a "Yes". A "Quasi Yes" will be assigned if the alternative criteria for Islamic macroprudential policy instruments partially support the optimal aspects but have certain shortcomings in other aspects. Then, the "Depend" categorization will be obtained if the alternative criteria for Islamic macroprudential policy instruments support the optimal aspects but are highly dependent on other aspects. Moreover, a "Quasi No" will be assigned if the alternative criteria for Islamic macroprudential policy instruments fail to adequately align with the desired optimal aspects, albeit with minimal impact. Lastly, a "No" categorization will be warranted when the alternative criteria for Islamic macroprudential policy instruments fail to align with any of the optimal aspects.

3. Results

This section consists of three subsections. First, it discusses priority of criteria cluster, followed by the sub-criteria prioritization of each criterion in the second section. The third section discusses the prioritization of alternative optimal Islamic macroprudential instruments to support financing for staple agriculture sector. Then, it presents meta-analysis to strengthen the research findings as a robustness check. Lastly, the optimal analysis is employed to disseminate the author's perspective.

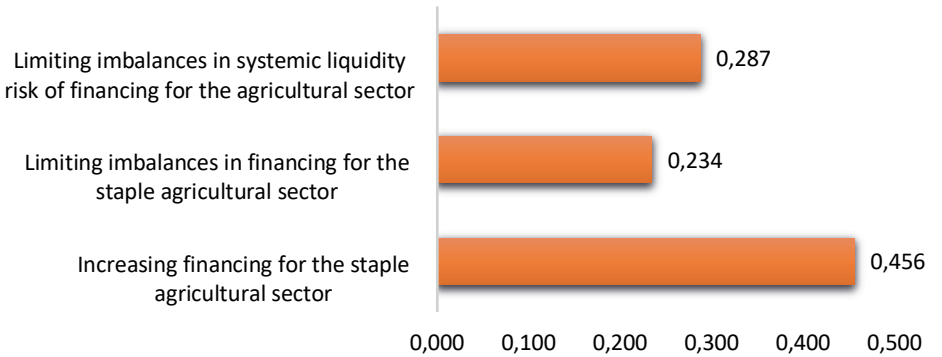
3.1. *Delphi-ANP Analysis*

3.1.1. Priority of Criteria Cluster

In this section, to determine the suitable Islamic macroprudential policy instruments to support the financing of Indonesia's staple agricultural sector,

three key aspects need to be taken into consideration, including increasing financing for the staple agricultural sector, limiting imbalances in financing for the staple agricultural sector, and limiting imbalances in systemic liquidity risk of financing for the staple agricultural sector. As illustrated in Figure 3, the criterion of increasing financing for the staple agricultural sector has the highest geometric mean value, meaning that this criterion is prioritized in determining Islamic macroprudential policy instruments to support the staple agricultural sector financing.

Figure 3 - Geometric Mean Value of Criteria

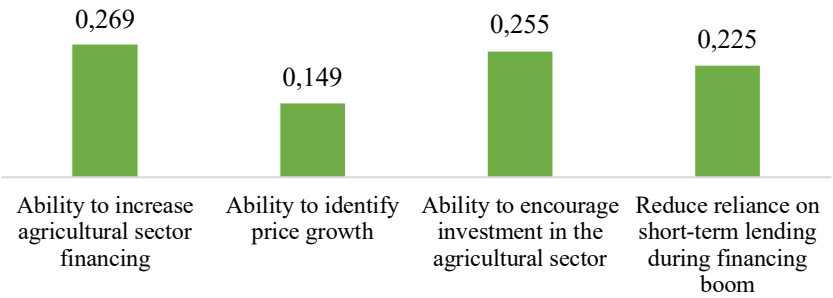


Source: Author's own elaboration based on Super Decisions software.

3.1.2. Priority of sub-criteria in each cluster criteria

Regarding the criteria for improving staple agriculture sector financing, the ability to increase the financing of the staple agriculture sector has the highest geometric mean value of 26.9%. This implied that the sub-criterion is the top priority in supporting the staple agricultural sector financing within the framework of Islamic macroprudential policy (Figure 4). It is followed by sub-criteria of ability to encourage the investment in the agricultural sector which has the second highest geometric mean value of 25.5% and to reduce reliance on short-term lending during financing boom with geometric mean value of 22.5%. The last priority in this criterion to support staple agricultural sector financing is the ability to identify price growth which has the lowest value of geometric mean of 14.9%.

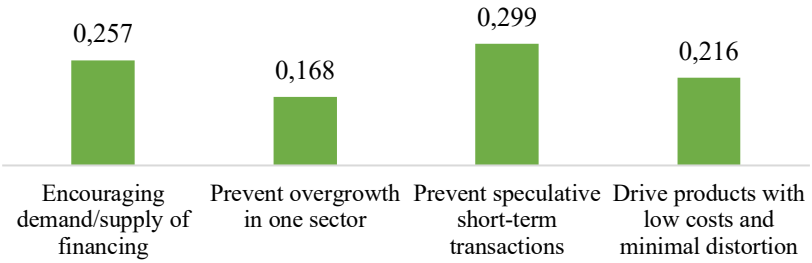
Figure 4 - Sub-criteria Geometric Mean Value of Increasing Staple Agricultural Sector Financing



Source: Author's own elaboration based on Super Decisions software.

The top priority of sub-criteria in limiting imbalances in financing the staple agricultural sector is preventing speculative short-term transactions with a geometric mean value of 29.9% (Figure 5). Speculative transactions can take many different forms in the context of agriculture, including commodity price speculation, futures and options trading, as well as investments in agricultural businesses. These have significant risks and the potential for large gains or losses. On the other hand, to prevent overgrowth in one sector is the least priority criterion to be used in encouraging financing in the food crop agriculture sector with geometric mean value of 26.8%.

Figure 5 - Sub-criteria Geometric Mean Value of Limiting Financing Imbalances in the Staple Agricultural Sector

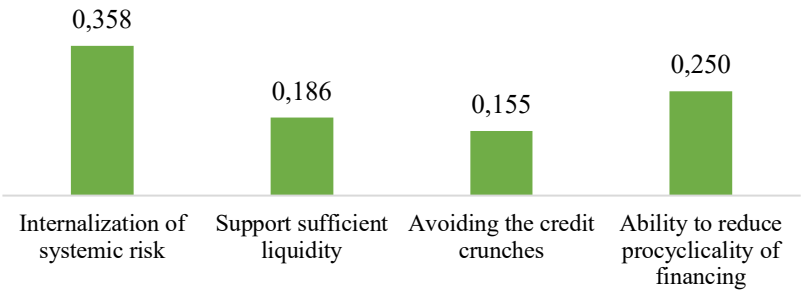


Source: Author's own elaboration based on Super Decisions software.

The sub-criterion of internalization of systemic risk is the most priority in the criteria of limiting liquidity risk in financing the staple agricultural sector.

The sub-criterion has the highest geometric mean value of 35.8% (Figure 6). It is followed by the ability to reduce the procyclicality of financing as the second priority sub-criterion with the geometric mean value of 25.0%. The least important sub-criterion is to avoid the credit crunches which have the lowest geometric mean value of 15.5%.

Figure 6 - Sub-criteria Geometric Mean Value of Limiting Liquidity Risk of Staple Agriculture Sector Financing

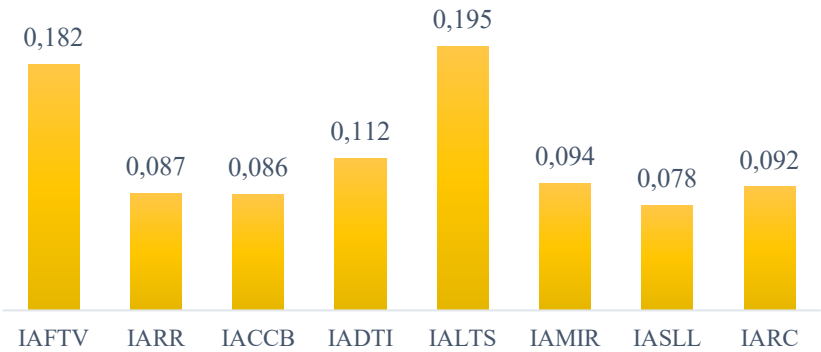


Source: Author's own elaboration based on Super Decisions software.

3.1.3. Prioritization of Alternative Instruments for Islamic Macroprudential Policy

Finally, the Delphi-ANP approach is employed to identify the most preferred Islamic macroprudential policy instruments for enhancing financing in the staple agricultural sector. According to the analysis results, the foremost instrument for stimulating financing in this sector is Islamic Agricultural Lending to Sector (IALTS), as indicated by the highest geometric mean value of 0.195. Islamic Agricultural Financing to Value (IAFTV) is ranked second with a geometric mean value of 0.182, followed by Islamic Agricultural Debt to Income (IADTI) at 0.112 geometric mean value, representing the third priority instrument (Figure 7).

Figure 7 - Geometric Mean Value of Alternative Instruments for Islamic Macroprudential Policy



Source: Author's own elaboration based on Super Decisions software.

3.2. *Meta-analysis result*

As a means of affirming the previously attained analytical findings, this study further performed a meta-analysis to fortify the rationale behind the adoption of IALTS as the most prioritized instrument. This instrument, backed by the central bank and non-bank institutions, operates as a percentage-based incentive policy aimed at augmenting financing in the agricultural sector. To ensure that the implementation of this instrument can provide significant benefits, especially in terms of increasing agricultural financing, this analysis will show how much agricultural financing (Islamic and conventional) affects agricultural productivity. A total of nine studies meeting the predetermined criteria were identified. The sample size (N) and correlation coefficient (r) from those studies were utilized for further analysis. The distribution of publications is presented in Table 4.

Next, the correlation coefficient values as shown in Table 4, were transformed into an effect size, which is then used in heterogeneity testing. Heterogeneity was tested to determine the appropriate estimation model. The result is shown in Table 5.

The τ^2 value indicates the variance of the true effect size parameter across the study population, or the total amount of heterogeneity, whilst τ represents the estimated standard deviation of the true effect sizes distribution (Borenstein *et al.*, 2009). The I^2 value indicates the level of heterogeneity that is not caused by sampling error. The value of I^2 can range from 0 to 100 percent. If I^2 is less than or equal to 50 percent, the study is said to be homogeneous, hence fixed effect model will be used to calculate

Table 4 - Summary of Studies for Meta-analysis

Variable	No	Author	Year	*N*	*r*
Agricultural financing affects agricultural productivity	1	Fariduddin	2010	20	0.432
	2	Bolarinwa & Fakoya	2011	250	0.382
	3	Butler & Cornaggia	2011	6	0.021
	4	Allimi *et al.*	2019	45	0.295
	5	Ubi & Udah	2019	14	0.559
	6	Seven & Tumen	2020	2944	0.490
	7	Rashid	2021	1188	0.104
	8	Mladenović & Mladenović	2023	513	0.085
	9	Wang *et al.*	2023	330	0.084

Source: Author's own elaboration based on each each study used in meta-analysis.

Table 5 - Heterogeneity test

	Estimate
τ^2	0.035
τ	0.188
I^2 (%)	93.689
H^2	15.844

Source: Author's own elaboration based on JASP software

the summary effect. On the other hand, the I^2 value greater than 50 percent means the study has high heterogeneity, thus it is required to use a random effect model to calculate the summary effect (Hak *et al.*, 2016). The H^2 value represents the between-study variance (Goss-Sampson, 2020). This study employed a random effect model because τ^2 and τ is more than zero, the I^2 value greater 50 percent and the H^2 value is greater than one.

The next step is to calculate the summary effect using the Wald test, as shown in Table 6. A summary effect is calculated to determine the summary or overview of the effect size to be observed (Retnawati *et al.*, 2018).

The p-value of the estimated effect size on all variables in this study is less than 0.001. Thus, it is proven that there is a significant relationship between agricultural finance and agricultural productivity, which the estimated effect size is 0.276.

Table 6 - Summary effect calculation

	Estimate	Standard Error	*z*	*p*	95% Confidence Interval	
					Lower	Upper
Intercept	0.276	0.076	3.621	<.001	0.127	0.426

Source: Author's own elaboration based on JASP software.

The final step is to evaluate the publication bias. This step plays a pivotal role in establishing the significance of sources, attaining accurate conclusions of the study, and assessing the influence of different sample sizes on research findings with minimal bias (Agarwal *et al*., 2012; Chamdani *et al*., 2022). To detect the publication bias, Egger's test is employed. The results of Egger's test are presented in Table 7 with the *p*-value of 0.613, which is greater than 0.05. This indicates the absence of publication bias, which means the excluded studies yield similar results to the included studies in this meta-analysis.

Table 7 - Regression Test for Funnel Plot Asymmetry (Egger's Test)

	z	*p*
sei	0.505	0.613

Source: Author's own elaboration based on JASP software.

3.3. *Optimum Analysis*

The author provides his own insights through the valuation of each Islamic macroprudential instrument to strengthen the acquired research findings using the optimum analysis. In this case, this study assessed each instrument on each criterion based on the existing literature (attached in the Appendix). This study presents the matrix assessment form as described in Table 8.

The results of the optimum analysis show that IALTS has the highest scores. Hence, it is selected as the most optimal alternative instrument for supporting agricultural sector financing. The obtained optimal analysis outcome validates and enhances the conclusions drawn from the two other methodologies employed in this study.

Table 8 - Priority of Alternative Instruments for Islamic Macroprudential Policy

	Islamic Macroprudential Policy Instruments							
Characteristics	**A: (IAFTV)**	**B: (IARR)**	**C: (IACCB)**	**D: (IADTI)**	**E: (IALTS)**	**F: (IAMIR)**	**G: (IASLL)**	**H: (IARC)**
Increasing staple agriculture sector financing								
P1: Ability to increase agricultural sector financing	1	1	1	0,50	1	0,25	0,50	0,75
P2: Ability to identify price growth	0,50	0,75	0,50	0,50	0,75	0,50	0,25	0
P3: Ability to encourage investment in the agricultural sector	1	0,50	0,75	0,75	1	0,75	0,25	0,75
P4: Reduce reliance on short-term lending during financing boom	1	0,75	1	1	0,75	0,50	0,50	0,25
Total Score (P)	**3,5**	**3**	**3,25**	**2,8**	**3,5**	**2**	**1,5**	**1,8**
Limiting financing imbalances risk in the staple agricultural sector								
Q1: Encouraging demand/supply of financing	0,75	0,75	0,75	0,75	0,50	0,75	0,50	0,25
Q2: Prevent overgrowth in one sector	0,50	0,75	0,25	0,75	0,75	0,25	0,25	0,75
Q3: Prevent speculative short-term transactions	0,75	1	0,75	0,75	1	0,25	0,75	0,25
Q4: Drive products with low costs and minimal distortion	0,75	0,50	0,75	0,50	1	0	0,25	0
Total Score (Q)	**2,75**	**3**	**2,5**	**2,8**	**3**	**1,3**	**1,8**	**1,3**
Limiting systemic liquidity risk of the staple agriculture sector								
R1: Internalization of systemic risk	1	1	0,75	1	1	1	0,25	0,25
R2: Support sufficient liquidity	0,75	0,75	1	0,50	0,75	1	0,50	0,50
R3: Avoiding the credit crunches	0,75	0,75	0,75	0,50	1	0,75	0,50	0,75
R4: Ability to reduce procyclicality of financing	1	0,50	1	1	0,75	1	1	0
Total Score (R)	**3,5**	**3**	**3,5**	**3**	**3,5**	**3,8**	**2,3**	**1,5**
Total	**9,8**	**9**	**9,3**	**8,5**	**10**	**7**	**5,5**	**4,5**

Source: Author's own elaboration.

4. Discussion

Based on the outcome of Delphi-ANP method, it is essential to increase financing for the staple agricultural sector. For example, in Pakistan, the regulation of agricultural loans is an essential component of the central bank's functions as it aligns with the State Bank of Pakistan's policy for sectoral development financing. The policy is an equitable distribution of credit under the agricultural loan scheme where mandatory targets are given to commercial banks for agricultural loans. Until now, fifty-two institutions including five large banks, two specialized banks (ZTBL & PPCBL) for agriculture, 14 domestic private banks, 11 microfinance banks, five Islamic banks and 15 microfinance institutions directly provide financing to the agricultural community in the country (State Bank of Pakistan, 2021).

Based on the findings of meta-analysis, there is a positive and significant correlation between agricultural financing and agricultural productivity (effect size value 27.6% and p-value < .001). This is also in line with several studies in various countries that show agricultural credit or financing has a positive impact on productivity (Aguilar & Tovar, 2013; Ali *et al*., 2014; Chandio *et al*., 2018; Florence & Nathan, 2020; Manoharan & Varkey, 2021; Minten *et al*., 2023; Okore & Nwadiubu, 2022; Yunusa & Ariyibi, 2022). Furthermore, Abubakar & Muhammad (2023) stated that commercial bank agricultural financing rates have a positive and substantial impact on agricultural output in the long run.

In line with this, numerous studies have demonstrated that lending policies to the agricultural sector have a favorable impact on bank disbursements (Sarker, 2016), productivity (Manoharan & Varkey, 2021) and GDP (Obioma *et al*., 2021). Mohamed *et al*. (2021) also found that financing from Islamic banks has a long-term beneficial effect on agricultural output. The financing provided by Islamic banks not only positively impacts agricultural output in the long run but also contributes to the overall development of the agricultural sector. Furthermore, Islamic banks maintained stronger financing growth than conventional banks, with growth rates that were on average twice as high (Hasan & Dridi, 2010).

As indicated by the findings, it is crucial to prevent speculative short-term transactions to address the financing imbalances within the staple agricultural sector. The agricultural sector can avoid risks by utilizing the Islamic financial system in its policy rules. The Islamic financial system offers transactions which have to be based on the actual economic activity and to avoids elements of uncertainty as well as speculation to prevent speculative short-term transactions. Maulana (2020) stated that the Islamic financial system promotes business dealings based on legitimate economic activity, asset ownership, and risk sharing, all of which work to support

an equal and ethical financial system. By applying specific instruments tailored to the needs of the agricultural sector, such as flexible payment terms and profit-sharing arrangements, Islamic finance can further enhance their financing growth and contribute to the overall development of the sector. These benefits extend not only to the agricultural sector but also to strengthen the whole economy by increasing productivity, lending, and GDP (Mladenović & Mladenović, 2023).

The Islamic financial system, in principle, is considered to have less systemic risk than conventional finance due to the risk-sharing aspect and the prohibition of speculation (Kammer *et al*., 2015; Rizwan *et al*., 2022). Furthermore, procyclicality in Islamic banking is viewed favorably because it is consistent with the inherently stable features of Islamic finance and prevents the formation of bubbles that could lead to systemic risk (Albinali, 2023). Therefore, instruments with these criteria can support financing in the agricultural sector with the intermediation of Islamic financing institutions.

To enhance Indonesia's food crop productivity, an increase in Islamic financing to the agricultural sector is necessary as part of the implementation of Islamic macroprudential policy. Nevertheless, to access the financing needed by the agricultural sector, agricultural policy plays an important role (Okore & Nwadiubu, 2022). Therefore, access to financing for the agricultural sector must be supported by agricultural policy instruments from the government (Kirechev, 2021). These policy instruments can include providing subsidies or low-interest loans to farmers, establishing specialized financial institutions for the agricultural sector, and implementing regulations that encourage banks to provide loans to farmers. Furthermore, agricultural policies should also focus on improving farmers' financial literacy and provide them with training on how to effectively manage their finances and access credit. This supports the implementation of Islamic macroprudential policies to encourage agricultural financing through Islamic financial institutions.

Based on the collective findings of the three approaches used in this study, it can be deduced that Islamic Agriculture Lending to Sector (IALTS) serves as the most suitable Islamic macroprudential instrument for effectively promoting financing in the staple agricultural sector. IALTS instrument is a percentage-based incentive from the central bank for banks and non-banking institutions to lend more money to the staple agriculture sector. It aims to achieve development and food security goals by providing special treatment to sub-optimal sectors. According to several studies, agricultural financing policies from the authority can increase agricultural productivity (Manoharan & Varkey, 2021; Okore & Nwadiubu, 2022; Sarker, 2016). The implementation of such policies will lead to a positive relationship between bank financing and the development of the agricultural sector (Kirechev,

2021). Banks are essential for the development of the agricultural sector (Ngong *et al*., 2023), as appropriate credit flows ensure farmers' needs and productivity.

In term of limiting financing imbalances in the staple agricultural financing risk, IALTS increase financing for the agricultural sector through Islamic principles, focusing on asset-based value and no interest rate (Aidah & Anugrah, 2021). In the context of the agricultural sector, this policy can help control liquidity and limit the risk of financing allocated to the sector. IALTS also allows a sector to access affordable and flexible financing options, enabling farmers to invest in modern technologies and improve productivity (ADB, 2019). Additionally, IALTS provides a transparent and efficient policy for lenders and borrowers to connect, fostering greater financial inclusion in the agricultural sector.

IALTS can also limits systemic liquidity risk of the staple agriculture sector. Islamic macroprudential policies encourage diversification of lenders and borrowers, using risk-sharing mechanisms like *mudaraba* and *musharaka*, instead of interest-based lending. This approach provides more equitable and stable financing arrangements, sharing risks and benefits between lenders and borrowers. LTS policy limits lending to high-risk sectors, reducing credit default risk and strengthening financial system resilience. Central banks and financial supervisory authorities play a crucial role in implementing LTS (Haniff *et al*., 2019). IALTS policy promotes sustainable economic growth, but requires careful implementation and coordination with other policies for effective macroeconomic stabilization.

Using appropriate macroprudential instruments, the agricultural sector can experience sustainable growth, increase productivity, and better manage financial risks. This will have a positive impact on overall economic resilience, food security, as well as the welfare of people who depend on the agricultural sector. Despite the results of this study conclude that the most suitable Islamic macroprudential policy instruments to support staple agricultural sector financing is IALTS, its implementation is insufficient to address the complex financing issues in the agricultural sector. Hence, additional supporting measures are imperative for bolstering the financing of the agricultural sector (particularly in the staple agriculture sector). Other supporting policies include specialized financing institutions for the agricultural sector (such as agricultural banks), financial risk mitigation for farmers (agricultural insurance), and allocation of social funds for the agricultural sector. It is also necessary for policy instruments to be tailored to the smallholder farmers who dominate in Indonesia, so that the IALTS policy can support all layers in the agricultural sector.

Conclusions

Based on Delphi-ANP and Optimum Method approaches, they show that the most suitable Islamic macroprudential instruments considered to support staple agriculture sector financing in Indonesia are Islamic Agricultural Lending to Sector (IALTS). These instruments fulfill three criteria i.e., increasing financing for the staple agriculture sector, limiting imbalances in financing (preventing speculative short-term transactions), and limiting systemic liquidity risk (internalizing systemic risk) for the staple agricultural sector. IALTS suggests Sharia banks and other financial institutions to provide a greater percentage of financing to the agricultural sector. The existence of these policies is able to address the issues of financing in the agricultural sector, which is restricted by a lack of financing commitments from banks and non-banks for the agricultural sector, and to support the issue of collateral for farmers (especially small and medium farmers) when engaging in farming activities so that it can have an impact on boosting the productivity of food crops to realize national food security.

Furthermore, using meta-analysis this study supports Delphi-ANP premies indicated by the effect size of 9 publications which are proven to be heterogenous and have a positive value and significant correlation between agricultural finance and agricultural productivity. In this research, the publications bias does not exist, which means that the publication truly reflects the actual situation. Based on optimum analysis, IALTS come agricultural policy has an important role in accessing the financing needed by the agricultural sector. Therefore, access to financing for the agricultural sector must be supported by agricultural policy instruments from the government. These policy instruments can include providing subsidies or low-interest loans to farmers, establishing specialized financial institutions for the agricultural sector, and implementing regulations that encourage banks to provide loans to farmers.

Although extensive analysis has been conducted, this study is not without limitations. Time and cost constraints prevented use of number of respondents to participate in the study. Like the ANP method in general, the results of this study are somewhat influenced by the subjective assessments of the respondents. Moreover, there is a possibility that other indicators may have been disregarded due to the limitations of the indicator-based approach utilized in this study. Despite the limitations, this study opens new doors for research related to Islamic macroprudential in general in the future, specifically related to agricultural financing development.

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Guest editorial

Twin transition in agrifood: Digital and green transitions for sustainable, competitive, and resilient food systems

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The "twin transition" has been a key feature of the European policy discourse over the past five years. The idea that the widespread adoption of digital technologies in the European economic fabric would have made it more efficient, competitive, and sustainable made European policies stand out for their ambition (carbon neutrality by 2050) and the European Commission be considered for its strategic intent and apparent realism (Valatsas, 2019). The European Green Deal's centrality was reinforced by the need to reignite the engine of growth and inclusion in Europe after the devastating effects of the Covid-19 pandemic. On the one hand, the contingencies that brought the world economy to a sudden and almost total halt in the first part of 2020 revealed once again the complexity of global value chains, the delicate interdependences among economies, and the risks entailed in the exponential propagation of problems linked to lack of environmental awareness. On the other hand, digital technologies functioned as an effective and reassuring link between the prospective routes towards sustainability for Europe and the previous European Agenda, which focused largely on significant increase in competitiveness, innovation and efficiency through industry 4.0 technologies (Reischauer, 2018; Coco *et al.*, 2024).

Agriculture, food processing, and all the complementary value chains that populate contemporary food systems were obviously key to the transition of the European economy towards the desired outcomes. It is widely accepted

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that food systems are responsible for a relevant share of negative effects on the environment. The IPCC estimated that 22% of global greenhouse gas emissions come from agriculture, forestry and land use (IPCC, 2023). According to FAO (2024), emissions from agrifood systems from the field to the table increased by 10% in the period 2000-2022. For agrifood systems, as for other highly polluting sectors, an accelerated transition to more sustainable ways of operating is needed to avoid catastrophic outcomes. Again, through virtualization, digitalization, better control of data and thus more efficient decision-making and forecasting, digital technologies were pictured as fundamental enablers of such a change in the sector's situation.

Agrifood systems, then, are victims of the environmental crisis that occupied the economic policy debate for the past five years. The vulnerability of agrifood systems to climate-related disasters is clearly perceived by operators and national and regional governments when facing the aftermath of floods, droughts, and extreme weather conditions, and by public opinion at large when the effects of climate change are manifested in the availability (or lack thereof) of food items and in the fluctuations in their prices (and thus their accessibility).

Public investment in the twin transition agenda followed suit. The European Recovery Plan – Next Generation EU anchored every single line of action to achieving high performances in digitalization and sustainability. Despite the apparent consensus on the direction to be taken, 2024 was also the year in which resistance to green policies and requests for the renegotiation of sustainability targets emerged vigorously. While calls for a radical revision of the targets of the European Green Deal emerged and continue to manifest throughout the European economy in almost every sector, agriculture was symbolically at the center of the political debate that preceded the recent European elections and the subsequent agreement to rethink the sustainability agenda.

Farmers and their tractors occupied squares, streets and cities at the beginning of 2024; the discontent has been creeping visibly into the agricultural sectors of the Netherlands, Ireland, France, Italy and almost all of Europe since 2021 and in the wake of the European elections.

While the analysis of the discontent and its implications is not the topic of this special issue, nor of the conference it summarizes, the protests play a relevant signaling function: assumptions and incentives continue to collide with obstacles to the adoption of more modern strategies and practices that could be conducive to better economic, social and environmental performances. Research in the social sciences, and especially in those that focus on agrifood systems, is called upon to provide a much-needed contribution to understanding the entity of such obstacles, their origins and determinants, and, above all, the ways to remove them, in order to advance

theoretical elaboration and, most of all, the contribution of research to solving pressing problems that require a collective mobilization and the responsibility to effectively connect theory and practice.

The scientific committee of the SIEA 2023 Conference, held at the Ca' Foscari University of Venice, was guided by the desire to direct the scientific debate on the twin transition towards the elaboration of a sound and rigorous body of knowledge that could be rapidly deployed at the service of society, the economy and the environment.

We received several submissions and accepted seven papers covering a wide range of issues underlying the realization of twin transition practices in the agrifood sector. This special issue is characterized by a remarkable interdisciplinary effort that underlines the relevance and timeliness of this topic for members of the SIEA community.

During the two days of the conference, the research community coalesced by SIEA shed light on the numerous areas where either constraints and bottlenecks to the twin transition might emerge, or where solutions become viable and allow to imagine their replication at scale. Often, constraints and resistance to transitions depend on the structure of value chains and on the existence of imbalances in the power some actors can leverage on, as is often the case for small and micro agricultural firms, which have to cope with a chronic shortage of resources and a misalignment with the pressures coming from retail operators or other actors. In many other cases, the delay in adopting technologies and approaches is not due to a lack of resources, but to a mismatch between the logics wired in the technologies and solutions, and those by which businesses operate. That is, digital technologies are often developed in and for large organisations and their deployment in small firms requires intense labor in "scaling down" the solutions. Moreover, sometimes technologies and approaches are born in sectors other than agriculture and food and require modifications and adaptations to be accepted. Thus, delays may be due to technical and operational mismatches rather than resource constraints or cultural issues. In addition, retail channels and final consumers can be the source of obstacles and constraints: resistance is often documented downstream in a variety of supply chains and can play a role in creating disincentives for operators.

The special issue launched during the conference was brought to its present form thanks to the work of authors, reviewers, and the editorial team. The final result effectively expresses how the demand for relevant and critical knowledge met a research community willing to actively participate in the process of increasing the sustainability and competitiveness of agrifood systems. Moreover, the final selection of the papers reflects the composite set of "entry points" and critical junctures we just mentioned and allows

to appreciate the existence of a variety of approaches to shed light on the complex problems connected to the twin transition.

In the opening research note, Gianluca Brunori tackles the interactions between digitalization and sustainability delving well below the surface of political claims and documenting how the interaction between the «physical world and the infosphere» could be the harbinger of advances in making agrifood systems more sustainable. The contribution is valuable in that it draws the attention of readers, scholars and policymakers to the systemic nature of the transition we are facing: the more sustainability problems are framed in a systems perspective, the more digital technologies will unleash their potential in connecting ends to ends (e.g. final consumers and producers, complementors and suppliers, firms and institutions) and providing feedbacks and feedforwards that allow for more effective and timely governance of food systems.

The work of Ingrassia, Bellia, Disclafani, Chinnici and Chironi addresses another relevant issue in transitions, namely consumer acceptance of novelty. Their work can be attributed to the larger debate on circular solutions to the sustainability crisis and considers eco-packaging as a potential avenue to solve pressing environmental issues in a variety of *supply chains*. The merit of the paper lies in clearly highlighting the determinants of consumer preferences, the way such novelties are framed, and the roots of resistance and skepticism, thus expanding our theoretical understanding of consumer behavior and informing policymakers to increase their effectiveness in promoting circular behaviors. Digital tools and channels are seen as crucial levers for synchronizing the transition of firms and the evolution of customers' behavior. In particular, e-commerce is seen as conducive to novel business models in which small producers of niche products or specialty items can avoid the pressures on margins made by large physical retailers. Online marketing and advertising are often seen as a more accessible tools to communicate and interact with consumers so to reinforce their propensity to buy certain items and "convert" their intentions into actual behaviors. Of course, when it comes to sustainability, the issue becomes central: while a number of consumers declare they are inclined to buy sustainable products in principle, they often do not do so due to a variety of constraints.

Palmieri, Covino and Boccia consider the relative importance of some factors over others in influencing consumers' willingness to buy organic food online, and the plausible interactions between green marketing campaigns and the revealed purchase behavior of organic food consumers on e-commerce websites.

Organic producers are the focus of another paper that addresses a different facet of the twin transition: the use of digital technologies to support decision-making in agrifood firms. Immersed as they are in ever-increasing

streams of data, and generating multiple data points through their operations, companies could become more efficient and sustainable by treating this data as a relevant input to sound decisions. Decision support systems are a family of technologies that will play a pivotal role in addressing the cognitive dimension underlying the transition of food systems to more sustainable states; however, their fit with the logics, resources, and processes of small-scale agricultural enterprises may be problematic and require adaptation efforts. The paper by Righi and Viganò deals with the factors influencing the motivations of organic farmers to equip their farms with such systems, revealing a wide range of intervention areas for research and policymaking.

Digital technologies then make assessing and measuring the environmental footprint of operations feasible and scaled adequately to fit the logic of small farms, which account for the vast majority of firms in many agrifood systems worldwide. Lifecycle assessment (LCA) allows firms to evaluate the performance of alternative solutions and processes in order to reconcile efficiency and sustainability, and to generate data that lend substance to claims of harm reduction and mitigation, or simply transition to sustainable strategies and processes. The paper by Pergola investigates the interaction between digital technologies and LCA methods and links it to the intention to use digital technologies among small farms in Southern Italy.

Benedetto and Forleo explored the potential of blockchain technology and other digital tools to enable the sustainable transition of the Vermentino di Gallura PDO (Protected Designation of Origin) Quality Agri-Food District in the Sardinia region. The authors shed light on the opportunities and criticalities underlying the implementation of the twin transition across the very different actors constituting the Vermentino PDO district, who participated in multi-stakeholder meetings. They highlighted the potential of digital tools to support integration within the wine supply chain as well as at the intersection of the wine and tourism value chains.

The paper by Mignani, Ferrara, Tomasi, Moretti and Cavicchi also addresses the need to undertake a twin transition path for the viticulture and wine sector, but from the perspective of Operational Groups (OGs) within the European Partnership for Innovation in Agriculture (EIP-AGRI). They pointed out that the participatory, multi-actor and bottom-up approaches underlying the OGs can be drivers of innovation. OGs can be seen as innovation intermediaries working toward more environmentally sustainable practices and disseminating current innovations that can better orient operators toward a digital and sustainable production system.

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The transition of food systems towards sustainability: The role of digitalization

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Abstract

The paper explores the complex relationship between digital and ecological transitions, particularly focusing on their interdependence and potential to drive sustainability. It acknowledges that digitalization, while offering numerous benefits such as efficiency and scalability, does not inherently lead to sustainability. The text highlights three critical aspects influencing digitalization's impact: the design of digital solutions, access to these solutions, and the complexity of systems integrating digital technologies. Challenges such as the risk of exacerbating inequalities and the necessity for comprehensive governance to mitigate negative effects are discussed. The paper also delves into the digital transition within the agri-food sector, emphasizing the contrast between conventional agriculture and agroecological approaches, which prioritize diversity and resilience. It argues that digital tools can support more sustainable and diverse agricultural practices if correctly aligned with ecological principles. Finally, the text calls for targeted innovation policies to ensure that digital transition contributes effectively to ecological goals, suggesting that a thoughtful and directed approach is essential for realizing the transformative potential of digitalization in fostering a sustainable future.

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Introduction

How, and to what extent, can the digital transition be a driver of the ecological transition? The question is relevant, as it cannot be taken for granted that digitalization generates sustainability. There is evidence that in many circumstances digitalization has accelerated the privatization of benefits and socialization of costs (Rolandi *et al.*, 2021). The recent debate over Artificial Intelligence (Novelli *et al.*, 2023) shows that the risks related to unregulated digitalization can be high.

To address this question, we need to consider that the impact of digitalization depends on three aspects: a) the design of the digitalized solutions; b) the access to digitalized solutions; c) the complexity of the systems wherein digital technologies are embedded (Rijswijk *et al.*, 2021). Even when the design of digital solutions links explicitly the technology to sustainability objectives (for example, reduction of inputs per unit of output) (Büyüközkan *et al.*, 2024), digitalization might fail to challenge the existing models, and we know that the room for improvement of agricultural conventional models is little (Webbs *et al.*, 2020). Access entitlements select who can capture the benefits of technology uptake: for example, if technologies are designed for large-scale farms, they will penalize small farmers, generating selection pressure (Carolan, 2018). Connectivity and human capital are other critical access entitlements (Scheerder *et al.*, 2017). Given the high interdependence of technologies and competencies involved in digital solutions, system complexity can be high, so system feedback and poor governance can generate negative impacts. One example concerns the lack of technology interoperability, which generates high transaction costs (Kerber and Schweitzer, 2017). Rebound effects, occurring when improvements at one level of complexity trigger negative impact at a higher level, are another example of system complexity: water efficiency at the farm level can increase consumption at the basin level because the attractiveness of the technology encourages many non-irrigated farms to adopt irrigation (Berbel, & Mateos, 2014).

The mission of innovation policies in the new context is to create the conditions for a twin transition (Brunori, 2022), that is, a sustainability transition accompanied, and fostered, by a digital transition. In this paper, which elaborates on the invited speech at the SIEA conference *Digital and environmental innovation for the sustainability of business models in the agri-food sector*, Venice 2024, I aim at contributing to lay down a narrative useful to link digitalization to transition in agriculture and rural areas.

1. The digital transition

In the Green Deal, the digital transition is considered instrumental to the ecological transition. To understand the importance of the digital transition, and the new wave of system innovation that it can generate, we must consider that digitalization affects the human capacity to generate representations of the physical world (Floridi, 2014). Representations are generated by encoding expressions of the physical world into data (signs and symbols that represent the diversity of the world), frames (rules that allow the interpretation of information in given contexts), and concepts (abstract entities that identify regularities within the world diversity). Models assemble data, frames, and concepts into patterns to represent complex entities (May and Perry, 2017). The network of data, frames, concepts, and models, produced and stored in individuals' minds and various supports, gives rise to what we call, after Floridi (2014), the infosphere.

Digitalization has established itself as the driving force for a significant quantum leap in the formation and development of the infosphere. This process has radically transformed the way we interact with information, making it possible to encode physical signals into numbers. Once transformed into digital form, data can be easily stored, replicated, transmitted, and integrated, far exceeding the capabilities of traditional methods of information management. The speed, efficiency, and scalability offered by digital technologies have made data management extremely agile and powerful (Vial, 2021).

Digitalization facilitates a dynamic interaction between the physical world and the infosphere, mediated by technologies capable of performing two crucial functions: sensing and actuation. Sensing makes it possible to capture signals from the physical world and turn them into digital data. Actuation, on the other hand, is about the ability to translate information into action in the physical world (Alur, 2015).

Within the infosphere, digitalization has generated a specific subsystem, the digital sphere. This sphere is constantly expanding, fueled both by data generated through observation and interaction with the physical world and by the integration and processing of pre-existing data. Within the digital sphere, data are stored, transported, combined, and elaborated. The outputs of these processes are new data, which can be turned into new information. Digital technologies can create imaginary worlds and transform them into real sources of experience for humans, as in the case of "virtual reality". With generative AI, the infosphere can be further expanded without human intervention. The digital sphere thus becomes a dynamic environment of rapidly evolving information, a self-sustaining and exponentially growing ecosystem of knowledge. Given that the digital sphere is a key resource

for human activities, the regulation of its access and its use is of primary importance for sustainable and equitable development.

2. A system approach to digitalization

The interaction between the infosphere and the physical sphere cannot be fully understood with reductionist approaches, which isolate a few variables and study them separately. Indeed, the potential of interaction between entities in the digital sphere is much higher than in an analogic world. Digitalization allows "presence without localization" (Floridi, 2014) so that actors very far from each other can communicate as if they were physically in the same place. Digitalization allows the dematerialization of all the objects that have information content: news, books, music, visual art, money, cables, tickets, invoices, games, etc. Dematerialization/rematerialization processes reconfigure economic activities and the mix between goods and services: in mobility, car sharing can replace the ownership of cars, in computing, local physical computing and storage units are replaced by 'virtual machines' accessible via the cloud (Estagnasié *et al.*, 2022).

As the economy is increasingly moving from the analogical to the digital sphere, there are important implications for the understanding of the economy. In the digital sphere, given the capacity of digital technologies to foster interaction, business success is linked to the capacity of firms to harness 'network economies', which are exponentially correlated to the number of members of the network a company belongs. The 'platform economy' has replaced the 'pipeline economy' (Parker *et al.*, 2016) because platforms, which are governed spaces within the digital sphere, can generate and regulate 'digital ecosystems' (Barykin *et al.*, 2020). The ecosystem metaphor highlights the role of cooperation, coevolution (also concerning changes in the environment), the evolving nature of organizational boundaries, and the functional differentiation within networks.

System approaches help to understand the direct and indirect, short-term and long-term, individual, and collective impact of digital technologies on complex environments. Without claiming to build a complete synthesis of system theories, I have considered in Figure 1 the key concepts of system approaches and provided only a few key references for system approaches.

To put it in simple terms, a system can be defined as a set of elements organized into activities to perform a function (Meadows, 2008)[1]. When systems are studied in the social realm, components are named actors, to

1. The literal definition of Donella Meadows A system is an interconnected set of elements that is coherently organized in a way that achieves something (Meadows, 2008).

underlie that components are endowed with agency, that is capacity to choose different courses of action.

In order to perform their functions, actors require the necessary resources, and the activities within a system are subject to the constraints of established rules. Rules regulate the utilization of resources, the categorization of actors who are permitted to engage in the activities, the interactions between them, and so forth. Systems can be open or closed. Open systems, the ones we consider, interact with their environment and adapt to it. A system environment provides rules, resources, constraints, and opportunities for system components: changes in the system environment are drivers of system change. Adaptation to the system environment implies modifying the activities, the actors, the rules, and the resources mobilized to perform system functions.

Rules and resources are generated within the system as well as outside the system. Internal rules and resources are generated through repeated interaction. Routines, customs, and traditions, for example, are 'emerging properties' of system components' interaction. They evolve as an effect of the system's activities and its adaptation to the system's environment.

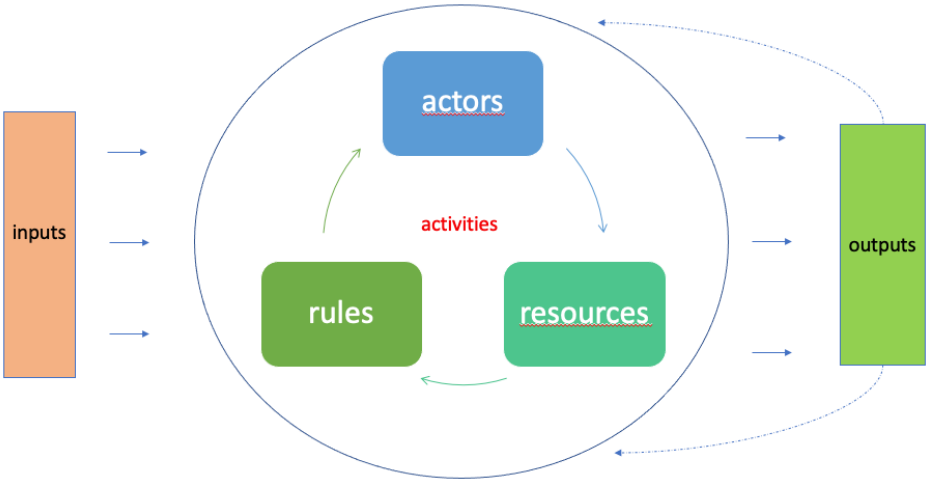
Another set of rules and resources is provided by the system environment: they are factors that cannot be modified by the components of the system.

The activities of a system affect the social, environmental, and economic spheres, and these outcomes are feedback on the activities, depending on actors' expectations and effects on other subsystems.

Systems can be characterized by components of different nature, such as social, ecological, and technological components. This implies that, for example, technological components are affected and affect social interaction. When considering and in this case, they can be analyzed, according to the purpose of the analysis, as socio-technical or socio-ecological systems.

Digital systems are based on the cyber-physical paradigm (Alur, 2015): they simulate the real world with models, feed these models through data taken from the physical world, and change the physical world based on the instructions that the model provides. For example, digital irrigation systems are based on representations of the relevant environment for irrigation: soil, plant, temperature, and water. The more accurate these representations are, the more effective these systems will be. Accuracy is related to the variety, the granularity, and the frequency of gathered data, as models are based on statistical inference. Sensors gather data from the components of the physical environment and send data to control units and storage units. Communication devices, communication protocols, storage, and software to elaborate the data, actuators use the input data to predict relevant variables (for example, water stress) and provide practical instructions (for example, when and how much to irrigate). In other words, digital technologies are 'assemblages', dynamic entities that tend to co-evolve.

Figure 1 - Scheme representing a system



When digital technologies are applied to human activities, they affect the social sphere, so that their assessment can be made considering the interaction between digital and social components as socio-technical systems. To be more precise, we can speak of socio-cyber-physical systems, the elements of which can belong to the social, physical, and digital spheres (Rijswijk *et al.*, 2021). The relevance of using the socio-cyber-physical concept is that it helps to assess to what extent any change to one sphere will generate change in the others. Likewise, rules and resources that characterize one sphere can affect the others.

3. Digitalization in the agri-food sector

The variety of tasks that digital technologies can perform depends on how different digital functions are assembled. To understand and evaluate the potential of digital transformation with a system approach, we must start by identifying and mapping the activities that digital applications perform. Among these activities, we can consider data gathering, storage and search, monitoring, classification, forecasting, coordination, content generation, automation, and communication.

Monitoring is the systematic collection of information to assess the state of the processes and their change. Digital monitoring technologies such as satellite imagery, drones, and IoT sensors collect biophysical, image, and

movement data. At the processing stage, sensors monitor critical parameters during processing and storage. In the distribution phase, digital technologies track the location and condition of food items in real time. At the consumer level, applications for mobile phones provide information on the nutritional content of food products helping them to adapt their diets to desired targets. Digital technologies can also monitor the disposal and recycling of food waste.

Classification is the detection of differences between items based on multiple parameters. In the production phase, it can help to analyze data related to soil, crop types, pests, products, and customers. In the food processing phase, classification technologies can recognize the origin and quality of raw materials. In distribution, they help in managing inventory and optimizing logistics. Digital platforms classify consumer preferences and dietary needs, personalizing food recommendations and nutritional advice. In waste management, digital classification systems identify and sort organic waste for composting, recycling, or bioenergy production. By distinguishing between different types of food waste, these technologies facilitate efficient processing.

Matching is the association of items with complementary features. For example, matching can speed up supply and demand by identifying the right customer for a given seller and can identify alternatives for the same functions, speeding up product innovation. Charaka, an AI software developed by a US startup, has a database of around 1,000 plants and their properties and provides recommendations for replacing preservatives and chemical additives with 100% plant-based ingredients[2].

Prediction is the capacity to anticipate future events. Through the analysis of historical data and the development of simulation models that replicate the functioning of existing systems ("digital twins"), prediction systems can provide farmers with an estimation of crop yields, water and fertilizer needs, the occurrence of pest attacks, and machinery failures. Prediction can also regard inventory as well as supply chain disruptions (Purcell, Neubauer, 2023).

Coordination among the various components of the food system, including producers, suppliers, distributors, retailers, and consumers can be obtained through tools that, through data sharing and communication, allow to optimize operations in the space and in the time adjusting to others' activities in real-time.

Automation allows the replacement of humans in tasks that are repetitive, labor-intensive, or hazardous. Robotics in agriculture assists humans in

2. https://proteindirectory.com/company/the-live-green-co/.

planting, weeding, pest management, water management, and harvesting. In food processing, automated systems ensure consistent product quality and safety. Automation allows a dramatic reduction of administrative tasks: for example, ordering, invoicing, and payments. Digitalization of traceability allows seamless exchange of information between business partners and reduces sensibly the risk of fraud and the time to retrieve information about a product.

Communication technologies enhance the flow of information between components of a system. Within the food system, they enable stakeholders to stay informed, make timely decisions, and respond to market and environmental changes. Mobile applications, social media, and online platforms facilitate direct communication between farmers and consumers, promoting local food networks and enabling consumers to make informed choices about their food. In addition, these technologies play a crucial role in disseminating agricultural knowledge, weather forecasts, and market trends to rural communities.

The activities that digital technologies perform are combined into 'digital solutions', assemblages of a multiplicity of digital technologies to address socio-technical problems through the digitalization of analogic operations. For example, 'virtual fence' technologies are composed of collars worn by the livestock that get from the satellite the information about its position and send it to a control unit, satellites with which the collar communicates, wireless communication protocols, software for data management, cloud for data storage, actuators that provide an electric shock whenever the animal trespasses a given boundary (Muminov *et al.*, 2019). Often these solutions are connected to platforms that provide data-based services and collect users' data to create new solutions and new services. The performance of digital solutions depends on the capacity of its components to communicate seamlessly with each other and to respond to the specificities of the given context.

4. Digital Innovation and transition

Transition can be defined as the process of transformation of socio-ecological systems from their initial configuration to a new one. Transformation implies a radical change of activities, actors, and artifacts in the system. The food system is considered one of the key areas of the ecological transition (Geels *et al.*, 2019).

As any system is endowed with mechanisms that provide its stability, we can expect that the components of an established system will resist transformation, and more so as the transformation goals are more radical. In

the multi-level literature (Geels, 2005), the tension between transformation and stability is explained through the interaction between the 'regime', that is, the system of rules that guarantee the stability of the system, and the 'niches', local subsystems which operate with rules that deviate from those of the regime. The rules that constitute the regimes are of several types: they can be legal (that tell people what is allowed and what is sanctioned), ethical (rules that regulate what is considered right/wrong), and technical (rules that establish how to make things). We can thus speak of economic regimes, technical regimes, and so on. Among the rules, cognitive rules are particularly important for innovation (Ingram, 2018). They establish which information is relevant and which is not, what are the appropriate interpretation frames, and, in the end, what is considered true and what is not. Cognitive rules are created and maintained by specific organizations that provide research, education, advisory services, training, and inspire technical rules.

Challenging the existing regimes can be hard, as regimes sustain strong coalitions of interests. Conservation forces can also inhabit organizations the mission of which is innovation, such as universities and research centers. Back in 1962, Kuhn demonstrated how academia can be a conservative institution, defending 'normal' science from scientific revolutions. In 1982 Dosi noticed that innovation can proceed along pathways fed by knowledge paradigms, in which enterprises are locked in by past investments in knowledge and infrastructures (Dosi, 1982). Understanding that knowledge-related institutions can be sources of conservation implies that public policies need to work to address the self-conservation defenses of the regime and manage the birth, proliferation, and scaling up of the niches and their successful incorporation into the regime. Innovation policies are key to this process.

The dynamics of socio-technical systems imply that innovation niches challenge the regime by experimenting with new socio-technical configurations through rule-breaking practices. Existing routines are put into discussion, and the interests of the actors are affected. The regime can react by defending itself from the innovation. In the cognitive realm, the effectiveness and even the scientific validity of alternative practices are questioned in the public sphere and the scientific sphere. In the legal realm, the sanctions of rule breakers are tightened and new conservative rules are introduced.

In some cases, niches are so disruptive that they scale up and replace the existing regime, as has happened in the field of entertainment or the field of tourism (Buhalis, 2019). To avoid this, the regime can try to adapt to the new situation by relaxing its rules and incorporating successful niches. The regime can be changed also with a top-down intervention: in the field

of mobility, hardly the regime based on combustion engines could shift to an electric car-based regime without acting on infrastructures, incentives, technical standards, and regulations.

With the challenge of climate change, public policies are encouraged to recognize that 'business as usual' is no option: in this case, 'normal' innovation policies don't work, and transformative innovation policies are needed. Transformative innovation aims at changing current socio-technical regimes (Novy *et al*., 2022). In this regard, it is radically different from 'normal' innovation, which aims at stabilizing the existing regime by improving its efficiency and effectiveness. Transformative innovation mobilizes the agents of transformation, proposes new paradigms, builds new infrastructures, and leverages the dynamics of the interaction between niches and regimes. Transformative innovation is both creative and destructive, as it removes the obstacles to change while building new configurations.

Innovation, in this regard, is not only technological but also social and institutional. Without a synergy between these three types of innovation, transition can be much more difficult. Institutional innovation is needed to change the rules of the regime embedded into administrations, business associations, and policy networks (Olsson and Galaz, 2012). Social innovation is necessary to let different mindsets emerge from society, let new business goals and operating principles consolidate, let new actors find a space in the institutional and market networks, and create new coalitions and partnerships (Avelino *et al*., 2017).

Transformative innovation can be pursued through encouraging bottom-up initiatives. It needs to rely on the agency of actors, on their capacity to build networks and coalitions for change, and on the capacity to motivate other actors to innovate (Molas-Gallart *et al*., 2021). Even when it is based on top-down intervention, transformative change cannot be designed once and for all, but needs to emerge from trial, error, and learning.

5. Digitalization and the agroecological transition

In the agri-food sector the sustainability transition, envisaged by the Agenda 2030 and underpinned by the climate-related goals that the international community has set, takes the shape of an agro-ecological transition. According to FAO, agroecology is a framework based on ten principles that address social, economic, and ecological components[3]. The agroecological transition implies a shift from homogeneity to diversity,

3. www.fao.org/agroecology/overview/overview10elements/en/.

from linear to circular economies, from the primacy of market laws to the primacy of social and human values, from top-down innovation to co-creation and knowledge sharing. The agroecology transition implies a system transformation that affects agricultural practices, market configurations, power relations, and knowledge production processes. About practices, it advocates nature-based solutions and respect for traditional knowledge.

The Green Deal and the Farm to Fork strategy mention agroecology as one of the drivers of the necessary system transformation, and many of its principles are already embodied in European policies. The CAP has introduced agroecology principles into its measures such as 'ecoschemes' and 'agri-climate payments'. According to its proposers, agroecology is at the same time a science, a set of practices, and a social movement (Wezel *et al*., 2009), and this multidimensionality makes it fit to address the system dynamics that policies can generate. It reminds us that transition implies a change of mindsets, and this change can be achieved through action in the cultural field.

When considering the intersection between digital transition and ecological transition, the real question is not just whether digitalization is transformative, but how and to what end it drives transformation. Digitalization, for example, plays out differently when applied to conventional agriculture versus agroecological systems.

Agriculture is part of a regime established originally in Western countries and then exported globally, that links together legal, ethical, technical, and cognitive rules for production and consumption. The agricultural regime known as the 'green revolution' (Kiers *et al*., 2008) defines the activities, the actors, the resources, and the artifacts related to agriculture, making it easier to adopt conventional practices rather than alternative practices. Conventional agriculture has largely been about achieving uniformity to increase efficiency and productivity (Misra and Gosh, 2024). This approach relies on creating homogenous environments where high yields are pursued through the reduction of variability in crop performance – known as reducing the yield gap. Digital technologies in this realm, including precision agriculture tools like GPS-guided tractors, drones, and sensor networks, aim to optimize this homogenization. They provide farmers with the means to apply inputs (like water, fertilizers, and pesticides) precisely where and when they are needed, minimizing waste and maximizing yield. However, this precision can lead to a simplification of agricultural systems. The push for uniform high-yield crops can lock in agricultural systems into monocultures, reducing biodiversity and potentially increasing vulnerability to pests, diseases, and changing climate conditions. In this sense, digital technologies, while transformative in terms of efficiency, can also entrench a system that is arguably less resilient and less sustainable in the long term.

Agroecological agriculture takes a contrasting approach. Here, performance is tied to diversity – the idea that a variety of plants, animals, and microorganisms can work together to create a more resilient and sustainable system (Mouratiadou *et al*., 2024). Diversity in agroecology is not just tolerated but celebrated and encouraged, as it can lead to systems that are more robust against shocks and stresses. In this context, rather than harnessing diversity to homogenize, they should harness diversity to diversify. Digital solutions in agroecology might include decision-support systems that help farmers understand and enhance the complex interactions in their fields, or mapping tools that allow for more diverse planting that can mimic natural ecosystems (Bellon Maurel, 2022).

Such technologies encourage the management of complexity rather than simplification. They support polycultures, intercropping, and other practices that build soil health, conserve water, and enhance biodiversity (Mouratiadou *et al*., 2024). Digital solutions in agroecology can guide farmers in managing these complex systems in a way that aligns with natural processes and cycles, potentially leading to systems that are more sustainable and just as productive, if not more so, than conventional systems.

Facing the imperative of 'food system transformation', digitalization can be definitively a driver for agroecological transformation. Business disintermediation, digital ecosystems, and data availability on the performance of socio-technical systems are powerful drivers of change, able to encourage the actors to change practices to build new networks and to look for innovative innovation pathways.

6. Principles for a transformative digitalization

Digitalization has rapidly reshaped the landscape of our societies and economies. However, to assume that market forces alone can guide this revolution is naive and potentially perilous. Access to data, new market concentrations, power structures, and dependencies, changing knowledge requirements for farmers, and information asymmetries may cause potentially negative effects on the social fabric and even on food security (Zscheischler, 2022). Digitalization can also be a strong force of conservation when regime rules are encoded into opaque algorithms (Dourish, 2016).

The true sustainability potential of digitalization can only be unleashed when it is directed with intention and consideration for its wide-ranging impacts. The market is driven by profit, and without guidance, digitalization could exacerbate inequalities, overlook important societal needs, and fail to secure critical data and infrastructure. Therefore, for digitalization to be transformative it requires thoughtful policy directionality and actors' responsibility.

Directionality implies a clear set of priorities (Duncan *et al.*, 2022). As we have seen, innovation per se does not create sustainable outcomes and less so market-driven innovation. On the contrary, innovation should be able to shape markets to generate practices coherent with sustainability, and the public sector should play an entrepreneurial role (Mazzucato, 2011). However, directionality without participation would risk falling into top-down approaches, generating resistance and rejection within society.

Transformative innovation entails a certain degree of responsibility on the part of the actors involved in the innovation process.

Responsibility implies procedures that encourage researchers and research organizations to look beyond the specific field where innovation operates and to look to the broader societal impact that research and innovation could have. Responsibility implies the availability of researchers and research organizations to involve stakeholders in the design and implementation of research, the capacity to anticipate the impact of research at the system level, the attitude to reflect on past results of innovation and to act accordingly, and commitment to pursue a common endeavor aimed at the public good (Owen *et al.*, 2013).

Moreover, transformative research and innovation should investigate the role of rules, infrastructures, skills, coordination, and leadership. Clear regulations are needed to ensure data privacy, benefit sharing of the value of data, data security, and ethical standards. This includes intellectual property rights, user protection laws, and standards for interoperability. Robust digital infrastructures are the foundation of digitalization, including not only connectivity but also platforms that can support digital ecosystems. The public sector and cooperatives will have an important role in this regard.

So far, digitalization strategies have been technology-centered, while food systems and rural areas need coordination of instruments and resources around well-defined problems and priorities. Leadership, at all levels, is needed to navigate the complex landscape of digitalization. Successful niches presuppose visionary leaders, able to identify opportunities, anticipate challenges, and mobilize social resources around ambitious objectives. Policies should be able to create the environment for these individual and institutional leaders and provide them with the necessary resources.

Digitalization strategies should be flexible enough to adapt to these diverse contexts, as different regions and sectors have unique needs and challenges: local communities should be involved in the definition of digitalization strategies. Experimental policy approaches should be encouraged, allowing for trial and error to find the most effective ways to integrate digital technologies into socio-technical systems to provide sustainability. Policy assessment is crucial to ensure they are delivering desired outcomes and to learn from bottom-up initiatives.

The path to digitalization is complex and multi-faceted, demanding a well-thought-out approach that is attuned to the needs and realities of different stakeholders. It is a process that calls for regulation, infrastructure development, skill enhancement, coordination among different actors, and insightful leadership. It also requires an adaptive mindset that values diversity, experimentation, and evaluation to integrate effectively with market forces. Only with a directed and adaptive approach can digitalization serve as a transformative force for good, fostering inclusive growth, innovation, and prosperity in the 21st century.

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Eco-packaging and fresh food products. Analysis of demand and consumer behavior in Italy

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Abstract

This paper presents the first results of marketing studies for the positioning of a new sustainable biobased plastic packaging for fresh food, as part of the research project "CItrus waste ReciCLing for added valuE products – CIRCLE" for improving the sustainability of the citrus processing production chain through the valorization of processing waste. The present study, conducted on Italian consumers, contributes to the flow of literature on consumer demand of sustainable food packaging, highlighting the preferences, concerns, and skepticism, the factors that explain behaviors, and the role of information on their choices. Findings may be of interest for firms and Public Institutions to promote circularity behaviors among citizens and to consolidate their ethical motivations through correct information and experience.

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Introduction

Demand for plastics is increasing worldwide, and the European Commission predicts that global production will double in the next 20 years (European Commission, 2018). About half of global demand for plastics is for packaging, but only 14% of plastic-based packaging is recycled. Huge amounts end up in landfills or are incinerated (European Commission, 2018; Jambeck *et al*., 2015). Plastic packaging not only consumes limited fossil resources, but also contributes to large amounts of waste that damage marine and freshwater ecosystems (Macht *et al*., 2023).

Against this backdrop, on the one hand, companies in the food industry have for years been working to reduce the amount of plastic packaging used and investing in research to find solutions that impact the environment as little as possible (Ada *et al*., 2023a).

Concomitantly, in the very last few years, consumer interest in environmentally sustainable packaging has grown, including in relation to fresh food products, due to growing concerns about the effects of global pollution (Wandosell *et al*., 2021). Research is geared toward finding materials for fresh produce packaging that can ensure food preservation. The choice of sustainable and biodegradable food-saving wrappers is growing from wax-weaved cotton sheets to bioplastics derived from corn or fish waste (Ada *et al*., 2023b). Nevertheless, studies on bio-based packaging as an alternative as well as on consumers' purchase intention for different bio-based food packaging alternatives are scarce. Especially the comparison of different food product categories is lacking – yet highly recommended (Herrmann *et al*., 2022).

The Italian sector of disposable biodegradable plastics is on the move. In general, there is not enough biodegradable plastic on the market for rigid products because demand is many times greater than European supply. Instead, there is strong availability of soft bioplastics, the kind used in shopping bags (Assobioplastiche, 2023).

Italians are increasingly aware of issues related to climate change (European Investment Bank, 2021). Due to the high cost of living that has continued to erode the purchasing power of Italian households in recent years, with impacts in food preferences also, the citizen's ethical environmental choices could be influenced by the actual availability and possibility of paying a higher price for food products with environmentally sustainable packaging. Nevertheless, eco-friendly packaging is absolutely a crucial aspect to make a food product sustainable (Nomisma, 2024).

Some recent studies explored consumer perceptions and purchase intentions for different alternatives of sustainable packaging and bioplastics (Herbes *et al*., 2018; Taufik *et al*., 2020; Wensing *et al*., 2020). These studies

conclude that bioplastics are perceived positively by consumers mainly due to their perceived eco-friendliness. Moreover, studies to date highlight that consumers infer the sustainability and quality of a food product from the packaging material (Herrmann *et al*., 2022; Liem *et al*., 2022; Magnier *et al*., 2016). In particular, regarding organic fruit and vegetables, it has been shown that unpackaged products are preferred to packaged ones (Herrmann et al, 2022; Van Herpen *et al*., 2016).

A study comparing the perception of different plastic packaging solutions for fruit juice bottles, i.e. recyclable, recycled and compostable plastic (Testa *et al*., 2021), found that consumers are not able to evaluate one solution as superior to the others. With regard to recyclability, there is evidence that reusable packaging for online meal kits is perceived positively by consumers (Yoon *et al*., 2022).

Many studies examined the sphere of the consumer's behavior and factors that may influence purchasing and recycling behaviors by consumers with respect to sustainable packaging (Martinho *et al*., 2015; Boz *et al*., 2020; Rusyani *et al*., 2021).

Consumers' attitude to choose sustainable food packaging are shaped by various variables (Yin *et al*., 2022), including premium price and their familiarity with it (Patel *et al*., 2020). Herrmann *et al.* (2022) in a recent study highlighted found a negative willingness to pay for grapes packaged in bioplastic packaging. Nevertheless, there are very few studies in Italy on sustainable packaging as an alternative for consumers as well as on consumers' purchase intentions and motivations to choose sustainable packaging for different products. In particular, some authors (Herrmann *et al*., 2022) highly recommended further studies on the comparison between different product categories. Moreover, so far, studies on communication of the attributes of environmentally friendly packaging are limited (Dörnyei *et al*., 2022).

Against this background, aiming to fill the actual gap in the literature, the object of this paper is to investigate the Italian consumers' demand and behavior with regard to sustainable packaging tying to discover the motivational factors driving their purchasing choices and the type of information they have.

The present study, conducted on Italian consumers, contributes to the literature stream on consumers' demand and behavior of sustainable food packaging, by answering the following research questions:

R1) What are the characteristics of sustainable packaging that are considered important for consumers and may influence their purchasing choices?

R2) What are the means of information for consumers to know about environmentally sustainable packaging? What are the consumers' characteristics that may provide information? Are there statistical

associations between consumers' characteristics? and may these associations describe their purchase behavior with regard to environmentally sustainable packaging?

R3) What factors (vectors of variables) may influence purchase intentions and behaviors?

R4) What is the ideal surcharge consumers are willing to pay for some food products with an environmentally sustainable packaging?

R5) What dimensions of communication are most effective in conveying correct information? Who is responsible for conveying information to consumers to build awareness and a sense of responsibility toward environmental sustainability?

In this paper, we present the information gathered from the first step of marketing studies for positioning of a new sustainable bio-based plastics packaging for fresh foods, as part of the research project "CItrus waste RecyCLing for added valuE products - CIRCLE". This project aimed to improve the sustainability of the citrus processing production chain by enhancing the processing waste (mainly composed of peels, pulps and seeds) as a low-cost raw material for production of various high value-added products, namely, bacterial cellulose films, perillyl alcohol, perillaldehyde and perillartin from the biotransformation of limonene, biodegradable pectin-based food packaging films.

1. Background

1.1. *European Union and Italian strategies and regulations on Circular Economy*

The improvement in the quality of life and widespread well-being that have characterized the era in which we live has, in contrast, given rise to an environmental, economic and social emergency, such as that of waste management. This issue is related to the concept of the linear production model implemented until now (the creation of a good, its use and eventually its abandonment), which today is no longer entirely sustainable because resources are not infinite, cheap and low-cost for disposal and, above all, because of the high negative impacts caused on the environment.

Plastic constitutes the third most widely used human material on Earth after steel and concrete. World plastic production has increased from 15 million in 1964 to more than 310 million today (Global Plastics Outlook, 2022). The use of plastic packaging has grown by 40% in the past 20 years, with deleterious effects on the environment (Babaremu *et al.*, 2023). Italy

is the second largest consumer of plastic at the European level; in 2020, almost 6 ml/t of plastic was consumed in our country, equivalent to 98.6 kg per person. It holds the European record for bottled water consumption, with about 221 L/year per capita, while in 1980 it was 47 L/year per capita (Gambino *et al*., 2020). This is mainly due to the change in people's lifestyles and consumption habits (e.g., habitual eating out, demand for take-out food, disposable packaging, etc.), but also because plastics are routinely used for packaging, construction and automotive (Macht *et al*., 2023; Poças *et al*., 2023).

Over the past few years, the EU has developed strategies and issued regulations aimed at discouraging the use of single-use plastics and promoting recycled and renewable, bio-based materials (European Commission, 2018). The last EU legislation on waste management is the Directive of the European Parliament and the EU Council No. 2008/98/EC of November 19, 2008. In 2018, the so-called "Circular Economy Package" (Package) was published in the Official Journal of the European Union. This Package consisted of the following four Directives:

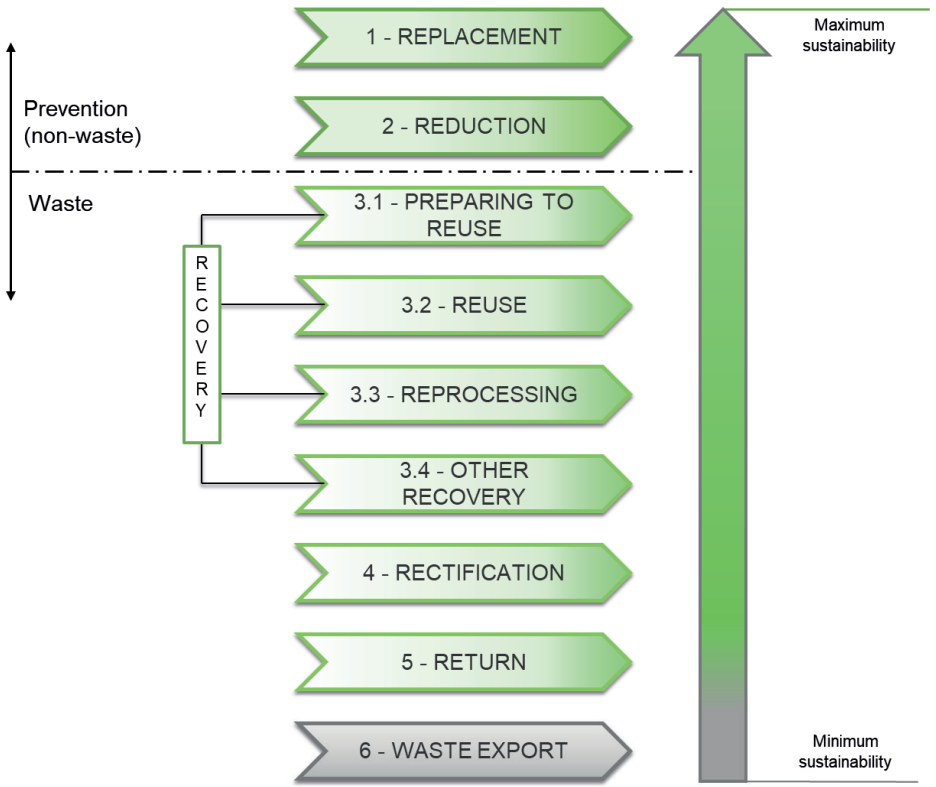
1. Directive 2018/851/EU amending the Waste Framework Directive (2008/98/EC);
2. Directive 2018/850/EU amending the Landfill Directive (1999/31/EC);
3. Directive 2018/852/EU amending the Packaging Directive (94/62/EC);
4. Directive 2018/849/EU amending the End-of-Life Vehicles (2000/53/EC), Batteries and Accumulators (2006/66/EC) and Waste Electrical and Electronic Equipment - WEEE (2012/19/EU) Directives.

With the first Directive 2018/851/EU, all Member States have committed to achieving ambitious goals and recycling targets as specified in Art. 11, i.e., to raise the preparation for reuse and recycling of municipal waste at least to 55% by 2025, to 60% by 2030, to 65% by 2035.

All these EU Directives, which constitute the Circular Economy Package, are developed around the core concept of the "Waste hierarchy". The so-called waste hierarchy defines the order of priority of waste prevention and management policies.

The waste hierarchy was initially shown as an inverted pyramid with prevention and minimization of waste generation at the apex, followed by the options of reuse, recycling, material and energy recovery, and at the last level disposal (Zhang *et al*., 2022). Subsequently, this representation has undergone developments due to the introduction of specifications such as recovery options, rectification, and return (Zhang *et al*., 2022). In this paper we aimed to make a contribution to literature by providing an authors' elaboration of the latest representation of the waste hierarchy from Gharfalkar *et al*. 2015 (Figure 1).

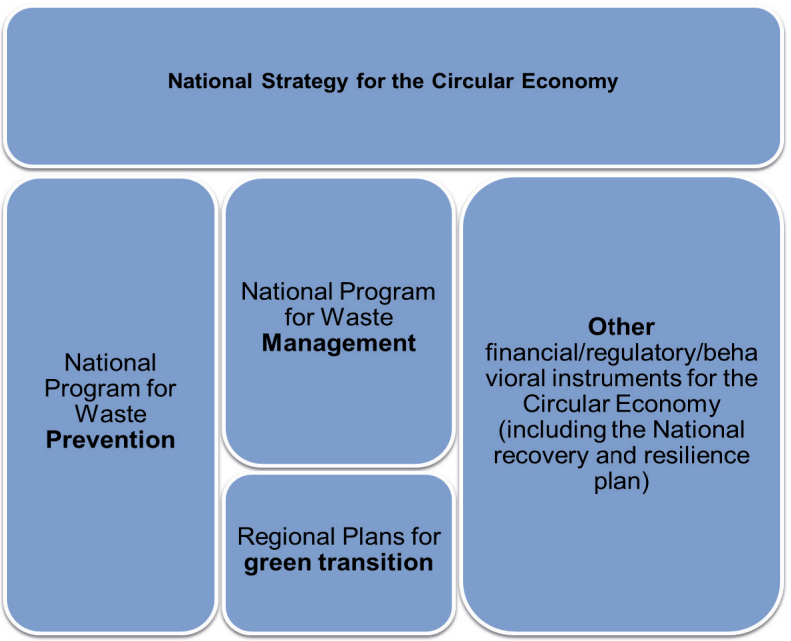
Figure 1 - Authors' elaboration of the Waste hierarchy model from Gharfalkar et al. (2015)



The implementation of the Circular Economy Package in Italy consists of four implementation decrees all issued from 2020, about waste, batteries and accumulators, electrical and electronic equipment, end-of-life vehicles, landfilled waste with a ban on landfilling, starting in 2030, all waste that is suitable for recycling or other forms of recovery. As part of the Italian "National Strategy for the Circular Economy" (Lucchi *et al.*, 2024), the "National Program for Waste Management" is the tool, provided for and defined by Article 198-bis of the Consolidated Environmental Act, to guide the Italian Regions and the Autonomous Provinces in planning waste management. This is one of the tools needed to implement the principles of the circular economy dictated by the European legislation and to meet the objectives of the National Recovery and Resilience Plan. Nevertheless, there are other national Programs and Plans in Italy that finance with public funds

investments to realize the objectives of the National Strategy for the Circular Economy (Figure 2).

Figure 2 - Authors' elaboration of visual representation of public funds (National Programs and Plans) regarding the National Strategy for the Circular Economy



1.2. *Advances in sustainable food packaging*

The transition to a circular economy model is a fundamental change that brings about a shift in production systems, business models, and most importantly, people's consumption styles, with beneficial repercussions for the environment, climate, and human health. Consumers have become more aware of environmental issues, and many companies have recognized the importance of sustainable packaging as a "green marketing" tool to gain a competitive advantage (Ahmad and Thyagaraj, 2015).

Sustainability of packaging must encompass the entire value chain, starting from the sourcing of raw materials and energy required for packaging, to the processing of components, to post-consumption. Among the most significant circular economy goals in the food sector is the use of models to prevent food waste and promote circular management of packaging used to pack and hold food over time.

In food packaging, sustainability is meant for food preservation. Traditional food packages are passive barriers designed to retard the negative effects of the environment on the food product (the role is to be as inert as possible). Several research efforts have focused on enhancing materials barrier properties for sustainable food packaging (Versino *et al*., 2023). In addition to product protection, designing the most effective and sustainable packaging is a complex process involving many sectors of the entire supply chain, including the target market (Springle *et al*., 2022). Is important to consider foods packaging ability to contain, protect, and preserve the product to extend its shelf life and ensure food safety, but also its appropriate size, ease of opening and emptying, and clearly accessible information to avoid food waste. In addition, packaging materials must meet desired mechanical and barrier properties while remaining as light as possible, safe for food, ideally reusable or recyclable, and disposed of with little or no pollution. However, the design of environmentally friendly food packaging is very complex because one must try as much as possible to preserve product quality while meeting marketing and environmental sustainability requirements (Mendes and Pedersen, 2021).

Renewable resources are needed to design eco-friendly bio-based food packaging. The term "biobased" refers to products derived from renewable organic raw materials, such as corn or grass (European Commission, 2018). Two biobased alternatives are promoted: bioplastic and paper-based packaging. These two alternatives have different advantages in terms of environmental friendliness, but it is important that consumers understand the differences, including in terms of quality characteristics.

Bioplastics are considered promising because they have some similar characteristics to petroleum-based plastics and possible benefits, including reduced carbon footprint. However, much confusion exists among consumers about bioplastics, which may be but are not necessarily biodegradable. Consequently, each bioplastic solution has to be evaluated separately (Spierling *et al*., 2018).

The advantages of paper are its recyclability and biodegradability. Paper-based packaging for fresh soft fruits or vegetables is increasingly found in supermarkets. Current research activities focus on the development of innovative paper packaging. Active materials are specifically designed to interact with the food or its environment, changing its composition or characteristics to preserve the organoleptic or sensory characteristics of the product and ensure its quality for long periods of time. Antimicrobials, antioxidants, aroma and gas scavengers, and light blockers are some examples of active substances usually used in food packaging (Amin *et al*., 2022). Nowadays, intelligent packaging materials are aimed to sense changes within the food package and to provide information about the quality of foods inside

(Cheng *et al.*, 2022). Moreover, recent studies (Amin *et al.*, 2022; Chen *et al.,* 2020) highlighted that innovative packaging and intelligent packaging may provide, in real-time, quantitative information on package integrity and food freshness, maturity, or contamination. Finally, smart packaging is derived by the mix of technologies used for intelligent and active packaging (Jamróz *et al.*, 2019). However, food packaging with the sole function of maintaining product freshness may not meet all practical requirements (Tracey *et al.*, 2022). Therefore, it seems essential to know the motivational factors that determine consumers' purchase choices for different eco-friendly packaging alternatives for many products, and their level of information about types of sustainable packaging and circular economy practices. In addition, another element to investigate is the potential willingness to pay a possible premium for these types of food packaging.

2. Materials and methods

2.1. *Study design*

For this study the reference universe was identified with the southern Italian Metropolitan cities, i.e. Catania and Palermo, as having homogeneous characteristics in terms of geographical location, number of inhabitants, population density and level of development for green transition. The sample size was calculated as a function of the error to be accepted, in the hypothesis of a Normal distribution (where p = q = 0.5), and setting Prob = 0.954. Then, with Prob = 0.954, and with an accepted error = 5%, the sample size will be n = 400. The sample was drawn by random method according to the rule $n=n_1+n_2$ i.e. 200 individuals from Catania (n_1) and 200 from Palermo (n_2).

A sample belonging to the age group of 20-60 years was chosen for this study. Stratification was carried out for the following age groups: 20-29 (young Generation Z), 30-39 (Generation Y), 40-49 (Generation XY), 50-60 (Generation X); a relatively homogeneous number of respondents was drawn across generational groups, with a slight priority given to younger people because they may contribute to and be protagonists of economic and social challenges that require a process of change by adopting choices that will impact their future (Ogiemwonyi, 2022).

2.2. *Questionnaire and measurement*

The questionnaires were prepared using Google Forms in order to send them digitally through the use of a link. They were spread through

institutional links, institutional social networks and word of mouth. The questionnaire's structure is divided into three main sections:

1. sociodemographic data (biographical information, educational qualification, subject area of studies, occupation, and average income);
2. prior knowledge of separate collection, reuse and recycling;
3. awareness of the concept of sustainable packaging, purpose of use and characteristics (general/substantial, specific, visual) of the eco-sustainable packaging, ability to recognize a bioplastic food packaging among three of which two consist of plastics;
4. ideal propensity to pay a surcharge for the purchase of some specific food products (i.e. common pasta, 100% Italian extra virgin olive oil PDO, Sicilian red oranges PGI, and cherry tomatoes PGI) with a sustainable packaging.

The questionnaire contained only closed questions. In addition, 5 qualitative variables, each with 10 items were chosen by the authors based on a review of relevant literature (Macht *et al.*, 2023; Norton *et al.*, 2023) on the topic, and a preliminary study of the characteristics of the use and consumption of environmentally sustainable packaging for food products in Italy. These items belong to 5 homogeneous macro topics (variables), each macro group consisted of 10 items (Figure 3):

1. Motivation to choose an eco-sustainable packaging – named AIM, on the topic (according to personal judgment) of the usefulness or non-usefulness of adopting correct behaviors aimed at environmental protection;
2. Characteristics of sustainable packaging – named CAR_SUST_PKG, on what should be (according to personal judgment) the main characteristics of an environmentally sustainable packaging;
3. Characteristics of eco-packaging for food products – named CAR_SUST_FOODPKG, on the importance (according to personal judgment) of the characteristics of a packaging for a food product;
4. Differentiation among packaging for different types of products – named DIFF_PRODS, on the importance (according to personal judgment) of the eco-sustainability of the packaging (use of environmentally friendly materials) for each of the following food products: Fresh food products, Long-life food products at room temperature, Frozen/frozen food products, Take-out food, Beverages Food in liquid form (e.g. oil, vinegar, milk, etc.), Electronic products and equipment, Clothing and accessories, Furniture and household appliances, Other (publishing, stationery);
5. Visual attraction – named VISUAL_ATTR, on the topic related to what were (in personal judgment) the features of a package that mainly attracted their attention.

Figure 3 - Variables and items

Variables or macro-topics	Variables' items
1. Motivation to choose an eco-sustainable packaging – labelled AIM	AIM_ Contributing to the reduction of pollution AIM_ Contributing to public awareness of the environment AIM_ Facilitating waste disposal AIM_ Having the opportunity to purchase products in recycled packaging AIM_ Reduce local taxes for municipal waste disposal AIM_ Improving air quality/reducing degradation in Metropolitan Cities AIM_ Reduce the amount of unsorted waste for disposal AIM_ Reduce the amount of toxic waste in the environment AIM_ Recovering materials through recycling (circular economy) AIM_ Encouraging the production of sustainable packaging
Variables or macro-topics	**Variables' items**
2. Characteristics of sustainable packaging – labelled CAR_SUST_PKG	CAR_SUST_PKG_ Contributes to social sustainability CAR_SUST_PKG_ Contributes to economic/environmental sustainability CAR_SUST_PKG_ Designed to create the least possible impact CAR_SUST_PKG_ Lower consumption of raw materials and energy CAR_SUST_PKG_ Reduces disposal costs CAR_SUST_PKG_ Made through the use of renewable energy CAR_SUST_PKG_ Designed packaging following rules of environmental sustainability CAR_SUST_PKG_ Facilitates recycling/reuse activities CAR_SUST_PKG_ Composed of recycled material CAR_SUST_PKG_ Adopts correct and environmentally friendly behaviors
Variables or macro-topics	**Variables' items**
3. Characteristics of eco-packaging for food products – labelled CAR_SUST_FOODPKG	CAR_SUST_FOODPKG_ Possibility to choose from different formats CAR_SUST_FOODPKG_ Practicality of disposal CAR_SUST_FOODPKG_ Nice design CAR_SUST_FOODPKG_ Presence of detailed product and packaging information CAR_SUST_FOODPKG_ Presence of information for its disposal CAR_SUST_FOODPKG_ Use of materials to ensure its good preservation CAR_SUST_FOODPKG_ Use of environmentally friendly materials CAR_SUST_FOODPKG_ Use of innovative materials (hi-tech, QR code) CAR_SUST_FOODPKG_ Possibility of recycling/reuse/composting CAR_SUST_FOODPKG_ Use of materials that do not significantly affect the final price of the product
Variables or macro-topics	**Variables' items**
4. Differentiation among packaging for different types of products – labelled DIFF_PRODS	DIFF_PRODS_ Electronics products and equipment DIFF_PRODS_ Furniture and household appliances DIFF_PRODS_ Clothing and accessories DIFF_PRODS_ Long-life food products at room temperature (pasta, dried fruits, canned products) DIFF_PRODS_ Fresh food products (fruits, vegetables, fresh-cut, etc,) DIFF_PRODS_ Food in liquid form (oil, vinegar, milk, etc), DIFF_PRODS_ Beverages DIFF_PRODS_ Frozen/frozen food products DIFF_PRODS_ Take-away food DIFF_PRODS_ Other (publishing, stationery)
Variables or macro-topics	**Variables' items**
5. Visual attraction – labelled VISUAL_ATTR	VISUAL_ATTR_ Colors and visual appeal of the Brand in general VISUAL_ATTR_ Sensations of touch (smooth, rough, etc,) VISUAL_ATTR_ Figures and designs intended to advertise the product VISUAL_ATTR_ Manageability VISUAL_ATTR_ Easy-to-use VISUAL_ATTR_ Contained volume/quantity ratio VISUAL_ATTR_ Product Certifications VISUAL_ATTR_ Materials VISUAL_ATTR_ Written information and/or particular words VISUAL_ATTR_ Overall design in general (shape, colors, materials)

For each variable, respondents were asked to give a score (using a rating scale) from 1 to 10 to each of the 10 items based on their personal opinion, where 1 = disagree or minimally agree, and 10 = totally agree or maximum agreement, in order to measure respondents' opinions, agreement or disagreement, quantitatively.

2.3. *Data analysis*

All the statistical analyses were carried out using the statistical software IBM SPSS Statistics 21.

2.3.1. Yule's association index

Yule's association index was used to calculate the association between the observed qualitative binary variables (Yule, 1912), for research question 2. This index is useful in highlighting whether there is independence between two phenomena or characters (qualitative variables) or whether they are linked by a positive (direct) or negative (inverse) association. It is commonly referred to as the coefficient of colligation:

$$Q = ad - bc \div ad + bc$$

The index takes the value zero in the above assumption of independence, takes the value 1 when bc = 0 (and in that case we speak of maximum direct association) and the value –1 when ad = 0, that is, when maximum inverse association (or dissociation) occurs. As Yule's Q measures the association of two events, each with two possible outcomes, we can represent all the possible outcomes in a "2x2" matrix. Within and outside behavior analysis, Yule's Q has become a recommended statistic used to quantify sequential associations between 2 events (Lloyd *et al.*, 2013).

2.3.2. Factor Analysis

Factor Analysis (FA) was used in this study because the researcher's interest was to identify a smaller number of factors underlying many observed variables and items (as in this case) (Chironi and Ingrassia, 2010; Fabrigar *et al.*, 2011; Taherdoost *et al.*, 2022; Faris *et al.*, 2022), for the research question 3. The purpose of the FA is not to perfectly reproduce variance, but rather to simplify the correlation matrix so that it can be

explained in terms of a few underlying factors (Chironi and Ingrassia, 2010; Taherdoost *et al.*, 2022; Fabrigar *et al.*, 2011; Faris *et al.*, 2022). Therefore, the components are real dimensions, and the factors are hypothetical dimensions that are estimated from the observed variables (Chironi and Ingrassia, 2010; Fabrigar *et al.*, 2011; Taherdoost *et al.*, 2022; Faris *et al.*, 2022). In this study, we are interested in highlighting the main factors that drive consumer's behaviors and choices with regard to ecofriendly packaging. Therefore, in this case, the Exploratory FA can better reveal the underlying dimensions of all the variables (and items) considered (Chironi and Ingrassia, 2010; Taherdoost *et al.*, 2022). No data standardization was applied because the analyzed variables (and items) had the same units of measurement, that is, in this case, the rating from 1 to 10; therefore, in this study, it was imposed the same contribution of the original variables (Fabrigar *et al.*, 2011; Faris *et al.*, 2022).

Two tests were applied to evaluate the adequacy of data, as usual in the case of FA: the Kaiser-Meyer-Olkin (KMO) test, that is the sample adequacy test, and the Bartlett's sphericity test for measuring goodness of fit. KMO statistic is a proportion of variance among variables, which might be common variance. It ranges from zero to one, where zero is inadequate, and values close to one are adequate; literature suggests accepting index values at least equal to 0.7 or higher (Chironi *et al.*, 2017). Bartlett's sphericity test compares the observed correlation matrix to the identity matrix (off-diagonal is zero). As is well known, this test provides indications about factorization goodness. In fact, when positive, it allows to reject the null hypothesis that there is no correlation between the variables. Once the formal factorization requirements of the data have been met, the chosen factorial model can be applied. Extraction refers to the process of obtaining underlying factors or components.

As far as the methods of extraction of factors are concerned, according to the literature on extraction methods (Taherdoost *et al.*, 2022; Fabrigar *et al.*, 2011), the Principal Components Method has been chosen, because no other methods of extraction of factors produce factors that explain a greater proportion of variance (it maximizes the variance explained). One of the most common strategies for deciding on the number of factors is the rule of "eigenvalues greater than 1" (the Guttman-Kaiser criterion allows you to select the initial eigenvalues higher than 1). Both eigenvalues greater than 1 and the "Scree" test using the decreasing graph of eigenvalues (namely the Scree Plot) were considered to identify the number of underlying factors after extraction (Chironi and Ingrassia, 2010; Taherdoost *et al.*, 2022; Fabrigar *et al.*, 2011; Faris *et al.*, 2022). The decreasing graph of the eigenvalues allows us to identify from the graphical point of view (scree test) the number of factors that deserve to be taken into account, in this case, those whose eigenvalue is greater than 1.

The FA provides the "factor weights" for each combination of extracted factors and observed variables, which are similar to the correlation coefficients between factors and variables. It is extremely difficult to interpret the factor weights of "non-rotated" factors, regardless of the extraction method chosen. The rotation of factors helps to arrive at a simpler model of factorial weights, maximizing the high correlations and minimizing the low ones (Ingrassia, *et al.*, 2022). The factors were rotated using the "Varimax" orthogonal rotation technique, which is the most widely used in the literature (Taherdoost *et al.*, 2022; Fabrigar *et al.*, 2011; Faris *et al.*, 2022) because it provides good outputs for types of analysis like this.

2.3.3. Talcott Parsons' AGIL scheme

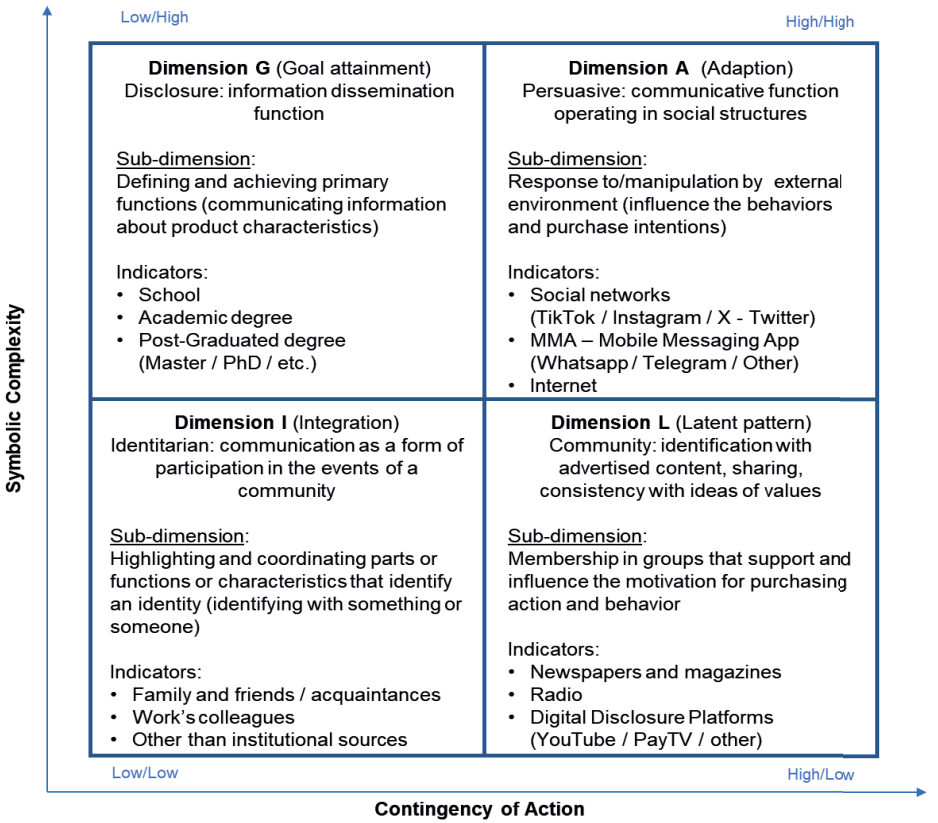
Finally, the main sources of information were identified and classified according to Talcott Parsons' AGIL scheme, for the research question 5. The AGIL method (originated from Talcott Parsons, 1961) (Parsons, 1961) is a model used to figure out and interpret the dimensions of "communication", one of the principal phenomena of social interactions and relationships (Ingrassia *et al.*, 2018; Ingrassia *et al.*, 2022).

In this study it was applied in order to highlight the main dimensions of consumer communication regarding the use of sustainable food packaging. Persuasive dimension (A - Adaption) is the one that evaluates the persuasive mode through the subdimension of engagement (social networks, influencers, web, internet, etc.), which is the one that evaluates the persuasive mode through the subdimension of engagement. Informational dimension (G - Goal attainment), assesses the informational mode through the subdimensions of continuity (school, university, postgraduate studies. Identitarian dimension (I - Integration) assesses the communal mode through the subdimensions of conversation (relatives, friends, acquaintances, work, other modes of information (cinema, fairs, etc.). Community dimension (L - Latent pattern) assesses the identity mode through the subdimensions of sharing (newspapers, magazines, radio, YouTube, Pay-TV). For this study, the most suitable indicators for each dimension and sub-dimension were developed to measure their effectiveness and to learn about the communicative context in which the consumers receive and exchange information about eco-friendly packaging (Figure 4).

To calculate the percent value of each Dimension's effectiveness it was used the following index:

$$\%DimEff. = \frac{\sum\ Score\ assigned\ to\ one\ Dimension}{\sum\ Scores\ assigned\ to\ all\ Dimensions} \times 100$$

Figure 4 - Authors' adaption of the AGIL scheme from T. Parsons' model, with Dimension, Sub-dimensions and Indicators



The AGIL method resulted in a very helpful and valid methodology to analyze and re-interpret the findings regarding the communication source of information, highlighting the most effective one with regard consumers' knowledge of eco-sustainable packaging.

3. Results

3.1. *Sample characteristics and declared preferences for sustainable packaging*

Table 1 shows the sample's characteristics. This first analysis of results can provide an answer to the research question number 1. The statistical

sample presents an equal distribution with regards to gender and age groups, with a slight propensity toward the younger people because, as mentioned above, they may be protagonists of future economic and social challenges that require a process of behavioral change and awareness, and also may be influenced by several external factors (Riva *et al.*, 2022; Ogiemwonyi, 2022).

Table 1 - Sample characteristics

Variables	**Variable character** (varchar)	**Frequency (%)**
Gender	Female	57.0
	Male	43.0
Age	20-29	33.7
	30-39	30.2
	40-49	15.5
	50-60	20.5
Education level	High school or less	45.0
	Degree (any level)	50.0
	Post graduate studies	5.0
Occupation	Student	25.0
	Employee (public/private)	35.5
	Researcher/Teacher/Professor	4.5
	Entrepreneur/freelancer	9.0
	Managers (public/private)	3.0
	Unemployed or inactive	23.0
Thematic Area of Studies	Economics/Justice/Political Science/Social Sciences	26.6
	Natural/Earth/Environmental/Agricultural Sciences	17.9
	Architectural/Engineering/Art Sciences	6.6
	Mathematics/Physics/Computer Science	12.5
	Humanities/Literature/Linguistics	16.4
	Pharmacy/Pharmaceutical Science and Technology	2.7
	Other	17.3
Number of cohabitants at home	3-4-person household	49.1
	Two-person households	24.6
	People living alone	16.2
	Living with large families (more than 4 persons)	10.1
Range of income	Below €25,000	65.0
	From 25.000 to 50.000 euros	19.0
	Above 50.000 euros	16.0

Regarding the education level, the sample is 45% with "high school or less", 50% with a degree and 5% with higher levels of education (with a light majority of degree and post graduate education 55%). As shown in Table 1, the sample shows different types of employment, and moreover 25% are students and 23% are unemployed or inactive. With regard to the thematic area of study, the sample shows many different types of studies, this is useful to investigate preferences and behaviors of different cultural segments of population.

According to the respondents' answers, the 58% of the respondents are part of a 3-4-person household, while 22% are two-person households; the residual part of the sample is almost equally distributed between people living alone and respondents living in larger families. 65% of respondents have an income below 25,000 euros (only 34.5% of respondents declared to have an income above 25.000 euros).

According to the respondents' answers, more than 99% of consumers thought it would be useful to make separate collection of packaging, and 78% of them wished they could reuse food packaging.

Regarding the characteristics that sustainable packaging should have, it was asked to respondents to give a score to three sets of characteristics for different types of packaging. Particularly sustainable packaging in general (Table 2), sustainable packaging for food products (Table 3), and importance of eco-sustainability of packaging (use of environmentally friendly materials) for some specific products, food and non-food (Table 4). The results showed that according to respondents (Table 2), environmentally sustainable packaging should be designed to create less impact on the environment (8.88), to facilitate recycling activities (8.79), according to the rules of environmental sustainability (8.72) and to reduce disposal costs (8.67).

According to Korhonen, 2012 and Otto *et al.*, 2021, also in this study (Table 3), the main features that consumers prefer or consider important for environmentally sustainable food products' packaging mainly concern the use of materials that ensure good preservation (8.57) and the possibility of being able to recycle/reuse/compost the packaging (8.33), as well as information about type of packaging and its disposal and practicality of use (8.31). At present, however, they are also interested in the use of environmentally friendly materials (8.18), and innovative materials such as hi tech or QR-code (6.75) and nice design (5.88).

Moreover, respondents appeared very interested (Table 4) to the use of eco-friendly packaging for fresh food products (8.60), take-away foods (8.38), long-life food products such as pasta or canned products (8.31), and generally all types of foods (beverages, liquid foods, frozen foods). However, showed a general interest for eco-packaging used for electronics products and equipment, clothing and accessories, furniture and household appliances.

Table 2 - Mean values of scores given by consumers to the characteristics that environmentally sustainable packaging should have

Desired characteristics of sustainable food packaging	Mean values of scores given by consumers
Designed to create the least possible impact	8.88
Facilitate recycling/reuse activities	8.79
Designed packaging following rules of environmental sustainability	8.72
Reduce disposal costs	8.67
Adopts and environmentally friendly behaviors	8.65
Lower consumption of raw materials and energy	8.64
Composed of recycled materials	8.58
Contributes to economic/environmental sustainability	8.44
Made through the use of renewable energy	8.39
Contributes to social sustainability	8.37

Table 3 - Mean values of scores given to the characteristics that environmentally sustainable food products' packaging should have

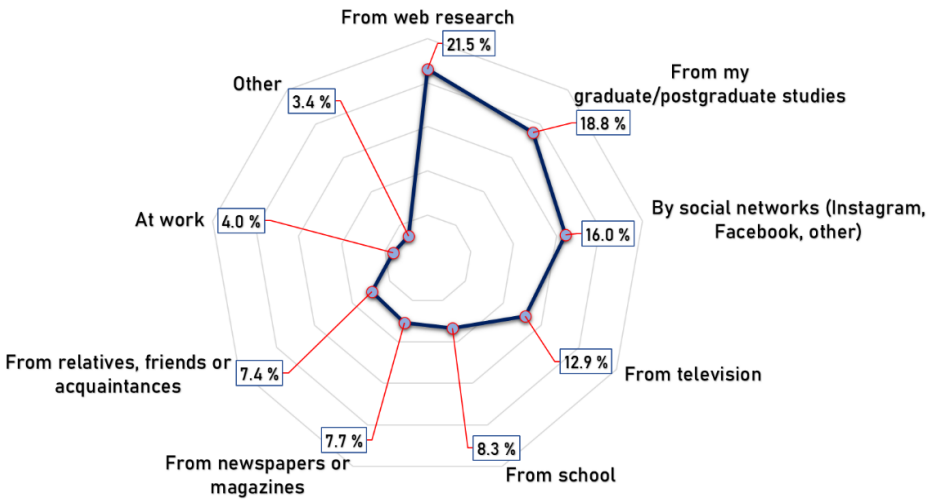
Characteristics	Mean values of scores given by consumers
Use of materials to ensure its good preservation	8.57
Possibility of recycling/reuse/composting	8.33
Presence of detailed product and packaging information	8.31
Practicality of disposal	8.31
Presence of information for its disposal	8.31
Use of environmentally friendly materials	8.18
Use of materials that do not significantly affect the final price of the product	8.04
Possibility to choose from different formats	7.54
Use of innovative materials (hi-tech, QR code)	6.75
Curated design	5.88

Table 4 - Mean values of scores according to the importance of eco-sustainability of packaging (use of environmentally friendly materials) for some specific products (food and non-food)

Characteristics	**Mean values of scores given by consumers**
Fresh food products (fruits, vegetables, fresh-cut, etc.)	8.60
Take-away food	8.38
Long-life food products at room temperature (pasta, dried fruits, canned products)	8.31
Beverages	8.22
Foods in liquid form (oil, vinegar, milk, etc.)	8.19
Frozen/Deep-freezing products	8.13
Other (publishing, stationery)	7.78
Electronics products and equipment	7.71
Clothing and accessories	7.66
Furniture and household appliances	7.64

Figure 5 shows the main sources of knowledge from which respondents declared that they had learned about environmentally sustainable packaging. The internet appeared to be the first one (21.5%), followed by university and post-graduate studies (18.8%), and social networks (16%). A modest number of respondents indicated schools, newspapers and magazines, relatives, friends, acquaintances, work colleagues. Television maintains a fundamental role for Italians for information acquisition (12.9%). It is interesting to highlight that, the "digital" source of information (social networks and the web), cumulatively was indicated by 37.5% respondents. And if we and if we also juxtapose the percentage of those who said they learned from television, it is observed that these three information sources alone account for 50.4%.

Figure 5 - Sources of knowledge for acquiring information/learning about eco-sustainable packaging



3.2. *Analysis of statistical associations between characters*

Following the existing literature on the influence of some qualitative variables on consumers' propensity to green sensitivity and their attitude to change behaviors toward circular economy practices (Liu, *et al.*, 2024; Lavuri, 2022a; Rusyani *et al.*, 2021), in this study it was investigated the existence of independence or alternatively, of association among some qualitative variables (characteristics of the sample) by the use of the Q Yule's index (Table 5), with the aim to answer to the research question number 2.

A high association was revealed between the character "knowledge of the meaning of environmentally sustainable packaging" (93% of the sample said they know the meaning of eco-friendly packaging) and the sources of information from which they learned the meaning, grouped by "study at school/university/higher" and "other different from study-mass media". Particularly, the index value (+69.22 Table 5) highlights a positive association of 69.22%, this means that 72% of those who say they know the meaning of environmentally sustainable packaging simultaneously claim to have learned about it through mass media (or other different from studies). The internet, and the use of social media, represent a good vehicle of information, although, the possibility of deriving incorrect information is higher than having learned about it through institutional information sources. A modest positive association was also observed between knowledge of

Table 5 - Values of Q Yules's association index for association between characters

Pairs of qualitative variables	Yule index value Q (%)
Knowledge of the meaning of "environmentally sustainable packaging" (YES/NO) - Sources of information on sustainable packaging	69.22
Knowledge of the meaning of "environmentally sustainable packaging" (YES/NO) - Education level	19.29
Knowledge of the meaning of "environmentally sustainable packaging" (YES/NO) - Time period from waste differentiation	2.72
Utility of separate collection (YES/NO) - Age groups	45.14
Utility of separate collection (YES/NO) – Education level	58.35
Utility of separate collection (YES/NO) - Income ranges (stated)	31.12
Willingness to reuse or recycle fresh food packaging (YES/NO) - Sources of information on sustainable packaging	35.95
Willingness to reuse or recycle fresh food packaging - Time period from waste differentiation	5.40
Ability to recognize the elements that distinguish "eco-sustainable" packaging - Time period from waste differentiation	5.06
Ability to recognize the elements that distinguish an "eco-sustainable packaging" - Sources of information on sustainable packaging	6.52

meaning and level of education, this confirms the previous result. The 99% of respondents declared it is useful to carry out separate waste collection, the 95% of the sample say that in the district where they live the differentiated waste collection is carried out, and the 54% of this subgroup say that the differentiated waste collection is carried out for at least 4 years. Nevertheless, a good positive association was outlined between the character "Utility of separate collection" and "Age groups" (+45.14), Education level (+58.35) and "Income ranges" (+31.12) this means the existence of other variables that influence people's behaviors and choices (Yin *et al.*, 2022). Moreover, a low index value (+5.4%) resulted for the association between "Willingness to reuse or recycle fresh food packaging" and "Time period from waste differentiation", this highlights that respondents, although effectuating waste differentiation (99%) and 59% of them for more than 3 years (data not shown), only the 43% of the sample declared they reuse and recycle yet fresh food packaging, and the 34% said they "would be liking to do this",

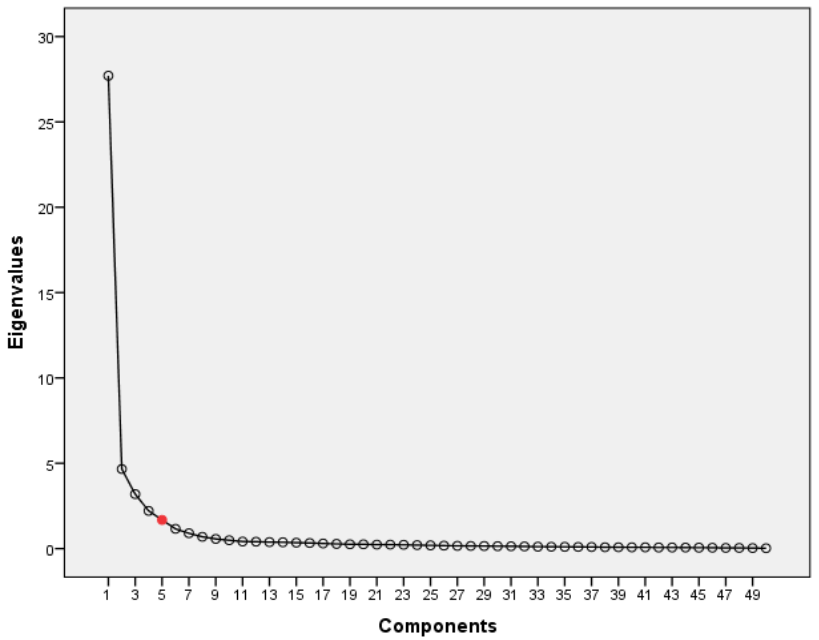
the 12% has not clear about the difference between reuse and recycling, and the remaining sample size (11%) said not to carry it out but would like to be better informed about the possible individual and community benefits of reuse/recycling. These results highlight that most of consumers say they are informed about environmentally sustainable packaging, and have been recycling for more than 3 years, the information they have is generic and specifically about fresh food packaging they need to receive information about the characteristics of these types of packaging and instructions on how to dispose of or reuse them. Contrarily, a high association emerged between the "Willingness to reuse or recycle fresh food packaging" information sources (+35.95), 71% affirm their willingness and simultaneously to have learnt from "mass media" or other information sources different from studies this highlight the social importance of these information sources.

An interesting result emerged with respect to the ability to recognize bioplastic packaging used for ready-to-eat salads. In fact, three different plastic bags of which only one had environmentally sustainable packaging (bioplastic) containing salad greens were shown to the respondents as pictures in the questionnaire. It was asked to identify the sustainable packaging (bioplastic). The results showed that 74% of the consumers correctly identified the environmentally sustainable packaging. Therefore, it was investigated whether there was an association between the ability to recognize eco-packaging and "Time period from waste differentiation" and also "Sources of information on sustainable packaging". The results show a very low association with both the characters. In the picture shown, a green logo with the word "Green" was displayed in the sustainable package. This highlights the importance of information in the packaging (not only the source of information/communication) and the quality and clarity of this information (Vilasanti Da Luz *et al*., 2020).

3.3. *Factor Analysis*

Factor analysis was applied because it was considered very useful for the research question number 3. There were extracted six main factors in 7 iterations. The KMO test resulted equal to 0.967, which shows the goodness of the data. The Bartlett's sphericity test is = 23887.472 (df = 1225; Sig. 0.000). As from Table 1, only the first 5 factors contribute noticeably to the composition of the total percentage of variance (81.219% of cumulated variance explained), and the sixth factor adds a very low percentage of variance (3.568%) to the previous ones. In addition, the Scree plot (Figure 6) shows clearly that the fifth factor is the last with eigenvalue > 1, and thus it confirms that the following factors have no statistical relevance.

Figure 6 - Scree Plot of decreasing eigenvalues (scree test of eigenvalues >1)



The first component has a total initial eigenvalue of 27.706, which is equal to 55.413% of the total variance in the case of non-rotated factors, and the18.447% after factors' rotation (Table 5). The second component has a total initial eigenvalue of 4.663, which is equivalent to a further 9.326% of the total variance for the non-rotated factors and 17.877% after rotation. Interestingly, the first factor, before rotation (Table 6, Weights of non-rotated factors), explains as much as the total variance (55.413%), while from the second factor onward the percentages of variance explained by each one are very low. The values of variance after rotation highlighted three factors having very closed percentages of variance explained (Table 6). To conclude data analysis, the first six factors have a cumulated explained variance of 81.219%, which means that they represent almost the whole information assets provided by the data, and therefore acceptably explain the phenomenon under investigation.

By analyzing the factorial coefficients (Table 7), it is possible to identify the main items for each factor extracted. These variables are those that contribute to determining the factors' variance. In particular, for example, we can observe that 69.72% (0.835^2) of the item's variance "Reduce the amount of toxic waste in the environment" is explained by the first factor, as

is 69.05% (0.831[2]) of the item "Improving air quality/reducing degradation in metropolitan cities", and so on.

Table 6 - Total explained Variance

Comp.	Initial Eigenvalue			Weights of non-rotated factors			Weights of rotated factors[1]		
	Total	Variance (%)	Cumulated (%)	Total	Variance (%)	Cumulated (%)	Total	Variance (%)	Cumulated (%)
1	27.706	55.413	55.413	27.706	55.413	55.413	9.224	18.447	18.447
2	4.663	9.326	64.738	4.663	9.326	64.738	8.939	17.877	36.325
3	3.191	6.382	71.12	3.191	6.382	71.12	8.742	17.485	53.809
4	2.211	4.421	75.541	2.211	4.421	75.541	6.444	12.888	66.697
5	1.681	3.362	78.904	1.681	3.362	78.904	5.477	10.953	77.651
6	1.157	2.315	81.219	1.157	2.315	81.219	1.784	3.568	81.219

[1] Varimax rotation

Table 7 - Matrix of rotated components

Variables' items	Factorial coefficients of extracted factors					
	Factor 1 (F1)	Factor 2 (F2)	Factor 3 (F3)	Factor 4 (F4)	Factor 5 (F5)	Factor 6 (F6)
AIM_ Reduce the amount of toxic waste in the environment	**0.835**	0.346	0.186	0.188	0.183	0.096
AIM_ Improving air quality/reducing degradation in Metropolitan Cities	**0.831**	0.336	0.190	0.179	0.198	0.055
AIM_ Reduce the amount of unsorted waste for disposal	**0.830**	0.333	0.214	0.196	0.163	0.097
AIM_ Contributing to public awareness of the environment	**0.816**	0.371	0.164	0.201	0.194	0.052
AIM_ Encouraging the production of sustainable packaging	**0.812**	0.329	0.235	0.141	0.170	0.052
AIM_ Recovering materials through recycling (circular economy)	**0.809**	0.368	0.216	0.195	0.136	0.106
AIM_ Facilitating waste disposal	**0.805**	0.339	0.228	0.164	0.148	0.145
AIM _ Contributing to the reduction of pollution	**0.800**	0.387	0.234	0.158	0.164	0.144
AIM_ Reduce local taxes for municipal waste disposal	**0.789**	0.319	0.221	0.187	0.206	-0.017
AIM_ Having the opportunity to purchase products in recycled packaging	**0.705**	0.280	0.230	0.157	0.175	-0.039

CAR_SUST_PKG_ Lower consumption of raw materials and energy	0.346	**0.808**	0.223	0.126	0.218	0.073
CAR_SUST_PKG_ Contributes to social sustainability	0.321	**0.807**	0.251	0.122	0.184	-0.003
CAR_SUST_PKG_ Facilitates recycling/ reuse activities	0.346	**0.807**	0.246	0.104	0.181	0.072
CAR_SUST_PKG_ Contributes to economic/environmental sustainability	0.321	**0.796**	0.232	0.119	0.227	0.018
CAR_SUST_PKG_ Designed to create the least possible impact	0.370	**0.792**	0.211	0.158	0.179	0.151
CAR_SUST_PKG_ Made through the use of renewable energy	0.344	**0.787**	0.233	0.144	0.187	0.007
CAR_SUST_PKG_ Reduces disposal costs	0.362	**0.782**	0.194	0.124	0.248	0.067
CAR_SUST_PKG_ Composed of recycled material	0.354	**0.779**	0.205	0.164	0.184	0.066
CAR_SUST_PKG_ Adopts correct and environmentally friendly behaviors	0.364	**0.766**	0.220	0.119	0.230	0.029
CAR_SUST_PKG_ Designed packaging following rules of environmental sustainability	0.368	**0.733**	0.260	0.112	0.184	0.243
DIFF_PRODS_ Clothing and accessories	0.127	0.227	**0.846**	0.239	0.154	-0.109
DIFF_PRODS_ Furniture and household appliances	0.136	0.240	**0.839**	0.204	0.162	-0.068
DIFF_PRODS_ Electronics products and equipment	0.115	0.207	**0.820**	0.217	0.172	-0.066
DIFF_PRODS_ Other (publishing, stationery)	0.150	0.230	**0.819**	0.222	0.147	-0.029
DIFF_PRODS_ Food in liquid form (oil, vinegar, milk, etc.),	0.196	0.222	**0.779**	0.142	0.235	0.126
DIFF_PRODS_ Frozen/frozen food products	0.276	0.179	**0.778**	0.181	0.280	0.139
DIFF_PRODS_ Beverages	0.230	0.168	**0.762**	0.159	0.225	0.175
DIFF_PRODS_ Long-life food products at room temperature (pasta, dried fruits, canned products)	0.316	0.195	**0.731**	0.198	0.284	0.167
DIFF_PRODS_ Take-away food	0.259	0.215	**0.709**	0.169	0.243	0.248
DIFF_PRODS_ Fresh food products (fruits, vegetables, fresh-cut, etc,)	0.371	0.203	**0.689**	0.130	0.308	0.267
VISUAL_ATTR_ Product Certifications	0.295	0.267	**0.440**	0.280	0.316	0.386
VISUAL_ATTR_ Colors and visual appeal of the Brand in general	0.168	0.091	0.187	**0.867**	0.083	-0.015
VISUAL_ATTR_ Overall design in general (shape, colors, materials)	0.162	0.115	0.235	**0.849**	0.096	0.005
VISUAL_ATTR_ Figures and designs intended to advertise the product	0.173	0.061	0.135	**0.840**	0.165	0.034

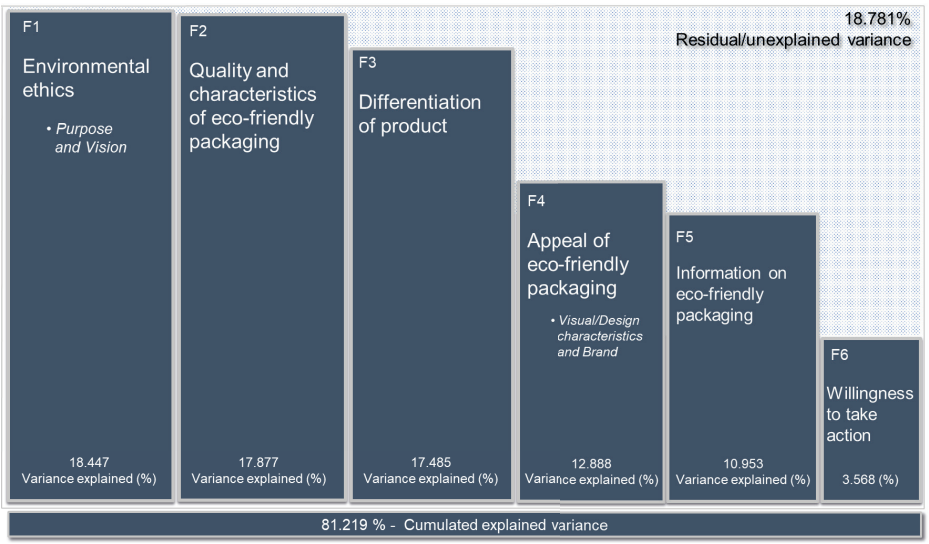
VISUAL_ATTR_ Sensations of touch (smooth, rough, etc.)	0.116	0.085	0.160	**0.767**	0.160	0.010
VISUAL_ATTR_ Written information and/ or particular words	0.197	0.189	0.173	**0.713**	0.186	0.289
CAR_SUST_FOODPKG_ Nice design	0.058	0.044	0.140	**0.630**	0.479	–0.292
VISUAL_ATTR_ Contained volume/ quantity ratio	0.273	0.184	0.285	**0.589**	0.175	0.436
VISUAL_ATTR_ Manageability	0.253	0.296	0.267	**0.586**	0.154	0.475
VISUAL_ATTR_Easy-to-use	0.312	0.280	0.266	**0.568**	0.133	0.510
VISUAL_ATTR_Materials	0.178	0.219	0.329	**0.512**	0.318	0.405
CAR_SUST_FOODPKG_ Presence of information for its disposal	0.296	0.242	0.367	0.098	**0.677**	0.131
CAR_SUST_FOODPKG_ Presence of detailed product and packaging information	0.193	0.342	0.269	0.272	**0.665**	0.173
CAR_SUST_FOODPKG_ Use of materials to ensure its good preservation	0.267	0.387	0.300	0.176	**0.664**	0.195
CAR_SUST_FOODPKG_ Practicality of disposal	0.220	0.349	0.320	0.229	**0.641**	0.078
CAR_SUST_FOODPKG_ Possibility of recycling/reuse/composting	0.278	0.291	0.420	0.154	**0.625**	0.108
CAR_SUST_FOODPKG_ Use of materials that do not significantly affect the final price of the product	0.222	0.319	0.295	0.224	**0.625**	0.076
CAR_SUST_FOODPKG_ Use of innovative materials (hi-tech, QR code)	0.160	0.065	0.299	0.365	**0.618**	–0.251
CAR_SUST_FOODPKG_ Use of environmentally friendly materials	0.302	0.221	0.460	0.088	**0.602**	0.139
CAR_SUST_FOODPKG_ Possibility to choose from different formats	0.106	0.275	0.162	0.442	**0.593**	–0.023

* KMO and Bartlett test, main component extraction method, Varimax factor rotation, SPSS software v.21.

Results of Factor analysis highlighted the main factors that explain consumers' behaviors and motivations to choose eco-sustainable packaging (Figure 7). Specifically, packaging turned out to be a key feature of the overall product that brings significant benefits. Factor analysis revealed important groups of variables describing consumers' motivations for choosing the use of environmentally sustainable packaging and their priority as well as influence with respect to a high multiplicity of influencing variables for the consumer (Figure 7).

The main factor driving consumer choices is ethical (F1). That is the purpose of preserving the Planet and the environment for future generations.

Figure 7 - Visual representation of the extracted factors with the assigned labels, percentage of variance, cumulative variance



It is a moral motivation, a vision (Zhang *et al*., 2024; Popovic *et al*., 2019; Martinho, *et al*., 2015).

The second important factor (F2) was found to be the characteristics that the packaging must have for the consumer. This factor highlights consumer interest in the effectiveness of environmentally sustainable packaging in contributing significantly to reduce environmental pollution and to sustainable development (economic. environmental and social sustainability) (Zhang *et al*., 2024; Choshaly, 2017).

In addition, consumers prefer eco-friendly packaging in particular types of products (F3). According to respondents, the eco-sustainability of materials used for packaging is important but they place more emphasis when it comes to fresh food products whose perishability/perishability could be significantly accelerated by non-plastic packaging (Macht *et al*., 2023). This highlight consumer's skepticism with regard to eco-packaging for very perishable foods and a greater acceptability of this type of packaging for other types of products (non-foods or not perishable foods).

Among the visual characteristics (F4) the overall design in general and the brand were the driving variables of the "Appeal and eco-friendly packaging" factor (Zhang *et al*., 2024).

And finally, as for the characteristics that consumers want mainly in the environmentally sustainable food packaging (F5), information about

method of waste disposal, characteristics of product and the material used for packaging resulted priorities, especially with regard to fresh food (how to maintain quality) (Macht *et al*., 2023; Lisboa, *et al*., 2022).

Therefore, it is possible to conclude that the most important factors that influence consumers to choose an eco-sustainable packaging are:

1. Environmental Ethics - Consumers today turn out to be willing to use packaging with features that meet their needs for Environmental Ethics (Nadeem *et al*., 2021);
2. Quality – Consumers are interested to the specific quality characteristics of environmentally sustainable packaging (Muralidharan *et al*., 2024);
3. Differentiation – Differentiation of preferences based on product type and visual appearance: with a little skepticism with regard to eco-packaging for fresh food products (except take-away or food-delivery of cooked foods to be consumed immediately) (Zhang *et al*., 2023; Wenting *et al*., 2022; Nekmahmud, *et al*., 2020);
4. Information quality – Consumers indicate tools and priorities for obtaining information: QR code, type of innovative, how to reuse, recycle, dispose, use (specifically for food) to improve the quality of the information about eco-sustainable packaging (Nekmahmud, *et al*., 2020; Lopes *et al*., 2024; Lee *et al*., 2002), particularly for fresh food products.

3.4. *Analysis of consumers' declared average ideal surcharge for sustainable packaging of food products*

People's intention to purchase a product with environmentally sustainable packaging can be influenced by many variables (Yin *et al*., 2022), such as people's health concerns (Tewari *et al*., 2022), premium price (Patel *et al*., 2020), familiarity (Talwar *et al*., 2021), and education about environmental issues. In this study it was observed the subjective declared ideal propensity to spend a surcharge to buy a food product with an eco-friendly packaging, in order to have the first information to continue with future studies on the declared ideal willingness to pay for these selected food products. For this study, some of the most renowned products of the Italian agri-food quality tradition were chosen (Bellia and Safonte, 2015a): a package of IGP pasta of 1 kg, a package of IGP Pachino tomatoes od 1 kg, a package of IGP Sicilian red oranges of 1 kg, and a bottle of DOP extra virgin olive oil (EVO) of 1 lt. For these products the propensity of consumers to spend a premium for the use of eco-sustainable packaging was tested. Consumers were asked to choose, for each product, a range of average surcharges that they would ideally be inclined to pay to purchase the same product with environmentally sustainable packaging. The surcharge ranges were: (+ 0 – 0.5€), (+ 0.5

– 1€), (+ 1 – 1.5€). Respondents mainly declared themselves to be ideally inclined to pay from 0.5 euros to 1 euro for all the products and only a few consumers said they were willing to pay more than 1.00 euro. Specifically, for 1 kg package of Pachino IGP tomatoes of about 4 euros on average per kg, 50.45% of consumers expressed to be ideally willing to pay a premium for an eco-friendly package of no more than 0.5 euros and 36.42% up to 1 euro (Table 8).

Table 8 - Average declared ideal surcharge consumers are willing to pay for an environmentally sustainable packaging of some selected food products

Selected food products	**Percentage of consumers for each average range of surcharge**			
	(+ 0€ – 0.5€)	**(+ 0.5€ – 1€)**	**(+ 1€ – 1.5€)**	**I would not pay more for a sustainable packaging**
1 kg of "Pomodoro di Pachino IGP" (average market price in Italy 4€)	50.45%	36.42%	7.16%	5.97%
1 kg of "Arance rosse di Sicilia IGP" (average market price in Italy 1.50€)	54.93%	33.43%	5.07%	6.57%
1 kg of common "Pasta" (average market price in Italy 1.50€)	63.58%	26.57%	2.99%	6.87%
1 lt of 100% Italian "Olio Extra Vergine d'Oliva" (average market price in Italy 7€)	32.24%	35.52%	11.34%	20.90%

For 1 kg of Sicilian PGI blood oranges (Bellia and Safonte, 2015b) in a plastic net pack costing 1.5 euros, 54.93% of consumers expressed to be ideally willing to pay a premium of 0.5 euros for an eco-friendly packaging. For the 1 kg package of common pasta that costs 1.5 euro, in the traditional plastic package, 63.58% of consumers expressed to be ideally willing to pay a premium of 0.5 euros for an eco-sustainable packaging.

For 1 kg of 100% Italian extra virgin olive oil (EVO) in a glass bottle whose price is about 7 euros, only 35.52% of consumers declared they were ideally willing to pay a premium from 0.50 euros to 1 euro to buy the EVO oil in a more sustainable packaging than the glass bottle. Moreover, 20.9% of consumers declared they would not have paid more for more sustainable packaging (brick or can) confirming a trend of preferences for

glass bottles in case of olive oil of high quality. This result may outline the consumer's perception of product quality and credence in relation to the type of packaging. In the case of extra virgin olive oil, quality it is better associated with glass bottle than with sustainable material of other types, also in relation to the places of consumption, such as in the Ho.Re.Ca. channel, mainly hotels, luxury restaurants etc. where glass packaging is more elegant and appreciated by consumers (Ugwu *et al*., 2024). Therefore, the use of 100% recyclable glass could be considered.

3.5. *Analysis of key dimensions of communication*

Having identified the main sources of information, it was possible to classify them according to Parsons' AGIL scheme and analyze the current communication model from which respondents obtain information about environmentally sustainable packaging thanks to the four communication Dimensions' meaning and calculated effectiveness. Therefore, the most effective type of information to transfer knowledge to consumers is through modern ways of communication that can engage the consumer, such as social media, like Tik ToK, Instagram, Twitter, the web, etc. (categorized as sub-dimensions found within the Persuasive dimension (A) which is found to have the highest weight (36.42%) (Mulcahy *et al*., 2024).

The second highest dimension is the Informative dimension (G), which, through the training that one can receive in school, at university, can convey information about the main functions of these packaging, creating a basic culture in the consumer (26.27%). But it is precisely in this dimension that at the school sub-dimension level, communication needs to be implemented. Channels such as newspapers, magazines, Pay TV, YouTube, are the sub-dimensions within the Community (L) dimension that weighs 20.00%. The weakest dimension is Identitarian (I) with a weight of 17.31%, indicating that a common feeling with environmental sustainability is not yet strong and established among the population observed in this study, and that a community of citizens united by common interests, behaviors and consumption preferences on the sustainability principles should be still improved (Chavis & Wandersman, 1990; Koehler & Hecht, 2006; Medina *et al*., 2023).

Table 9 - AGIL results of dimension effectiveness

AGIL dimensions	Sub-Dimensions	Indicators	%DimEff.[1]
Dimension A ADAPTION	Response to/manipulation by external environment (influence the behaviors and purchase intentions)	Social networks (TikTok / Instagram / X - Twitter) MMA – Mobile Messaging App (Whatsapp / Telegram / Other) Internet	36.42%
Dimension G GOAL ATTAINMENT	Defining and achieving primary functions (communicating information about product characteristics)	School Academic Degree Post-Graduated degree (Master / PhD / etc.)	26.27%
Dimension I INTEGRATION	Highlighting and coordinating parts or functions or characteristics that identify an identity (identifying with something or someone)	Family and friends / acquaintances Work's colleagues Other than institutional sources	17.31%
Dimension L LATENT PATTERN	Membership in groups that support and influence the motivation for purchasing action and behavior	Newspapers and magazines Radio Digital Disclosure Platforms (YouTube / PayTV / other)	20.00%

1. Percentage value of dimensions' effectiveness

4. Discussion

Prior studies have demonstrated that customer health worries may influence their attitude toward eco-friendly green goods (Tewari *et al*., 2022) and that conscious consumers will take actions that benefit the environment (Talwar *et al*., 2021). The concept of green consumption values was specifically developed by (Haws *et al*., 2014) for the consumption context.

Green consumption values are defined as "the tendency to express the value of environmental protection through one's purchases and consumption

behaviors" (Haws *et al.*, 2014). For this study, Factor analysis was applied in order to discover the existence of factors (vectors of variables) that influence consumers' purchase intentions with regard to sustainable packaging. According to previous studies (Haws *et al.*, 2014; Zhang *et al.*, 2024), also in this case, the analysis highlighted a relationship between green consumption values, defined as "Environmental Ethics – Purpose and Vision", and consumers' purchase intention for an eco-sustainable packaging. According to the egoistic value theory, the individual or family health concern (Yang *et al.*, 2022), people may be motivated to engage in environmentally friendly activities by egoistic values, such as improved health and a higher quality of life (Verma *et al.*, 2019). Following this theory, consumer health concerns have been shown to influence consumer attitudes and purchasing decisions towards environmentally friendly and locally produced products (Lavuri, 2022a; Lavuri, 2022b; Sultan *et al.*, 2021), particularly for younger generations. In addition, customers who care about their health have a higher propensity to participate in environmentally friendly practices (Kim *et al.*, 2022). Moreover, results show that according to consumers, the sustainable packaging is very important for fresh food products (like fruits, vegetables and fresh cut food) and for prepared/cooked take away food because they have concerns about the ability of this packaging to preserve the quality of foods (Table 4). Another important finding was the existence of a high positive association between the sources of information on sustainable packaging and the consumers' knowledge about the meaning of sustainable packaging, and between the education level and the declared importance to make separate collection (Table 7). With regard to the declared average ideal surcharge that consumers declared they were willing to pay for the different food products offered, results showed that that the majority of respondents were willing to pay up to 0.5 euros more than the normal price of the product (Table 8).

Findings highlight that, for consumers of the sample, information regarding eco-sustainable packaging is obtained, predominantly, from digital sources (Figure 5). Moreover, perhaps because of this, such information is often incorrect (Doerr *et al.*, 2024; Ingrassia *et al.*, 2023; Ingrassia *et al.*, 2022), as the results of this study confirmed. All these results make us reflect on the role that institutions can play in informing consumers about issues that are fundamental (Doerr *et al.*, 2024; Ingrassia *et al.*, 2023) and, if acquired, first and foremost, through school education (which was found to be modest in this study), contribute to shaping ideas and personal behavior, as is already the case in many other European countries that are more avant-garde and more sensitive to issues related to environmental education of citizens (Doerr *et al.*, 2024; Huang *et al.*, 2024). It appears of paramount importance to communicate to consumers what it actually

is, as the absence of clear, easily understandable, and most importantly, educational communication can cause considerable consumer confusion. The AGIL scheme highlighted, in fact, a very important finding, communication deficiencies at this level. It is precisely the Goal Attainment dimension (Table 9) that needs to be pushed more through the role that Public Institutions can play (e.g., through the creation of educational advertisements, with funding for schools or projects to apply concretely the circular economy practices or use eco-sustainable packaging of foods at school/university canteens), to initiate citizens into awareness of the use of this packaging. In light of the findings of the analysis through the AGIL methodology, the information that is received, is very useful in forming consumer awareness on the subject. The educational experience that starts from institutions and conveyed through education (primary and secondary schools, universities) contributes to forming knowledge which then disseminated properly through the other dimensions of communication also comes to create value through the consumption experience (Zheng, *et al.*, 2024).

Therefore, combining the findings of factor analysis with the ones of the other analyses, it was possible to outline the importance of a quality education and a correct institutional communication and marketing strategies, in agreement with recent literature (Zheng, *et al.*, 2024) and design a communication model for Public Institutions (Figure 8) that may support the green transaction process started yet.

Figure 8 - Authors' proposed communication model for Public Authorities to disseminate proper information on Circular Economy and to build society's sustainable behaviors

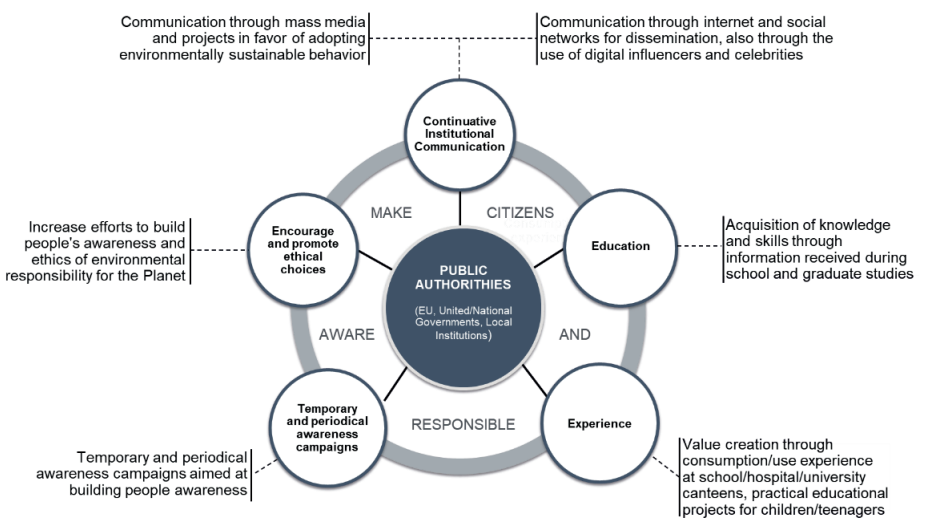


Figure 8 shows a communication model that may be considered by Public Institutions aimed to improve the citizens' information and sense of environmental ethics and responsibility toward issues related to respecting and protecting the ecosystem as a legacy to future generations. This model suggests some actions to disseminate proper information on Circular Economy and to build society's sustainable behaviors, building a community with a common sense of responsibility and making citizens aware and participative. The proposed actions should be conducted synergistically, cooperating so that information can be disseminated capillary in society and can become part of the citizens' culture.

Results show that the consumers do not intend to spend a high premium price for eco-sustainable packaging of quality food products. Nevertheless, the costs of technologies are still higher in Italy, and the firms that produce eco-packaging cannot take on the full cost of the technology. Therefore, Public Institutions should carry on supporting businesses with more funding to develop eco-sustainable technologies for packaging that take into consideration also circularity of economy, particularly in the agro-food sector.

Moreover, findings suggest that purchase intentions, toward these types of packaging, could be greatly influenced by a proper institutional information campaign with educational and explanatory advertisements that invite consumers to experience the product and its recycling or reuse mode (Shwarz *et al*., 2024). At the same time, it is of paramount importance, considering the actual Italian situation, to carry on project for creating experience and consequently knowledge in the individuals, particularly the young generations, starting with preschool, like it is in some EU Countries (Kerr *et al*., 2024). Moreover, as highlighted above, the digital world plays a key role with regard to information dissemination, in fact, for more than half of the sample surveyed (50.4%), knowledge on the issues under analysis comes from web searches, social networks, MMA and TV. Given the importance that the mass media and digital information sources have in today's communication system, public institutions should take advantage of these effective means of communication (Crapa *et al*., 2024; Masciandaro *et al*., 2024). In this scenario, it is crucial to take advantage of these channels to make the dissemination activities of public institutions more efficient and effective. Public Institutions may to take advantage also of digital influencers or opinion leaders/celebrities, who may be able to convey information that followers will receive as useful advice of daily life practices, certainly in a context of honesty and compliance with communication standards and regulations/laws.

Therefore, this model shows how institutional communication, when well conveyed, can play the role of a value multiplier for eco-sustainable packaging, together with business communication (Jha *et al*., 2024).

These findings may provide interesting insights both for agro-food enterprises to base medium-term choices of market targeting and positioning, and for policymakers at Italian and EU level, aiming to develop institutional information by awareness campaigns to the population (individuals and enterprises) to encourage the use of eco-sustainable packaging for fresh food products.

Limitations and future studies

This study, as mentioned in the introduction, is the first result, within the CIRCLE Project, resulting from a pilot investigation, i.e., a preliminary survey carried out on a set of the population for the purpose of obtaining information necessary for conducting a more complex survey through a subsequent larger sample. However, even in this first phase of the survey, the starting reference universe was established to represent as closely as possible the population residing in the Metropolitan Cities of Italy. Specifically, in this first study, for the southern Italian cities, the Metropolitan Cities of Catania and Palermo, were identified as having homogeneous characteristics in terms of geographical location, number of inhabitants, population density and level of development for green transition. Nevertheless, future studies will be carried out including other Metropolitan Cities of central and northern Italy in order to confirm and/or complete the results and the findings of this study.

Conclusions

This study has highlighted important first results useful to know the current Italian scenario regarding the current practices of home disposal and reuse of packaging with reference to eco-packaging for fresh food products, the consumption behavior, the information and communication channel used, and the ideal intentions to pay a higher price for eco-sustainable packaging for some food products. The results of the Factor analysis highlighted that the main factor that drives consumers' motivations to choose a sustainable packaging is ethical, particularly environmental ethics, that is, the importance given by consumers to the Planet's ecosystem and the desire to aim to contribute in some way to preserving it. In addition, it was discovered that there was a highly positive association between the knowledge of the meaning of sustainable packaging and the sources of information used. The AGIL method allowed to highlight that the most effective means of communication for consumers to achieve information about sustainable packaging are social networks, mobile messaging apps and the internet.

A communication model was proposed by the authors with the aim to communicate effectively to citizens, individuals and businesses, the correct information about the characteristics of eco-sustainable packaging and related advantages for the environment. This communication model could help public institutions to build an aware and responsible citizenry, i.e. people who can fully understand how much change is needed in their purchasing choices for building more environmentally friendly behaviors. Adequate and correct information and experience can foster changes in people's behavior toward more environmentally sustainable consumption styles and correct behavior patterns particularly in the younger generations, from childhood onward.

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Digital channels and green transition: Consumer behaviour as for organic food e-commerce platforms

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Abstract

This paper investigates how some factors affect the willingness to buy organic food on e-commerce platforms. Data have been collected using a web-based survey with 490 respondents. A factor analysis was used to analyze data and later to consider them in a Poisson Count Regression Model. The findings show that well-educated and high-income women are more willing to purchase organic food on e-commerce platforms than others. Moreover, other drivers, such as food quality attributes and people's attitudes towards green consumption and digital channels, affect people's willingness to buy organic food online. These results should be useful for experts dealing with organic food. Marketing campaigns should consider all the drivers affecting people's willingness to purchase organic food online to target the market by designing communication content susceptible to generating the greatest appeal.

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Introduction

In order to keep the livable and sustainable Earth, the European Union supports the twin green and digital transition (Muench *et al.*, 2022). Ecological transition wants to achieve sustainability and reduce pollution, while digital transition focuses on the use of digital tools to support economic growth (Muench *et al.*, 2022). In other words, ideally, the green and digital channels support each other (Muench *et al.*, 2022). In this framework, both green and digital transitions have interested many sectors, including agrifood (Camaréna, 2020; Hassoun *et al.*, 2023; Muench *et al.*, 2022). In fact, on the one hand, the usage of digital technology greatly affects the food sector, improving high-quality development and ecological growth in the agrifood sector (Camaréna, 2020; Pires *et al.*, 2022). On the other hand, digital technologies have changed consumer behaviour (Pires *et al.*, 2022). Thus, it is becoming central to study consumers' purchase decision-making process (do Paço *et al.*, 2019; Pires *et al.*, 2022). According to Palmieri *et al.* (2024), people's attitudes towards digital channels positively affect consumer buying behaviour. Moreover, platform characteristics and product attributes impact people's intention to purchase through digital channels (Lin *et al.*, 2021). Among attributes of food, people pay more attention to organic production, countries of provenience, and products with PDO, PGI, and TSG indication (Aizaki & Sato, 2020; Chryssochoidis *et al.*, 2007; Hempel & Hamm, 2016). In particular, organic food is considered to be more nutritious and healthier than traditional food (Lin *et al.*, 2021; Wang *et al.*, 2018). Hence, organic food is beneficial to both the consumer and the environment (Boccia & Tohidi, 2024; Cachero-Martínez, 2020). Thus, digital channels should be useful tools for advertising, selling organic food, and communicating with consumers (Jayakumar, 2021). People's attitudes toward digital channels positively affect both green consumption and consumer buying behaviour (Palmieri *et al.*, 2024). It is important to underline that organic food consumption, green advertising and buying environmentally friendly products are some topics related to green consumption in the current literature (Boccia & Tohidi, 2024). Thus, ecological promotion and green marketing also influence people's buying behaviour (do Paço & Reis, 2012). Bailey *et al.* (2016) observed a positive relationship between green consumption and people's responses to green publicity. In other words, green consumption values affect people's attitudes towards a firm that communicates ecological information. In this framework, if on the one hand, consumers buy food perceived as good for human health and nature (Ali & Ali, 2020; Nguyen, 2023; Ueasangkomsate & Santiteerakul, 2016); on the other hand, digital tools could help consumer decision-making by offering better information (Hennes, 2022). However, investigating trends of digital channels used

in promoting and/or selling organic products is scarce (Novytska *et al.*, 2021). In general, the usage of digital tools in the food sector is still in its primitive steps (Stranieri *et al.*, 2021), and according to Abbate *et al.* (2023), future studies could examine the factors influencing foodstuffs' sustainable consumer behaviour and their use of digital technologies. These suggestions are even more important if we think COVID-19 has left some heritage, such as increased consumption of organic food and increased purchasing of food through digital channels (De Filippis *et al.*, 2023). In fact, in 2022, food purchases through digital channels have been 80% higher than in the pre-Covid period (ISMEA, 2022a). However, most organic food purchases (63.5%) were made in Italian supermarkets, followed by specialized shops (22.9%) (ISMEA, 2022b). In this framework and as mentioned above, the current literature about consumer behaviour related to organic food in the e-commerce environment is scarce. For these reasons, the paper proposes to answer the following study questions:

- *What factors impact the willingness to buy organic food on e-commerce platforms?*
- *Can green marketing influence the willingness to buy organic food on e-commerce platforms?*

The present study aims to fill this gap and supply practical suggestions for the e-commerce marketing of organic food.

1. Materials and methods

Data collection, the sample, and questionnaire design

A web-based survey was used to collect a sample of 490 individuals in Italy between January and October 2023. The survey was spread through websites, Instagram, Facebook, and emails to reach the largest possible audience. The screening rules were for those over 18 years old, responsible for purchasing food items in the family and being a consumer of organic food. Moreover, a test on 57 people was carried out to find any possible misinterpretations and mistakes, as well as minor changes (to eliminate possible errors), to improve the questionnaire.

The questionnaire was composed of four sections: (1) statements regarding food quality attributes to which respondents pay attention when buying food, the number of organic foods they buy; (2) items about people's approaches to green consumption and their receptivity to marketing; (3) people's approaches as for digital channels, including their willingness to buy organic food online (4) questions about people's sociodemographic features. The current literature inspired the selected items (do Paço *et al.*, 2019; Lin *et al.*, 2021; Palmieri

et al., 2021a; Palmieri *et al*., 2021b; Palmieri *et al*., 2024) and are all closed statements, using Likert scales with 10-point format (i.e., from 1. totally disagree to 10. totally agree with statements done). Table 1 shows the list of items made to assess each aspect. Also, sociodemographic questions were included in the questionnaire to allow us to describe the sample; however, given their relative irrelevance in the table description, the socioeconomic features are not shown.

Table 1 - The questionnaire

Items group	Item	References
Quality attributes of food you pay attention on a Likert scale with 10-point (1. totally disagree to 10. totally agree)	The hygienic aspects The impacts on human health The nutritional content The ethics aspects The price of food The production method of food (i.e., conventional or organic) The sensory aspects of food The safety aspect of food The seasonality of food The quality certifications (i.e., POD, IGP STG)	(Palmieri *et al*., 2021a; Palmieri *et al*., 2021b)
Attitudes towards green consumption on Likert scales with 10-point	My food preferences are influenced by my concern for our ecosystem I could define myself as an ecologically responsible consumer I am willing to consume food that is more ecologically friendly	(Palmieri *et al*., 2024)
Receptiveness to marketing on Likert scales with 10-point	I buy food whose brands pay attention to the environment The green message in advertisements drives my buying attitudes Green messages are necessary forms of advertising I usually see advertisements on social media	(do Paço *et al*., 2019; Palmieri *et al*., 2024)
Digital attitudes on Likert scales with 10-point	I think buying on e-commerce platforms is easy The access speed on e-commerce platforms is an important aspect during the purchases I think buying online is useful to have beneficial offers I think that digital technologies are useful for food traceability	(Lin *et al*., 2021)

I think buying online is useful for reducing the environmental impact of the food supply chain	
I think that digital channels are reliable for buying a product	
I believe that digital channels' visual characteristics are important when people want to buy online	
I believe that e-commerce platforms provide sufficient information about products to buy	

The factor analysis

A factor analysis was used to validate the constructs (Alshaya *et al*., 2014), reduce the observed variables, and later consider them in the econometric model. The Keiser-Meyer-Olkin (KMO) measure and Barlett's test verified both the sampling and correlation adequacy, respectively. In particular, KMO was equal to 0.89 (Field, 2013) and Barlett's test (χ^2 = 10,448; df = 139; p_value < 0.000) was significant (Arsham & Lovric, 2011), indicating that the sample and correlation matrix were appropriate for such an analysis. Kaiser's criterion established the right number of factors to consider in the analysis. Four factors had eigenvalues over Kaiser's rule of 1 and explained 83% of the original variance together. The analysis with four factors showed a good fit (CFI = 0.94; TLI = 0.92; RMSEA = 0.08) (Hu & Bentler, 1999; Medsker, 1994). Also, the convergent and discriminant validity of constructs were validated (Galletta *et al*., 2011); in fact, questions included in the same factor were highly correlated with the studied factor, while questions involved in the different factors did not correlate highly with the investigated factor.

Table 2 displays the four factors considered in the study with their Cronbach's α value. Thus, the first factor is named *Attributes* and shows a Cronbach's α of 0.90 after having deleted one item (i.e., the price of food) with factor loadings less than 0.60. The second factor is called *Green* and shows a Cronbach's α of 0.85, while the third factor is called *Ads* with a Cronbach's α of 0.80. In the end, the fourth factor is called *Digital*, with a Cronbach's α of 0.90. Later, summated scales are made from the factors and used in the regression model.

Table 2 - The factor analysis with varimax rotation

Items group	Item	Attributes	Green	Ads	Digital
Quality attributes of food (α = 0.90)	The hygienic aspects	0.88			
	The impacts on human health	0.83			
	The nutritional content	0.86			
	The ethics aspects	0.89			
	The production method of food (i.e., conventional or organic)	0.80			
	The sensory aspects of food	0.72			
	The safety aspect of food	0.70			
	The seasonality of food	0.78			
	The quality certifications (i.e., POD, IGP STG)	0.88			
Attitudes towards green consumption (α = 0.85)	My food preferences are influenced by my concern for our ecosystem		0.80		
	I could define myself as an ecologically responsible consumer		0.76		
	I am willing to consume food that is more ecologically friendly		0.79		
Receptiveness to marketing (α = 0.80)	I buy food whose brands pay attention to the environment			0.88	
	The green message in advertisements drives my buying attitudes			0.75	
	Green messages are necessary forms of advertising			0.72	
	I usually see advertisements on social media			0.89	
Digital attitudes (α = 0.90)	I think buying on e-commerce platforms is easy				0.85
	The access speed on e-commerce platforms is an important aspect during the purchases				0.90
	I think buying online is useful to have beneficial offers				0.92
	I think that digital technologies are useful for food traceability				0.95
	I think buying online is useful for reducing the environmental impact of the food supply chain				0.90
	I think that digital channels are reliable for buying a product				0.80

I believe that digital channels' visual characteristics are important when people want to buy online	0.81
I believe that e-commerce platforms provide sufficient information about products to buy	0.88

Statistical analysis

In order to investigate which factors impact the buying intent of organic food on e-commerce platforms, a Poisson Count Regression Model (PCRM) is applied (Ali & Ali, 2020). The Poisson model of a count variable assesses the log of the expected count as follows:

$$log\ \lambda_i = \alpha + \beta_i X_i + \varepsilon_i \quad (1)$$

Where:

The dependent variable is the quantity (number) of organic food purchased by the respondents. Thus, log λ_i is the expected value of the dependent variable for the i_{th} observation, β_i is parameter estimates of the people's socioeconomic characteristics, quality attributes of food, people's receptivity to marketing, and consumers' attitudes towards the digital channel, indicated by the vector X_i, α is constant, and ε_i is an error term.

In addition, the findings of a PCRM can be explained as a rate ratio. This model can be useful in calculating the expected willingness to buy organic food on e-commerce platforms by exponentiating the coefficient value of each independent variable while assuming the effect of other variables is constant. Hence, the percentage change λ_i due to each independent variable X_i can be calculated as follows:

$$\Delta\lambda_i = 100 \times (exp^{\beta} - 1) \quad (2)$$

The sociodemographic variables have been transformed into binary values to evaluate the influence of independent variables on the dependent one. In addition, the independent variables relating to food quality attributes, people's attitudes towards green consumption, their receptivity to marketing, and people's attitudes towards digital channels come from the factor analysis. It is important to underline that, as mentioned above, summated scales are made from the factors and used in the regression model. The analysis was performed using RStudio (version 2023.12.1).

2. Results

The sample profile

The sample was composed of 274 women (56%) and 216 men (44%) with a mean age of 33 years (S.D: 11 years) and an average monthly income of € 2,150. In fact, 54% earn between € 1,801 to € 2,500, followed by 10% of the respondents with a monthly income between € 2,501 to € 3,200. Most participants live in Southern Italy (65%) and have a high education level (60% of the sample), i.e. university college or postgraduate degrees. Moreover, 55% of the respondents are willing to buy organic food on e-commerce platforms, indicating that digital channels have an important position in their buying behaviours.

Regarding the questions asked (Table 3), all groups gave positive answers for all items. In fact, among quality attributes of food, the production method (average: 9.0, SD: 0.1), the existence of quality certifications (average: 9.0, SD: 0.2), the effects of food on human health (average: 7.9, SD: 1.0), hygiene (average: 7.8, SD: 1.0) and ethics aspects of food (average: 7.7, SD: 1.0) reached the highest values. However, safety, sensory aspects, nutrition, and seasonality of food are also important quality attributes for respondents. In the items group named attitudes towards green consumption, respondents declared that their food habits are influenced by apprehension for the environment (average: 7.3, SD: 1.0), are willing to consume food that is more environmentally friendly (mean: 6.9, SD: 1.7), and they could describe themselves as environmentally responsible consumers (average: 6.7, SD: 1.0). As regarding the receptivity to marketing, instead, the respondents believe that green messages are necessary forms of advertising (average: 7.3, SD: 0.7), they see advertisements on social media (average: 7.0, SD: 0.2) and buy food whose brands pay attention to the environmental issues (average: 6.7, SD: 1.0). In the end, the items group called attitudes towards digital channels reported positive values for each item. According to the respondents, purchases online are useful for having beneficial offers (average: 8.0, SD: 0.8), digital technologies are useful for food traceability (average: 7.2, SD: 1.4) and the access speed on the e-commerce platforms is an important aspect during purchase phase (average: 7.0, SD: 0.4). Moreover, people believe that buying on e-commerce platforms is easy (average: 6.9, SD: 1.0), digital channels visual characteristics are important (average: 6.8, SD: 0.3) and digital channels are reliable when they want to buy a product (average: 6.7, SD: 1.1).

Table 3 - Descriptive statistics

	Item	Mean (SD)
Quality attributes of food on a Likert scale with 10-point (1. totally disagree to 10. totally agree)	The hygienic aspects	7.8 (1.0)
	The impacts on human health	7.9 (1.0)
	The nutritional content	6.3 (1.8)
	The ethics aspects	7.7 (1.0)
	The price of food	6.0 (1.3)
	The production method of food (i.e., conventional or organic)	9.0 (0.1)
	The sensory aspects of food	6.9 (0.2)
	The safety aspect of food	7.0 (0.8)
	The seasonality of food	6.3 (1.0)
	The quality certifications (i.e., POD, IGP STG)	9.0 (0.2)
Attitudes towards green consumption on Likert scales with 10-point	My food preferences are influenced by my concern for our ecosystem	7.3 (1.0)
	I could define myself as an ecologically responsible consumer	6.7 (1.0)
	I am willing to consume food that is more ecologically friendly	6.9 (1.7)
Receptiveness to marketing on Likert scales with 10-point	I buy food whose brands pay attention to the environment	6.7 (1.0)
	The green message in advertisements drives my attitude toward the ads	6.4 (1.2)
	Green messages are necessary forms of advertising	7.3 (0.7)
	I usually see advertisements on social media	7.0 (0.2)
Attitudes towards digital channels on Likert scales with 10-point	I think buying on e-commerce platforms is easy	6.9 (1.0)
	The access speed on e-commerce platforms is an important aspect during the purchases	7.0 (0.4)
	I think buying online is useful to have beneficial offers	8.0 (0.8)
	I think that digital technologies are useful for food traceability	7.2 (1.4)
	I think buying online is useful for reducing the environmental impact of the food supply chain	6.1 (1.0)
	I think that digital channels are reliable for buying a product	6.7 (1.1)
	I believe that digital channels' visual characteristics are important when people want to buy online	6.8 (0.3)
	I believe that e-commerce platforms provide sufficient information about products to buy	6.0 (0.8)

The Poisson Count Regression Model

Table 4 shows the findings of the PCRM model. In particular, the log-likelihood estimates and information criterion report that the explanatory variables utilized for predicting the willingness to buy organic food on e-commerce platforms explain a good fit in the model (Ali & Ali, 2020). The socioeconomic features of people are important drivers that may influence consumers' willingness to buy organic food on e-commerce platforms. Findings show that gender, education level and income are the demographic features that should significantly influence the people's willingness to buy. The regression coefficient for gender is significantly negative (β: 0.454, p_value < 0.05), indicating that women are 9.1% more likely to purchase organic food online than men. The regression coefficient for education level, instead, is significantly positive (β: 0.543, p_value < 0.01) suggesting that people with graduation and above are comparatively 8.7% more likely to buy organic food online than other people. Moreover, the willingness to buy is positively affected by people's income level (β: 0.323, p_value < 0.01). The expected percentage impact underlines that people with a monthly income of € 2,500 and above are 15% more likely to buy organic food online than other people. Another factor that should likely influence the willingness to buy organic food through digital channels is the quality attributes of food. As mentioned above, among quality attributes, the production method, the quality certifications, and the effects of food on human health, hygiene, and ethical aspects of food reached the highest values declared by the respondents. Thus, food quality significantly affects consumers' willingness to buy. This result suggests that those consumers who pay attention to quality attributes of food are 26.3% more likely to purchase organic food on e-commerce platforms than other people (β: 0.392, p_value < 0.01). Similarly, the regression coefficient for people's attitudes towards green consumption is significant (β: 0.103, p_value < 0.01), indicating that people with a positive attitude towards green consumption are comparatively 18.2% more likely to buy organic food online than other consumers.

Finally, the usage of digital channels is becoming progressively relevant in emerging shopping environments. In fact, under this study, the regression coefficient for digital channels is significantly positive (β: 0.226, p_value < 0.01), demonstrating that consumers who give more importance to digital channel attributes are 25.9% more likely to purchase organic food online than other respondents.

Table 4 - Regression estimates – willingness to buy organic food online (N = 490)

Parameter	β	Std. Error	Percentage change λ_i
Gender (0 = Female; 1 = Male)	–0.454[b]	0.096	–9.1
Age (0 = < 33 years; 1 = ≥ 33 years)	–0.144	0.092	–9.4
Education (1 ≥ graduate; 0 = otherwise)	0.543 [a]	0.085	8.7
Income (1 ≥ €2,500; 0 = otherwise)	0.323[a]	0.099	15.0
Attributes	0.392[a]	0.078	26.3
Green	0.103 [a]	0.098	18.2
Ads	0.115	0.087	3.3
Digital	0.226 [a]	0.099	25.9
Goodness of fit			
Log-likelihood	–888.792		
AIC	1997.333		
AICC	1888.933		
BIC	1955.222		
CAIC	1933.115		
Likelihood Ratio Chi-Square	144.233		
df	15		
Sig.	0.000		

Note: [a] Significant at the 0.01 level; [b] Significant at the 0.05 level; [c] Significant at the 0.10 level.
The percentage change λ_i was the result of equation 2 for each parameter.

3. Discussion

A study about digital channels used in purchasing organic food found that this issue needs to be explored more in scientific literature. The present paper wants to fill this gap by identifying the basic factors behind the buying intent of organic food on fresh food e-commerce platforms. Data were collected using a web-based survey, and the sample was composed of 490 individuals in Italy, with a mean age of 33 years (SD: 11 years), a high education level, and a high income.

As mentioned above, organic food consumption is one of the topics related to green consumption in the current literature (Boccia & Tohidi, 2024), and several academics have tried to draw an identikit of the green consumer (Testa, 2020). Although in the past, demographic characteristics (gender, age, education, and income) were believed to play a significant role in shaping consumer behaviour toward organic food (Boccia & Tohidi, 2024; Ottman,

1995), nowadays it is more difficult to associate this behaviour to the only socio-demographics features of people as other factors, and trends, come into play, in conjunction with the increasing presence and advertising for ecological goods (Testa, 2020). However, sociodemographic variables also impact the usage of digital channels (Scheerder *et al.*, 2017; Zilian & Zilian, 2020). Gong *et al.* (2020) found that well-educated and high-income women and public institution personnel are willing to use new digital technologies. Similarly, in our case, well-educated and high-income women are more willing to purchase organic food on e-commerce platforms than others.

Regarding food quality attributes, they are important elements influencing the buying decisions for healthy food (Azam *et al.*, 2012; Palmieri *et al.*, 2023). Some authors (Ali & Ali, 2020; Ngigi *et al.*, 2010) found that security, nourishment, price, sensory, economic benefits, environmental friendliness, hygiene, and moral aspects affect people's willingness to buy organic products. Migliore *et al.* (2015) showed that environmental sustainability and healthiness of food are positively relevant in driving people's buying behaviours. Other authors showed the importance of environmental welfare as a driver of consumers' choice of organic food (e.g., Palmieri *et al.*, 2023; Prada *et al.*, 2016), while other researchers found that health and safety concerns are the main factors that influence people to choose organic food (e.g., Boccia *et al.*, 2024; Lamonaca *et al.*, 2022). In addition, Prada *et al.* (2016) also suggest that consumers' perception of organic food is largely affected by the presence of specific labels. Similar results were reached by Palmieri *et al.* (2023), who showed that labels can influence people's willingness to consume organic products. Recently, Migliore *et al.* (2020) suggested that attitudes towards healthy eating and the environment are positively associated with a higher willingness to pay for organic products. Similarly, in our case, quality attributes of food significantly positively affect people's willingness to buy. Those buyers who pay attention to the quality attributes of products are 26.3% more likely to purchase organic food on e-commerce platforms than other consumers.

Consumers can buy products through digital channels (Qiu *et al.*, 2024), and the evaluation of digital channel characteristics is an important aspect for clients (Pires *et al.*, 2022). Clients' perceptions of the platform significantly influence their buying behaviour (Hsu *et al.*, 2014). Moreover, online search convenience is linked to the perceived ease and speed at which people can collect product information on the web (Aw *et al.*, 2021). According to Dekimpe *et al.* (2020), digital channels are favourably perceived as a useful search method due to their economical convenience, including ease of navigation and price comparison (Aw *et al.*, 2021). Prices in real stores are generally higher than those of digital channels (Gensler *et al.*, 2017), and if such price difference is greater than expected, customers will complete

the purchase journey online (Manss *et al*., 2020). In light of the above, our findings are in line with the current literature. Consumers paying more attention to aspects of digital channels are 25.9% more likely to buy organic food on e-commerce platforms than others.

According to Lavuri *et al*. (2023), people show a positive attitude toward environmental issues (Testa, 2020). Similarly, in our case, the results show a positive ecological attitude paired with a positive willingness to buy organic food. People with a positive attitude towards green consumption are 18.2% more likely to buy organic food online than other consumers. These results were not surprising because, as mentioned above, being a consumer of organic food was one of the inclusion criteria in the study. According to Tucker *et al.* (2012), people who care about nature are receptive to ecologically themed advertising. Some people are more receptive to ecological communications than other consumers (do Paço *et al*., 2019). Thus, although general ecological attitudes influence green consumption attitudes (do Paço *et al*., 2019), in our case, we did not observe evidence to support our research hypothesis according to which green advertisements drive people's willingness to purchase organic food on e-commerce platforms. This scepticism may be due to consumers' concerns that companies are spreading false and ambiguous green information (Palmieri *et al*., 2024). In fact, according to Kwong Goh & Balaji (2016), despite the increase in green offerings, there is growing concern among people that firms are spreading fake environmental information to increase their sales and reputation. False advertising or fake claims about green products or services is called "greenwashing", a type of dishonest marketing (Blome *et al*., 2017). Thus, greenwashing is a crucial problem that can reduce customer trust and undermine the effectiveness of real environmental efforts (Meet *et al*., 2024). However, according to Forehand and Grier (2003), sceptical consumers can change their minds when presented with sufficient proof.

Conclusions

This paper focuses on the consumer perspective, investigating whether and how some factors affect willingness to buy organic food on e-commerce platforms.

Findings show that respondents' sociodemographic characteristics, education, and income influence their willingness to purchase organic food on e-commerce platforms. Moreover, other factors, such as food quality and the consumer's attitudes towards both green consumption and digital channels, drive willingness to purchase organic food online.

The practical/managerial implications of our study are relevant. First, it is important to underline that the findings should be useful in stimulating the discussion about marketing strategies that can further nurture green behaviours. As mentioned above, in Italy, most organic food purchases are not online, and these findings should be important to support insights of discussion for producers and retailers. In this respect, our results should become significant to producers and experts dealing with organic products, particularly sellers. Food producers and marketers should develop strategies based on digital channels to influence buying behaviour.

Certainly, digital and green aspects are likely to affect consumers' willingness to buy organic food online, and marketers can utilize all information in their segmentation, targeting, and positioning strategies. Second, it could be useful for public policies promoting organic food to use digital channels. In this way, consumers would have more information about the characteristics and benefits of organic products, and thus, this should affect their decision-making process. Thus, digital channels in food consumption processes and sales will require tools that are clear, recognized, and used by people. The achievement of these goals will depend not only on technological development but also on consumers' behaviours towards this new scenario.

The sample considered is not representative of the whole Italian population. Future studies should be carried out on an Italian representative sample, and in different countries. In fact, regarding the latter aspect, some factors should vary across cultures, which may imply the need for changes in the items used to keep up with the prevailing cultural differences.

Conflicts of interest

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Innovativeness in organic farming system: The case of the Marche region

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Abstract

The importance of research and innovation is crucial for addressing the challenges posed by evolving climatic and environmental conditions, along with the urgent need to mitigate greenhouse gas emissions and to deal with unstable markets.
To establish Sustainable Agri-Food Systems, in environmental, social, and economic terms, it is essential to ensure access to technologies that can reduce biological and market risks.
The objective of this paper is to understand how different factors influence the innovativeness of organic farmers in the Marche region, in Italy, with a particular focus on the adoption of a digital tool, Decision Support System (DSS).
The analysis, developed through the application of the SEM model to a sample of organic farmers, highlights the significant role of support services in facilitating the implementation of innovations. Therefore, it is important for policymakers, especially at the regional level, to define specific and coherent measures that incentivize the adoption of innovations.

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Introduction

The agri-food system, both at the national and international level, is facing profound transformations related to the current global challenges resulting from the consequences of climate change and the Russian-Ukrainian conflict. Rising temperatures and related phenomena (i.e., reduced agricultural resources availability, loss of fertility, declining biodiversity, etc.) present multiple problems for agrarian enterprises, which are exposed to an increasing biological risk (Barberi, 2015; Hoek *et al.*, 2021). Conflict-related speculation and a post-pandemic situation also expose businesses to high market risk, resulting in an increasingly turbulent situation leading to a rise in price volatility, reinforced by other market-based drivers (generated by demand or supply shocks via levels of domestic consumption and production) and external shocks (e.g., trend in oil prices and exchange rates), especially in agricultural commodity markets such as wheat, corn, and barley (Santeramo *et al.*, 2018; Viganò *et al.*, 2022). In Italy, in years marked by extreme climatic phenomena (drought or excessive rainfall in the months preceding the harvest), durum wheat prices were characterized by strong variability and a downward trend, against an increase in production costs, mainly linked to the rising trend in fossil fuel prices (Righi *et al.*, 2022).

In this context, research and innovation play a pivotal role in facilitating adaptation to emerging climatic and environmental conditions, mitigating greenhouse gas emissions and responding to market shocks. This includes the provision of Decision Support System (DSS), defined as "a computer-based support system for decision-makers that uses data from different sources to provide recommendations to improve the quality of decisions" (Ara *et al.*, 2021; Fenu & Malloci, 2020; Zhai *et al.*, 2020). In the European Union, the application of these tools is increasing dramatically, primarily because they are considered essential for the transition to a more sustainable agri-food system, particularly within organic farming (European Commission, 2020). However their implementation may be hindered by a lack of support, specific knowledge, and farmers' motivations (Bàrberi *et al.*, 2017; Barnes *et al.*, 2019; Fenu & Malloci, 2020).

This paper aims to analyze the propensity to innovate and the relative motivations of a sample of organic farmers in the Marche region, located in central Italy. Specifically, we want to investigate the various factors (farmer and farm characteristics, personal innovation, social influence, effort expectancy in the use of innovation, performance expectancy, and various facilitating conditions) that may encourage (or hinder) the propensity to implement the DSS tool, paying particular attention to the organizational dimension.

The Marche region represents an interesting case because it is a "zipper region", between Northern and Southern Italy, both in geographical terms and in general economic and social conditions (Canavari *et al.*, 2022). It's also one of the most important Italian regions regarding agricultural area dedicated to organic farming, amounting to 21,416 hectares (ha), in 2022, or 25.5% of the UAA (www.sinab.it). The durum wheat sector is particularly noteworthy: Marche is the first region in the Centre-North in terms of the incidence of the area dedicated to the cultivation of organic durum wheat out of the total organic area (6.4%) and the fifth in Italy, following Basilicata (22.8%), Molise (13.5%), Apulia (13.5%) and Sicily (9.6%) (www.sinab.it/bio-statistiche).

The study was developed through a participatory approach, conducting focus groups with experts and stakeholders (in particular, associations of producers and regional consortium), interested in identifying the main elements of the innovation processes, designing a questionnaire, collecting data, and discussing the results.

Through a farmer survey and econometric analysis of the survey data, we analyzed the relationships between the farmer's choice to adopt DSS and the set of personal, professional, and organizational elements that may shape this decision.

The paper is structured as follows. The main conceptual arguments proposed in the literature to illustrate the factors influencing farmers' innovativeness are presented in Section 1. Section 2 describes the material and methodology adopted, starting with the data collection process and the presentation of the variables, followed by an illustration of the choice of the theoretical framework and the hypotheses of the study, and finally by explaining the statistical model chosen for the analysis. The results of the estimation procedures are reported and discussed in Section 3. Lastly, Section 4 presents the conclusions with some implications of the study carried out for stakeholders and policymakers and, at the same time, provides some suggestions for further research.

1. Literature review of factors influencing farmers' innovativeness

In the literature on the sustainability of agri-food systems, innovation is recognized as a clear opportunity for transitioning to specific production models, particularly organic farming, which represents the main alternative to industrial/intensive methods, offering numerous positive environmental benefits and revitalizing rural areas (Canavari *et al.*, 2022; Mouratiadou *et al.*, 2024; Rijswijk *et al.*, 2021; Sturla *et al.*, 2019). The European Commission's communication "Farm to Fork" as part of the "European

Green Deal" (European Commission, 2020), emphasizes that this transition will require greater investment in Research and Development (R&D) as well as a higher level of professionalization of entrepreneurs, which can be achieved through the enhancement of training programs and support services (such as advisory services) (Bàrberi *et al.*, 2017; Frantzeskaki *et al.*, 2012; Mencarelli & Mereu, 2021; Righi & Viganò, 2023).

A significant challenge for farmers in adopting more sustainable production models is the lack of knowledge transfer agencies and technical-organizational support (Barnes *et al.*, 2019; Läpple & Kelley, 2013; Liu *et al.*, 2019), which are increasingly essential.

Innovation is a broad and powerful concept and can be understood as the ability of different stakeholders to collaborate for "knowledge sharing" (Fieldsend *et al.*, 2020). This includes digital innovations and their implications for implementation (e.g., artificial intelligence, drones, big data, robotics, etc.), i.e., the so-called innovation 4.0 (Rijswijk *et al.*, 2021; Rose *et al.*, 2021).

Understanding the factors that contribute to the adoption of an innovative technology requires a deep awareness of the distinctive characteristics of farmers and farms. It is essential to consider the natural, geographical, and socio-economic conditions and reasons that may influence them (Firsova & Derunov, 2018; Pivoto *et al.*, 2019; Vecchio *et al.*, 2020). It is also crucial to go beyond just the "technical aspects", and to look at the attitudes, mindsets, social, organizational, environmental, and cultural contexts of farmers. This will help and support professionals working with technology and make them understand the key factors that can contribute to adoption (Mir & Padma, 2020).

In the literature, personal characteristics of the farmer ("Individual Factors") that can explain innovation adoption behaviour ("Use Behaviour") include, for instance, age, level of education, and gender (Canavari *et al.*, 2022; Diederen *et al.*, 2015; Firsova & Derunov, 2018; Ronaghi & Forouharfar, 2020). Additionally, farm characteristics, such as farm size, play a key role (Tamirat *et al.*, 2018). Some research papers point out that larger farms are more likely to innovate due to their greater financial resources and better access to technical assistance, contracts, and production planning services (Barnes *et al.*, 2019; Vecchio *et al.*, 2020; Xu *et al.*, 2020). However, some inherent characteristics of agriculture, such as small size, the lack of young and highly educated individuals, the prevalence of family farm business model, and the unregulated labour phenomena may be elements that slow down or block the adoption of innovation ("Personal Innovation") (Agarwal & Prasad, 1998; Pino *et al.*, 2017; Yi *et al.*, 2006). Often, agricultural entrepreneurs do not have access to scientific and technical advancements or to other information that could be crucial for

their development, so they find innovation too difficult to implement ("Effort Expectancy") (Ibragimov, 2014; Mencarelli & Mereu, 2021; Momani, 2020; Venkatesh *et al*., 2003; Verma & Sinha, 2018). Another important factor to consider is the risk aversion of agricultural entrepreneurs. They may feel uncertain about innovating without clear expectations regarding the outcomes of such innovation (Rommel *et al*., 2022; Takácsné György *et al*., 2018). In addition, the adopters' perceptions of innovation and its usefulness ("Performance Expectancy") (Avolio *et al*., 2014; Momani, 2020; Venkatesh *et al*., 2003; Verma & Sinha, 2018) and the influence of others' opinions on adopting these innovations ("Social influence") (Aubert *et al*., 2012; Momani, 2020; Sezgin *et al*., 2017; Venkatesh *et al*., 2003; Verma & Sinha, 2018) are also decisive. For farmers to effectively access certain services, they must recognize their usefulness and ease of use, as well as have the necessary tools and support to access them (Ibragimov, 2014; Olim *et al*., 2020).

Other factors that may influence the adoption of new technologies are the organizational and technical structures ("Facilitating Conditions") capable of supporting the use of technology (Momani, 2020; Ronaghi & Forouharfar, 2020; Venkatesh *et al*., 2003). For instance, organizational solutions, which involve greater coordination among supply chain actors and promote the dissemination of knowledge, can only be effective if organic farmers' levels of training and professionalization are sufficient to take advantage of them (Bàrberi *et al*., 2017).

Lastly, a user's intention ("Behavioral Intention"), defined as the decision to implement plans concerning technology use (Momani, 2020; Ronaghi & Forouharfar, 2020; Venkatesh *et al*., 2003).

2. Materials and methods

2.1. *Data collection*

Data were collected through a questionnaire entitled "The innovative needs of organic farms" sent to 400 organic farmers in the Marche region (cereal farmers) which has a total of 3.160 organic producers (www.sinab.it). Out of this group, 80 agricultural producers responded. The survey administration was made possible thanks to the support of various professional associations and cooperatives[1], which allowed us to get in touch with farmers during their

1. Among these, the *Consorzio Marche Biologiche*, that is an agricultural cooperative founded by three of the leading cooperative farms in the organic cereals sector, has developed new strategies to support organic farming and improve the competitiveness of organic products from the Marche region on national and international markets (https://conmarchebio.it/).

initiatives and meetings. Based on the literature and the goal of our analysis, we selected the variables to be included in our study, as detailed in Table 1.

Table 1 - Variables that influence farmers' innovativeness

	Items	**Scale**
Individual Factors		
Age	Age	From 18 to over 65
Educational Qualification	educ_n	1 = "Primary school"; 2 = "Middle school, high school diploma"; 3 = "university degree"; 4 = "postgraduate degree"
Gender	gender_d	0 = "Male"; 1 = "Female"
Farm Characteristics		
UAA	size_n	From "<10 ha" to ">100"
Legal Form	legalform_n	1 = "General Partnership"; 2 = "Sole Proprietorship"; 3 = "Simple Partnership"; 4 = "Limited Liability Company"
Totally organic	organic_d	0 = "No"; 1 = "Yes"
Facilitation Conditions		
Consortium	cons_n	0 = "No"; 1 = "Yes"
Cooperative/OP (Organization of Producers)	coop_n	0 = "No"; 1 = "Yes"
Association of Producers	ass_of_prod_n	0 = "No"; 1 = "Yes"
Enterprise Network	ent_net_n	0 = "No"; 1 = "Yes"
Supply Chain Contract	sup_chain_contr_n	0 = "No"; 1 = "Yes"
Consulting Services	cons_serv_n	0 = "No"; 1 = "Yes"
Personal Innovation		
If I became aware of a new digital technology that I thought would be useful for my company, I would try to implement it	PI_1_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"
Among my colleagues, I am usually one of the first to experiment with new digital technologies	PI_2_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"
I like experimenting with new digital technologies	PI_3_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"

Social Influence		
People whose opinions I value are in favour of adopting new digital technologies	SI_1_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"
At work, my colleagues and family members who are important to me think that I should adopt new technologies if I had the chance	SI_2_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"
Effort Expectancy		
I think a new technology such as the Decision Support System (DSS) is easy to implement	EE_1_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"
I think the importance of a new technology like the Decision Support System (DSS) is easy to understand	EE_2_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"
Overall, I believe that a new technology such as the Decision Support System (DSS) is easily understood	EE_3_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"
Performance Expectancy		
I think that implementing a new technology such as the Decision Support System (DSS) can improve my work performance and efficiency	PE_1_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"
Overall, I find the implementation of a new technology such as the Decision Support System (DSS) useful in my work	PE_2_n	0 = "Disagree"; 1 = "Undecided"; 2 = "Agree"
Innovation and Intention to Innovate		
Would you intend to implement the Decision Support System?	BehavIntent	0 = "No"; 1 = "Yes"
Does your farm have a Decision Support System (DSS)?	BehavUse_DSS	0 = "No"; 1 = "No but I'd like to use it in the future"; 2 = "Yes"

Source: Author's elaboration.

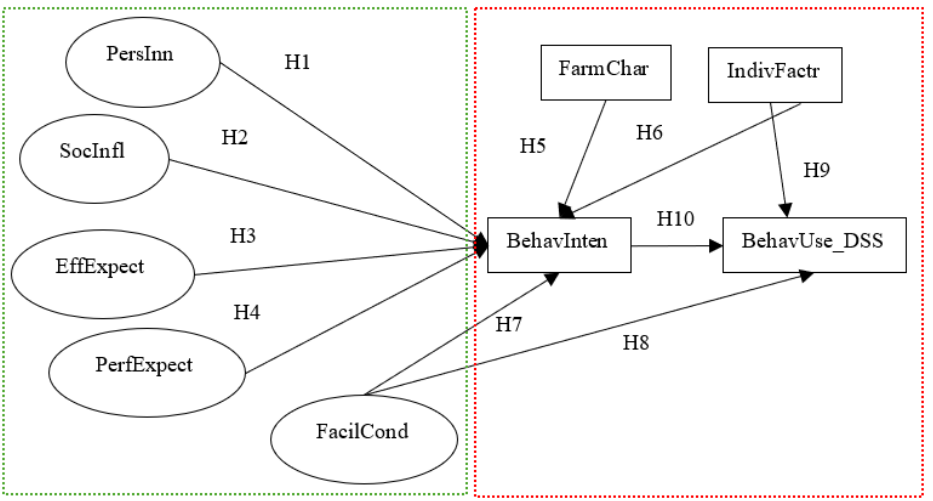
2.2. *Theoretical framework and hypothesis*

After analyzing several models related to the acceptance of new technologies (El Bilali *et al*., 2021; Momani, 2020; Sezgin *et al*., 2017; Shang

et al., 2021; Venkatesh *et al.*, 2003), including the "Theory of Reasoned Action (TRA)" (Davis *et al.*, 1989; Sheppard *et al.*, 1988), the "Theory of Planned Behavior (TPB)" (Ajzen, 1991), the "Innovation Diffusion Theory (IDT)" (Rogers *et al.*, 2014) and the "Technology Acceptance Model (TAM)" (Davis, 1985), the theoretical framework chosen for this analysis is a revised model of the "Unified Theory of Acceptance and Use of Technology (UTAUT)" (Venkatesh *et al.*, 2003). By integrating elements and the most advantageous constructs (theoretical concepts that cannot be measured directly, namely latent variables explained by observable indicators) of previous theories/models, the UTAUT has become one of the most exhaustive and widely adopted models for examining users' ability and motivation to accept new technologies.

More specifically, in this study, UTAUT allows us to: examine the direct effects of four determinants on behavioural intention ("Personal Innovation", "Social Influence", "Effort Expectancy", and "Performance Expectancy"); understand the impact of this intention variable, along with the variable expressing the "Facilitating Conditions" on the dependent variable "Behavioral Use" (referring to DSS); consider "Individual Factors" (i.e., farmer characteristics) and "Farm Characteristics" as moderator variables (i.e., capable of influencing the strength or direction of a relationship between two variables, which can be either latent or observable).

Figure 1 - Revised version of "Unified Theory of Technology Acceptance and Use (UTAUT)"



Source: Author's elaboration.

Figure 1 illustrates our theoretical framework, with all the variables involved and their relationships that allow us to understand how they influence farmers' adoption of DSS. The latent variables are within the ellipses, while the observed variables, i.e., the directly measured data, are within the rectangles.

All relations can be summarised according to the research of Venkatesh *et al*. (2003) as follows:

H1 =PE -> Behavioral Intention
H2 = SI -> Behavioral Intention
H3 = EE -> Behavioral Intention
H4 = PE -> Behavioral Intention
H5 = Farm char (legal form, size, organic) -> Behavioral Intention
H6 = Individual Factors (age educ and gender) -> Behavioral Intention
H7 = Facilitating Conditions -> Behavioral Intention
H8 = Facilitating Conditions -> Behavioral Use_DSS
H9 = Individual Factors (age educ and gender) -> Behavioral Use_DSS
H10 = Behavioral Intention -> Behavioral Use_DSS

2.3. *The Statistical Model*

The model chosen for the analysis of the theoretical model explained in the previous section is the "Structural Equation Modelling" (SEM) which involves the application of two analysis steps:

1. The measurement model allows us to assess the relationships between the different observable and latent variables, though it does not automatically determine them; therefore, before applying SEM, we define their structure by conducting a factor analysis (Sezgin *et al*., 2017; Wang *et al*., 2019) obtaining: "Personal Innovation" (PersInn), "Social Influence" (SocInfl), "Effort Expectancy" (EffExpect) and "Performance Expectancy" (PerfExpect) (green rectangle in Figure 1);
2. The structural part of the model, which includes regression analysis (eq. 1.1) to examine the relationships between the variables considered in the study, i.e., the "Effect of intention" (BehavInten) and different "Facilitating Conditions" (FacilCond) on the dependent variable expressing digital innovation (BehavUse_DSS) and by testing the model with moderator variables "Farm Characteristic" (FarmChar) and "Individual Factors" (IndivFact) (red rectangle in Figure 1).

$$BehavUse\_DSSi = \beta_0 + \beta_1 BehavInten_i + \beta_2 IndivFact_i + \beta_3 FacilCond_i + e_i \quad (1.1)$$

Where:

$$BehavInten_i = \alpha_0 + \beta_2 PI_i + \beta_3 SI_i + \beta_4 EE_i + \beta_5 PE_i + \beta_6 FarmChar_i + \beta_7 IndivFact_i + \beta_8 FacilCond_i + u_i$$

Specifically, given the relatively small sample size, we decided to use the "Maximum Likelihood with Missing Value (MLMV)" method, which involves an approach that uses the model variables to predict missing variables, under the assumption of joint normality of all variables (observed and latent) and that missing values are random (Acock, 2013). This technique is used in Social and Behavioral Science research where small observational samples (often between 50-100 participants) are possible (Maydeu-Olivares, 2017; Maydeu-Olivares & Shi, 2017).

3. Results

3.1. *Descriptive analysis results*

The frequencies and percentages of the variables referring to the sample of 80 farmers in the Marche Region, allow us to make some initial reflections.

In particular, Table 2 presents the results of the observable variables used in the model, which are the individual characteristics of the farmers, the attributes of their farms, and lastly their level of innovativeness (both intention and actual use of digital technology).

Firstly, we note that the majority of the sample is male, aged between 31 and 59, and with a high school diploma. Regarding utilized agricultural areas, most of the sample have a UAA between 11 and 30 ha; they predominantly operate as sole proprietorships, and nearly all of them are completely organic.

Table 2 - Sample profile: results of descriptive analysis (observable variables)

Variables		**Frequency**	**%**
Individual Factors			
Age (years)	18-30	8	10.81
	31-59	40	54.05
	60-90	26	35.14

Educational qualification	Primary school	2	2.50
	Middle school	14	17.50
	High school diploma	39	48.75
	University degree	19	23.75
	Postgraduate degree	6	7.50
Gender	Male	61	76.25
	Female	19	23.75
Farm characteristics			
UAA (ha)	<10	13	16.25
	11-30	22	27.50
	31-50	16	20.00
	51-100	20	25.00
	>101	9	11.25
Legal form	GenPart	2	2.60
	SoleProp	55	71.43
	SimplePart	18	23.38
	LLC	1	1.30
	Coop	1	1.30
Totally organic	No	5	6.25
	Yes	75	93.75
Innovation and intention to innovate			
Behavioral Intention	No	26	32.50
	Yes	54	67.50
Behavioral Use_DSS	No	41	51.25
	No, but I'd like to implement it	30	37.50
	Yes	9	11.25

Source: Author's elaboration.

Most of the sample does not currently use DSS but would like to implement it in the future. Therefore, it would be necessary to understand the factors that are problematic as well as those that may favour its adoption.

In Table 3, we have instead the additional variables considered in the analysis used to construct the latent variables, such as "Personal Innovation", "Social Influence", "Effort Expectancy", "Performance Expectancy", and various forms of "Facilitating Conditions" which refer to different organizational and integration forms in our case.

The majority of the sample states that they are passionate about innovations and that social influence is important in the adoption

of digital innovation. However, they are not entirely convinced that it is easy to implement, although they understand its potential to enhance the performance and efficiency of their production process.

Table 3 - Determinants for the adoption of innovations: results of descriptive analysis (constructs for latent variables)

Variables		Frequency	%
Personal Innovation			
If I became aware of a new digital technology that I thought would be useful for my company, I would try to implement it	Disagree	2	2.50
	Undecided	17	
	Agree	61	76.25
Among my colleagues, I am usually one of the first to experiment with new digital technologies	Disagree	10	12.50
	Undecided	36	45.00
	Agree	34	42.50
I like experimenting with new digital technologies	Disagree	7	8.75
	Undecided	20	25.00
	Agree	53	66.25
Social Influence			
People whose opinions I value are in favour of adopting new digital technologies	Disagree	3	3.75
	Undecided	24	30.00
	Agree	53	66.25
At work, my colleagues and family members who are important to me think that I should adopt new technologies if I had the chance	Disagree	4	5.00
	Undecided	21	26.25
	Agree	55	68.75
Effort Expectancy			
I think a new technology such as the Decision Support System (DSS) is easy to implement	Disagree	12	15.00
	Undecided	36	45.00
	Agree	32	40.00
I think the importance of a new technology like the Decision Support System (DSS) is easy to understand	Disagree	10	12.50
	Undecided	34	42.50
	Agree	36	45.00
Overall, I believe that a new technology such as the Decision Support System (DSS) is easily understood	Disagree	10	12.50
	Undecided	33	41.25
	Agree	37	46.25
Performance Expectancy			
I think that implementing a new technology such as the Decision Support System (DSS) can improve my work performance and efficiency	Disagree	0	
	Undecided	30	37.50
	Agree	50	62.50

Overall, I find the implementation of a new technology such as the Decision Support System (DSS) useful in my work	Disagree	1	1.25
	Undecided	29	36.25
	Agree	50	62.50
Facilitating Conditions			
Consortium	No	54	67.50
	Yes	26	32.50
Cooperative/OP (Organization of Producers)	No	34	42.50
	Yes	46	57.50
Association of Producers	No	61	76.25
	Yes	19	23.75
Enterprise Network	No	72	90.00
	Yes	8	10.00
Supply Chain Contract	No	29	36.25
	Yes	51	63.75
Consulting Services	No	51	63.75
	Yes	29	36.25

Source: Author's elaboration.

The results for the "Facilitating Conditions" variable show the involvement (or not) in different forms of aggregation. Many respondents engage in various forms of integration through supply chain contracts, while others belong to cooperatives and producer organizations. Adherence to consortia, producer associations, business networks, and even advisory support is present, though to a lesser and more variable extent.

3.2. *Statistical model results*

In the initial part of the analysis, the SEM, through the measurement model, enables us to see the relationship between the observables and latent variables. Before running the model, though, we decided to conduct a factor analysis to determine the latent variables. This allows us to reduce the measurement error and improves the overall interpretation of the model (Acock, 2013; Diamantopoulos *et al.*, 2012).

Table 4 reports the constructs used to create the latent variables that express the farmer's personal innovativeness, the influence of the social context, the expectation regarding the effort required to implement an innovation, and the benefit deriving from it. It also includes the facilitating conditions linked to the various forms of organization along with their correlation scores explained based on the factors after rotation.

Table 4 - Rotated factor loading_for PI, SI, EE, PE, FC

Variable	Value	Uniqueness
Personal Innovation		
If I became aware of a new digital technology that I thought would be useful for my company, I would try to implement it	0.8214	0.3252
Among my colleagues, I am usually one of the first to experiment with new digital technologies	0.6672	0.5548
I like experimenting with new digital technologies	0.8791	0.2272
Social Influence		
People whose opinions I value are in favour of adopting new digital technologies	0.6227	0.6123
At work, my colleagues and family members who are important to me think that I should adopt new technologies if I had the chance	0.6227	0.6123
Effort Expectancy		
I think a new technology such as the Decision Support System (DSS) is easy to implement	0.8405	0.2936
I think the importance of a new technology like the Decision Support System (DSS) is easy to understand	0.9244	0.1454
Overall, I believe that a new technology such as the Decision Support System (DSS) is easily understood	0.9179	0.1575
Performance Expectancy		
I think that implementing a new technology such as the Decision Support System (DSS) can improve my work performance and efficiency	0.9064	0.1785
Overall, I find the implementation of a new technology such as the Decision Support System (DSS) useful in my work	0.9064	0.1785
Facilitating Conditions		
Consortium	0.5228	0.7267
Cooperative/OP (Organization of Producers)	0.2880	0.9171
Association of producers	0.4710	0.7782
Enterprise Network	0.5077	0.7422
Supply Chain Contract	0.2850	0.9187
Consulting services	0.3826	0.8537

* An absolute value of at least 0.30 or 0.40 is generally considered significant and good when it is above 0.55
Source: Author's elaboration.

Table 5 provides the Cronbach's alpha values "α" for each construct used in the SEM analysis.

Table 5 - Values of reliability of the constructs used in the analysis

Synthesis variables	**Cronbach's alpha (α)***
Personal Innovation	0.8480
Social Influence	0.6778
Effort Expectancy	0.9325
Performance Expectancy	0.9338
Facilitating Conditions	0.5579

* α indicates strong reliability when $\alpha \geq 0.8$, good reliability if $0.7 \leq \alpha < 0.8$, and acceptable reliability if $0.6 \leq \alpha < 0.7$)
Source: Author's elaboration.

The values associated with "Personal innovation", "Effort Expectancy" and "Performance Expectancy" have high reliability, in contrast to "Social Influence" which has a slightly smaller measure. The lower value of the factor expressing "Facilitating Conditions" may be attributed to data variability, which has many different items.

The results from the MLMV estimation of the structural model reported in Table 6, show that both "Performance Expectancy" and "Personal Innovation" are significant and have a positive impact on the intention to innovate. This suggests that if farmers perceive the benefits and are more innovative this will have a positive impact on their intention. Additionally, among farm characteristics, "Size" positively influences the user's intention (the larger one is, the more one tends to innovate).

Table 6 - Standardized results from the Structural Equation Model

Number of observations: 80				
Estimation method = MLMV				
Log Likelihood = –1486.5991				
	Behavioral Use_DSS		**Behavioral Intention**	
Structural	**Coef.**	**S.E.**	**Coef.**	**S.E.**
Intercept	2.744	0.776	/	/
Behavioural Intention	0.220	0.107*** (0.040)	/	/

Facilitating Conditions	0.392	0.150*** (0.009)	–0.301	0.240
Gender	–0.014	0.110	–0.082	0.103
Age	–0.195	0.120* (0.103)	0.047	0.123
Educational level	–0.003	0.123	0.202	0.141
Size	/	/	0.226	0.135* (0.093)
Legal form	/	/	0.138	0.109
Totally organic	/	/	0.001	0.101
Personal Innovation	/	/	0.313	0.156** (0.045)
Social Influence	/	/	0.063	0.124
Effort Expectancy	/	/	–0.132	0.163
Performance Expectancy	/	/	0.535	0.140*** (0.000)

* = p < 0.1; ** = p < 0.05; *** = p < 0.01
Source: Author's elaboration.

To assess the model we used the Comparative Fit Index (CFI), the Root Mean Squared Error of Approximation (RMSEA), and, on the size of residuals, the Standardized Root Mean squared Residual (SRMR) and the Coefficient of Determination (CD) (Kline & St, 2022), which show good performance in all measures of fit (Table 7).

Table 7 - Evaluation of the model fit

Index	**Value***
CFI	0.909
RMSEA	0.069
SRMR	0.074
CD	1

*CFI acceptable when it is ≥ 0.90
RMSEA good adaptation when it is ≤ 0.05
SRMR good fit when it is ≤ 0.08
CD better explanation of the variance in the data when it is close to 1
Source: Author's elaboration.

Regarding the dependent variable of the use of digital innovation, the variables "Behavioral Intention" and "Facilitating Conditions" are significant and positively influence it, while, among personal characteristics, "Age" negatively affects the likelihood of implementing DSS (as people get older, they are less likely to implement digital technology).

Consequently, successfully disseminating these innovations requires a generational shift, alongside individuals who already have their propensity for change and innovation, as well as adequate organizational and support structures to facilitate them.

This is in accordance with the responses of the interviewees who expressed a willingness to explore new technology, recognizing its role in improving their work and efficiency. They emphasized the importance of proper support structures, appropriate farm sizes, and the involvement of enthusiastic, digitally literate young people for effective implementation.

Conclusions

To address current environmental challenges and face growing market risks, it is essential a transition to sustainable and innovative agri-food systems, capable of producing positive externalities (in terms of both conservation and protection of the landscape, ecosystems and biodiversity, and climate change mitigation). This transition will also require the adoption of digital innovations (European Commission, 2020). A "twin transition" (ecological and digital) (Brunori, 2022) is therefore necessary to achieve the Sustainable Development Goals of the "Agenda 2030" (Colglazier, 2015; UN, 2015), including those relating to food security.

However, the impact of innovations largely depends on farmers' acceptance level and their ability to perceive the benefits for their businesses, as well as their ability to use them (El Bilali *et al.*, 2021). In this respect, our work aimed to identify the set of factors that influence (positively or negatively) agricultural entrepreneurs' decisions, regarding a specific innovation, namely the DSS.

The first conclusion of our study is the need to strengthen not only R&D activities to create an adequate proposal of innovative packages but also the system of dissemination of information and knowledge, through the promotion of different forms of integration of agricultural enterprises. Among the various variables considered, indeed, "Facilitating Conditions" emerged as a significant factor to enhance the implementation of DSS. Clearly, the willingness to innovate and age are essential elements for changing business management models but sharing knowledge and understanding the benefits of innovations are essential steps to boost entrepreneurs' confidence in

adopting new technologies. This is particularly important in Italy, where the adoption of these is even more problematic than in other European countries. Structural and cultural characteristics, including small farm sizes, aging owners, and the prevalence of family businesses, alongside economic, social, institutional factors, and the geographical context, complicate this process.

Organizational innovation is therefore strategically important. This means that in the implementation of agricultural policies (especially the Common Agricultural Policy-CAP) it would be necessary to define new measures aimed at informing and training farmers. For instance, advisory services within Agricultural Knowledge and Innovation Systems (AKIS), through the involvement of professionals and advisors, can enhance the flow of knowledge from researchers to end-users (European Commission, 2022a, 2022b) and increase farmers' skills, reducing the perceived complexity of the adoption process (Vecchio *et al.*, 2020), with positive implications also for their socio-economic context. Similar considerations apply to strengthening of peer support, networking, and cooperation among farmers, as these can be effective vehicles for knowledge sharing (European Commission, 2017).

Facilitating this process requires both a cultural change within farmers and the definition of a coherent set of policies and interventions. Improving the management capacity of agricultural enterprises, through the adoption of specific actions, such as, for example, developing new products, making new structural and technological investments or implementing promotional activities, necessitates a change of perspective. A collaborative approach should be adopted, involving stakeholders across the supply chain, from companies to research institutions and policymakers.

Structures such as consortia, cooperatives, or other forms of association can play a significant role in developing projects for knowledge and information transfer also by accrediting themselves as consultancy providers, increasing the competitiveness of associated farmers, and strengthening production chains and relationships within them. However, to encourage farms to join the different forms of integration/association, not only ad hoc measures would be necessary, but also the introduction of rewarding criteria in their favour in the calls for the provision of the different types of funding under the CAP.

Our study presents several limitations, mainly due to the specific sectoral and territorial characteristics of the context examined and the small sample size. Nonetheless, the study's conclusions can be considered valid at least for the organic cereals supply chain of the Marche region. It should be emphasized, in any case, that the analysis involved the administration of a carefully defined questionnaire through continuous consultation with sector experts. This approach compensated for the limited data quantity with high quality.

To generalize the findings, however, it is essential to design and carry out further research activities in production contexts beyond the organic cereal sector and in other Italian regions. At the same time, it is important to further analyze the measures adopted by the various regional administrations (and the relative distribution of funding) that directly or indirectly promote the spread of integration among actors. These forms of collaboration, as highlighted in the study, remain crucial to facilitate innovative processes in agriculture.

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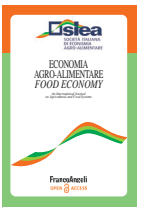

How environmentally sustainable are farms? An analysis in Southern Italy through the Life Cycle Assessment methodology

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Abstract

Promoting a sustainable economy through the digital and ecological transition of companies is one of the challenges of our century. Digital promises to reduce the ecological footprint of the agricultural sector by improving processes along the agri-food supply chains and enhancing the data generated in every single area of the value chain. One of the aims of the present research was to monitor farms in Southern Italy with the intention to evaluate the use in farm of digital technologies. A second aim was to estimate the environmental impacts and the social cost of pollution of different agricultural systems to identify the weak points in the cultivation phase. Then, more sustainable lines of intervention and alternatives in a green transition perspective were proposed. The study was carried out in three Italian regions of south of Italy and 46 cropping systems were analyzed and compared using the Life Cycle Methodology. According to the results, to date, only two farmers interviewed have started to adopt digital technologies. The comparison among the cultivation systems highlighted the greater sustainability of the organic ones. Those cropping systems characterized by a low use of resources and inputs, such as olive and hazelnut systems, were more sustainable than others. On the contrary, other systems had greater impacts due to the use of considerable quantities of materials (especially support and covering structures, as in table grapes systems, or plastic containers, as in strawberry systems). The

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disaggregation of the impacts by agricultural operations, in low material use systems, showed that the greatest impacts were due to fuel emissions, especially during the harvesting phase, and to fertilization and disease control. Hence, the need to increase organic cultivation and to carry out fertilizations using, instead of empirical approaches, modern digital and precision agriculture technologies able to consume fewer resources, reduce waste, and improve the quality of life.

Introduction

Digital technologies and environmental protection are the cornerstones of the Common Agricultural Policy (CAP) 2023-2027 (Guyomard *et al*., 2023), whose fundamental objectives are to promote a smart and resilient agricultural sector, support care for the environment and climate action, stimulate growth and employment in rural areas. Achieving these objectives requires innovation from the primary sector, which helps to reduce environmental impact, increase productivity, reduce production costs, thus becoming a basic factor for improving sustainability (Moreno *et al*., 2024).

The latest report from the Smart Agrifood Observatory highlights that the agriculture 4.0 market in Italy grew in 2022, reaching over 2 billion euros and recording a growth of +31% compared to 2021. Even the surface cultivated with 4.0 solutions has grown (from 6% in 2021 to 8% in 2022). Furthermore, the report shows that 65% of the market value is made up of connected machinery and monitoring and control systems for vehicles and equipment. Remote monitoring systems for crops, land and infrastructure are also growing strongly (+15% compared to 2021) (Aa.Vv., 2023).

The last few years have been complex for the European agri-food sector, especially due to the increase in the cost of raw materials and the severe drought that hit the entire European territory in 2022. Thus, to face the new challenges, farms are using digital technologies (agriculture 4.0), especially those related to improving efficiency and therefore reducing the use of the main production inputs (Patel and Bhatia, 2024). Referring to agri-food processing firms, 82% of these have used or experimented with at least one digital solution. Food traceability, production, logistics and quality control (of both raw materials and the finished product) are the areas where firms are innovating the most (Aa.Vv., 2023).

Many authors claim that the new technologies of Industry 4.0 can completely revolutionize agriculture, ensure greater food production

using few resources, reduce losses and waste food with overall improved environmental implications (Shepherd *et al.*, 2020; Lezoche *et al.*, 2020; Galanakis *et al.*, 2021). The application of new digital technologies (cyber-physical systems, the Internet of Things, cloud computing, advanced manufacturing solutions and big data analysis) (Leone *et al.*, 2021) would seem to lead to an improvement in the overall farm performance (Warner and Wäger, 2019). According to Abbate *et al.* (2023), the use of digital technologies can help control the impact of agricultural activities on soil and air quality, reduce the use of natural resources, pollutants, and CO_2 eq emissions, thus providing long-term economic, environmental, and social benefits.

In this context, it is important to evaluate how sustainable agri-food systems/supply chains are from an environmental point of view, in order to choose the right innovation that makes them capable of improving themselves and being truly green. The answer lies in the Life Cycle Assessment (LCA) methodology, which has been applied for years in various sectors, including the agri-food sector (De Backer *et al.*, 2009; Haas *et al.*, 2000; Brentrup *et al.*, 2001; Brentrup *et al.*, 2004; Nemecek *et al.*, 2024), which many agricultural producers already rely on to identify the weak link in the supply chain in order to adopt less impactful alternatives. We read in many places that "digital promises to reduce the ecological footprint of the agri-food sector", but this will only be possible by having a good collection of data, studies, and research on the impacts of the different production systems available.

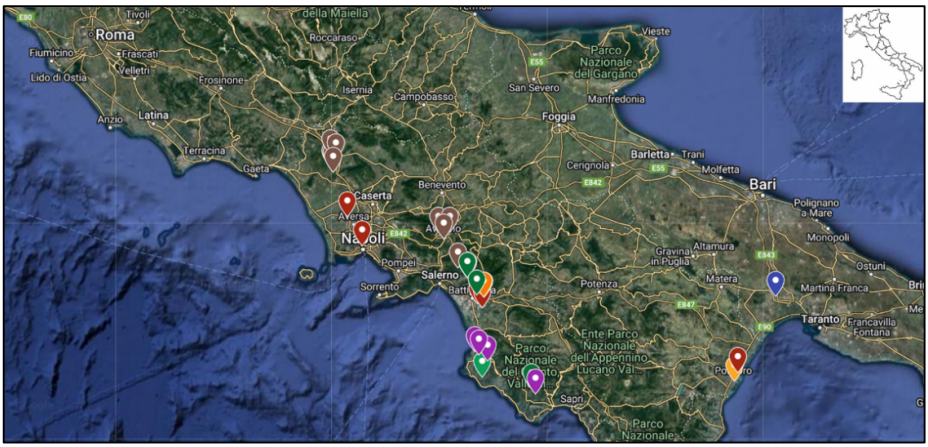
In line with what has been said, one of the aims of this research were to understand if farms located in Southern Italy are using digital technologies. A second aim was to estimate the environmental impacts and the social cost of pollution of different agricultural systems to identify the weak point in the cultivation phase and propose more sustainable lines of intervention and alternatives in a green transition perspective.

1. Materials and methods

1.1. *Description of the Analyzed Cropping Systems*

The study was carried out in Campania, Basilicata, and Apulia regions (Southern Italy) (Figure 1), where fruit growing represents one of the most important productive sectors.

Figure 1 - Study area (Campania, Basilicata, and Puglia regions - Southern Italy) and position of the cropping systems under study



The analyzed cropping systems were the following:

- three apricot growing systems including two integrated (Apricot INT1, Apricot INT2) and one biodynamic under greenhouse (Apricot B);
- eight strawberry growing systems under greenhouse including one conventional (Strawberry CON), five integrated (Strawberry INT1 - Strawberry INT5), and two organics (Strawberry OR1 and Strawberry OR2);
- one integrated kiwifruit growing system (Kiwi INT);
- one integrated peach growing system (Peach INT);
- twenty-one hazelnut growing systems including one conventional (Hazelnut CON), sixteen integrated (Hazelnut INT1 - Hazelnut INT16), and four organics (Hazelnut OR1 - Hazelnut OR4);
- six olive growing systems including two certified as organic (Olive OR1 and Olive OR2), two integrated (Olive INT1 and Olive INT2), and two organic-hobbyists (Olive HO1 and Olive HO2);
- four vineyards growing systems for wine grapes, including two organics (Grapevine OR1 and Grapevine OR2), one integrated (Grapevine INT), and one conventional (Grapevine CON);
- two vineyards growing systems for table grapes, including one organic (GRTable OR1) and one conventional (GRTable CON).

The main features of the investigated growing systems were collected by direct interviews with farmers, using a specific data collection sheet, visiting farms, and consultation on field notebooks. The cropping systems investigated differed in the:

- average yield (variable from a minimum of 1,000 kg per hectare per year, in two integrated hazelnut systems, to a maximum of 52,500 kg per hectare per year, in one of the two organic strawberry systems);
- duration of the production process (annual in the strawberry growing systems and multi-yearly in the others);
- plant density (from a minimum of 150 plants ha^{-1} in olive growing systems to a maximum of 75,000 plants ha^{-1} in strawberry growing systems);
- training system (specific to each crop and therefore multi stem, transverse ipsilon, vase, double guyot, espalier, free, awning, etc.);
- presence/absence of irrigation activities, covering and supporting structures;
- types of pruning (manual or mechanized);
- management of pruning residues (burned in the field, removed and burned in the open air, shredded in the field, composted, removed and burned in plants);
- fertilization (green manure, organic, natural, mineral);
- soil management (harrowing, milling, absent);
- disease control (natural products, conventional products, absent);
- harvesting (manual or mechanized);
- cultivation methods (conventional, integrated, organic, biodynamic, and hobbyist).

With respect to the cultivation methods, the integrated system was the most widespread in the studied areas, and it produced high-quality crop yields. It particularly followed specific protocols (MIPAF, 2008) to manage fertilization and control pests and diseases using both chemical and natural products.

More specifications on the systems analyzed can be found in Pergola *et al.* (2011, 2014, 2017, 2021, 2022, 2023, 2024) and Maffia *et al.* (2020).

1.2. *Quantification of the environmental impacts*

The LCA methodology was used to assess the environmental impacts of the cropping systems under study according to the ISO 14040-44 (ISO, 2006 a,b) through the main LCA standardized phases (goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation).

1.2.1. Goal and scope definition

The goal of the analyses was to estimate and compare the environmental impacts of 46 cropping systems in order to 1) understand if the analyzed farms were using digital technologies to be more sustainable and if there

were differences between organic, integrated, and conventional systems; 2) identify for each analyzed system (or groups of systems) the most impactful agricultural operation to try to realize how a LCA study can help in finding the optimal solution to adopt.

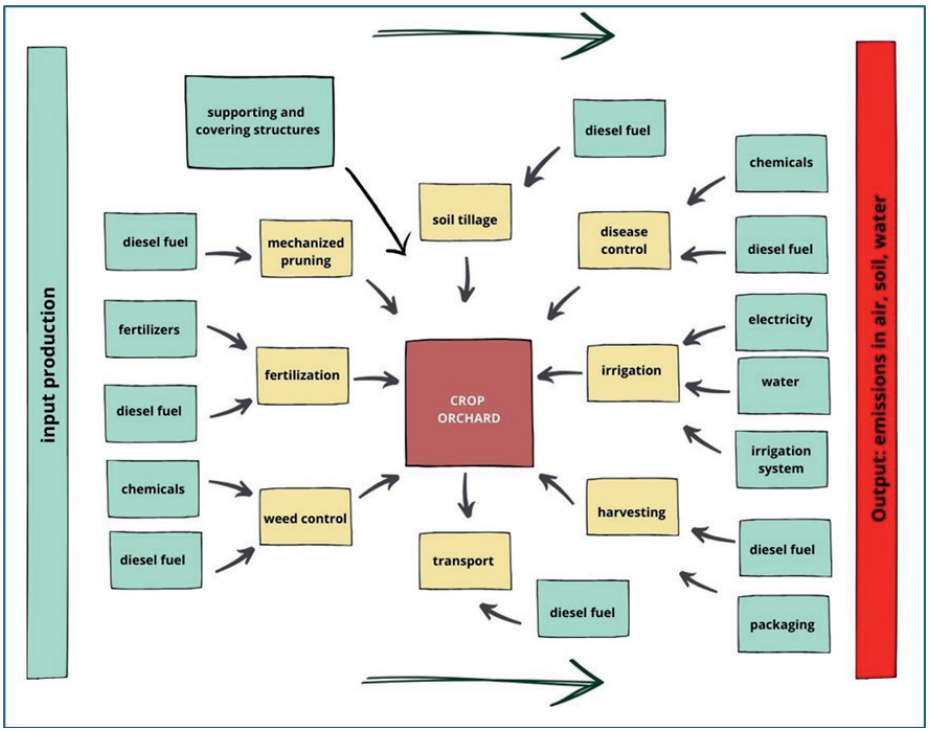
To achieve these aims, the reference period of the analysis was set to the end of one productive year and both the functional unit (the reference according to which all inputs and outputs were processed to allow comparison between systems or alternatives) (ISO, 2006) and the system boundaries were defined. The function of the systems under observation was the production of fruits, consequently, the basis for the comparison of the different systems, namely the functional unit (FU) of the service delivered, should have been the production of one kilo of fruits, as reported in other LCA studies (Coppola *et al.*, 2022; Cerutti *et al.*, 2011; Seda *et al.*, 2011). Anyway, to achieve the research aims and to better compare the analyzed systems, one hectare of cultivated land was used as FU. Indeed, it is well known that using production (1 kg) as FU can lead to errors given that less productive systems (such as organic ones) often have a greater impact per unit of product (Coppola *et al.*, 2022). Referring to the system boundaries (namely the operations and processes considered in the analysis), they went from the extraction of raw materials to the farm gate: it was a cradle to farm gate study which considered only the agricultural phase (Figure 2).

Thus, the analysis considered the production of input (fertilizers, chemicals, diesel fuel, electricity, water, etc.); the production of materials (irrigation systems; supporting and covering structures; packaging) and the following agronomical operations: soil tillage; mechanized pruning; fertilization; weed control; disease control; irrigation; harvesting and transport of the harvested products to the farm. No type of cut-off (mass, energy or economic) has been applied, namely processes contributing minimally (1%) to total impacts have not been excluded. The analysis did not consider input and materials transportation (due to lack of appropriate data), and buildings, machines and tools used in accordance with the product category rules of the different analyzed products.

1.2.2. Life cycle inventory

Primary data on the features of the investigated crops, quantity and type of materials used for irrigation systems and for support and covering structures (when present), amounts of fertilizers, chemicals, diesel fuel, water, and other items were collected in situ during the last agricultural years within technology transfer/dissemination programs within some Italian (at national and regional levels) and European projects using a data collection sheet. For

Figure 2 - The system boundaries of the LCA analysis



each operation, direct and indirect emissions were calculated considering the active ingredients of each product used. Specifically, direct emissions from fuel were taken from SimaPro's LCI databases (Ecoinvent v.3; Agri-footprint 5), while those from nitrogen fertilizers (emissions of ammonia and dinitrogen monoxide), as in other studies (Pergola *et al.*, 2017; Maffia *et al.*, 2020; Maffia *et al.*, 2022; Pergola *et al.*, 2023; Pergola *et al.*, 2024), were accounted considering the emission factors proposed by Bouwman (1995), Brentrup *et al.* (2000), and IPCC (2006). Referring to synthetic pesticides, direct emissions were estimated considering the amount of each active ingredient and following the methodology suggested by Hauschild (2000).

The embodied emissions, namely secondary data, were extrapolated from international databases of scientific importance and reliability, like Ecoinvent v.3.

1.2.3. Life cycle impact assessment

The software SimaPro 9.02 was used to perform the impact assessment according to the Environmental Prices' method developed by CE Delft (de Bruyn *et al.*, 2018). In particular, this method expresses the environmental impacts, depending on the impact category, in kg of substances emitted, square meters or cubic meters, but also in monetary units (euros). The characterization step was based on ReCiPe (2008) Midpoint, hierarchist perspective (RIVM *et al.*, 2016), with the exception of climate change, based on the IPCC 2013 values for a 100-year timeframe. The following impact categories were considered: climate change (CC); ozone depletion (OD); terrestrial acidification (TA); freshwater eutrophication (Feu); marine eutrophication (Meu); human toxicity (HT); photochemical oxidant formation (POF); particulate matter formation (PMF); terrestrial ecotoxicity (Tec); freshwater ecotoxicity (FEc); marine ecotoxicity (MEc); ionizing radiation (IR); agricultural land occupation (ALO); urban land occupation (ULO); natural land transformation (NLT); water depletion (WD); metal depletion (MD); fossil depletion (FD).

After assessing the environmental impacts (which represented the characterization phase of the analysis), the normalization of the results was performed by the estimation of the social cost of pollution. In particular, the loss of economic welfare, that occurs when one additional kilogram of the pollutant finds its way into the environment, was calculated by expressing the total impact as the sum of euros per kilogram pollutant (de Bruyn *et al.*, 2018). The environmental prices were not available for some impact categories (natural land transformation, water, metal, and fossil depletion), so they were not considered in this final step.

2. Results and discussion

Interviews with farmers showed that almost all analyzed farms to date have not adopted digital technologies useful to manage soil, water and crops (remote sensing based on satellites or drones) or farm and supply chains (Brunori, 2022). The electric forklifts, only found in the farm hosting the kiwifruit and peach systems and used for moving the harvested product, can be considered as a beginning of ecological transition. Furthermore, the capitalistic farms accommodating the Olive OR2, Kiwi INT, and Peach INT systems can be considered in transition, as they are starting to use decision support systems for disease control, irrigation networks with meteorological stations included, and grass cover control with autonomous driving with hybrid engine (diesel/electric).

The environmental analysis involved 46 systems that were very different from each other, especially in terms of crop type and cultivation system. Thus, to facilitate the presentation of the results, the systems analyzed were grouped by cultivation system. Tables 1a and 1b report the environmental impacts of organic crop systems and show that, referring to most of the impact categories (ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation and natural land transformation), the Olive OH2 system had the lowest impacts. This was included in a small, purely hobby farm that carried out no fertilization and no disease control operations, but performed manual pruning, temporary natural grass cover, disk harrowing, and manual harvesting using electric shakers (Maffia *et al*., 2020). Therefore, the unique impacts were linked to the movement of agricultural machinery in the field and to the transport of the harvested olives to the farm. Concerning climate change, particulate matter formation, and metal depletion, Strawberry OR2 was the most sustainable. This was an organic system which used solarization for soil disinfestation, biological fight for pest control, and corrugated boxes as packaging recycled at the end-of-life. Furthermore, the Grapevine OR2 was the least impacting system for the following impact categories: ionizing radiation, urban land occupation and water depletion. It was characterized by the use of chestnut poles, galvanized wire, and reeds rods as support structures; manual pruning; pruning residues used as soil mulching; organic fertilization every three years; permanent natural grass and subsequent shredding; disease control by synthetic products/resistance promoters; and manual harvesting.

On the contrary, GRTable OR1 system (organic table grapes cultivation with the "tendone" training system, a particular Apulian training system with double horizontal roofs and a planting distances of 2,5 X 2,5 meters) had the least impacts only on the category "fossil depletion" (Tables 1a and 1b).

Twenty-five integrated systems were also analyzed, but Table 2 shows only the environmental impacts of the most sustainable integrated systems and those of the most impactful ones. Data were much more variable than those observed in the organic systems. Indeed, some hazelnut systems (Hazelnut INT4, Hazelnut INT5; Hazelnut INT13; Hazelnut INT14; Hazelnut INT16) were very sustainable with respect to several impact categories. In particular, Hazelnut INT16 (an integrated hazelnut cultivation on embankments characterized by manual pruning, removal of pruning residues and their burning in the open air; annual and mineral fertilization; weed control by shredding; no soil cover management; disease control through the use of conventional products; and mechanized harvesting) stood out as the most sustainable integrated system in 8 of the 18 impact categories.

Table 1a - The environmental impact of organic systems (apricot, strawberry, and hazelnut) per *hectare*

Impact category	Unit of measurement	Apricot	Strawberry		Hazelnut			
		B	OR1	OR2	OR1	OR2	OR3	OR4
Climate Change	kg CO_2 eq	2778	8699	–972	1235	1173	1952	1387
Ozone Depletion	kg CFC-11 eq	0	0	0	0	0	0	0
Terrestrial Acidification	kg SO_2 eq	18	53	26	8	8	16	15
Freshwater Eutrophication	kg P eq	2	2	7	0	0	0	0
Marine Eutrophication	kg N eq	1	2	5	3	0	1	1
Human Toxicity	in kg 1,4-DB eq	4728	2734	9983	406	233	391	372
Photochemical Oxidant Formation	kg NMVOC	19	31	7	12	10	17	12
Particulate Matter Formation	kg PM10 eq	10	18	–10	4	4	7	6
Terrestrial Ecotoxicity	kg 1,4-DB eq	1	3	37	0	0	0	0
Freshwater Ecotoxicity	kg 1,4-DB eq	372	495	664	64	16	27	45
Marine Ecotoxicity	kg 1,4-DB eq	332	434	610	56	14	24	40
Ionizing Radiation	kBq U235 eq	429	882	1815	86	46	81	61
Agricultural Land Occupation	in m^2 $year^{-1}$	304	319	28134	868	189	320	233
Urban Land Occupation	in m^2 $year^{-1}$	275	884	97459	118	44	76	66
Natural Land Transformation	m^2	1	1	1	0	0	0	0
Water Depletion	m^3	3969	146	3334	5	3	5	4
Metal Depletion	kg Fe eq	1313	9214	–6508	208	117	202	194
Fossil Depletion	kg oil eq	308	4368	2087	373	315	540	397

Table 1b - The environmental impact of organic systems (olive, grapevine, and grape table) per *hectare*

Impact category	Unit of measurement	Olive				Grapevine		GRTable
		OR1	OR2	HO1	HO2	OR1	OR2	OR1
Climate Change	kg CO_2 eq	1065	591	855	314	1227	182	66495
Ozone Depletion	kg CFC-11 eq	0	0	0	0	0	0	1
Terrestrial Acidification	kg SO_2 eq	7	10	5	2	12	10	739
Freshwater Eutrophication	kg P eq	0	0	0	0	0	0	12
Marine Eutrophication	kg N eq	0	0	0	0	1	0	39
Human Toxicity	in kg 1,4-DB eq	425	154	176	68	626	245	26011
Photochemical Oxidant Formation	kg NMVOC	10	5	7	3	12	4	288
Particulate Matter Formation	kg PM10 eq	4	3	3	1	5	3	284
Terrestrial Ecotoxicity	kg 1,4-DB eq	21	16	0	0	0	24	95
Freshwater Ecotoxicity	kg 1,4-DB eq	79	22	19	7	80	22	558
Marine Ecotoxicity	kg 1,4-DB eq	236	145	17	6	70	211	526
Ionizing Radiation	kBq U235 eq	69	32	54	20	87	19	54
Agricultural Land Occupation	in m^2 $year^{-1}$	206	94	144	60	271	111	16704
Urban Land Occupation	in m^2 $year^{-1}$	88	35	62	23	92	21	27302
Natural Land Transformation	m^2	0	0	0	0	0	0	7
Water Depletion	m^3	4	2	3	8	3	–4	4573
Metal Depletion	kg Fe eq	236	80	90	35	304	89	1153
Fossil Depletion	kg oil eq	322	150	251	95	186	–361	–16600

Strawberry INT3 (strawberry cultivation in which the plants were grown on rows made ex novo during the production cycle, according to the ordinary cultivation techniques and supplemented by seven root applications – via fertigation – of compost tea produced on-farm) and Strawberry INT5 (strawberry cultivation in which the plants were grown on rows already used in the previous production cycle and in which the ordinary cultivation techniques were carried out together with seven root applications – through fertigation – of compost tea produced on-farm) were the most impactful systems among the integrated ones: the first regarding climate change, photochemical oxidant formation, agricultural land occupation, water depletion, and fossil depletion; the second regarding ozone depletion, marine eutrophication, human toxicity, freshwater ecotoxicity, marine ecotoxicity, ionizing radiation, urban land occupation, and natural land transformation (Table 2).

Among the conventional systems, Grapevine CON (a conventional vineyards characterized by chestnut poles, galvanized poles, PVC wire as support structures; manual pruning; pruning residues used as soil mulching; mineral fertilization performed every three years; temporary natural grass cover and disk harrowing; disease control by conventional products; manual harvesting) proved to be the least impactful system in reference to almost all impact categories, except for freshwater eutrophication, human toxicity, freshwater ecotoxicity, and marine ecotoxicity for which the greatest sustainability was recorded for Hazelnut CON system (a conventional hazelnut cultivation characterized by manual pruning; shredding of pruning residues on field; annual and mineral fertilization; weed control by shredding and rarely use of glyphosate; milling and harrowing operations; disease control through the use of conventional products; and mechanized harvesting). On the contrary, GRTable CON (a conventional table grapes cultivation with the "tendone" training system and a planting distances of 2,5 X 2,5 meters) was the most impactful system among the conventional ones (but also overall among all the systems analyzed). At the same time, Strawberry CON (a conventional strawberry cultivation in which the plants were grown on rows made ex novo and managed during the production cycle according to the ordinary cultivation techniques) was the most impactful towards the following categories: terrestrial ecotoxicity, marine ecotoxicity, ionizing radiation, and fossil depletion (Table 3).

Table 2 - The environmental impact of integrated systems per *hectare*

Impact category	Unit of measurement	Strawberry			Kiwi	Hazelnut				
		INT 1	INT 3	INT 5	INT	INT 4	INT 5	INT 13	INT 14	INT 16
Climate Change	kg CO_2 eq	7949	11431	11068	5186	1377	1276	1726	1810	1880
Ozone Depletion	kg CFC-11 eq	0	0	0	0	0	0	0	0	0
Terrestrial Acidification	kg SO_2 eq	135	64	63	51	16	22	9	16	12
Freshwater Eutrophication	kg P eq	1	6	6	1	7	0	0	0	0
Marine Eutrophication	kg N eq	5	4	6	2	0	1	1	1	1
Human Toxicity	in kg 1,4-DB eq	1230	14545	14641	2208	360	252	388	185	241
Photochemical Oxidant Formation	kg NMVOC	18	52	49	17	6	9	9	6	4
Particulate Matter Formation	kg PM10 eq	20	18	18	13	4	6	4	4	3
Terrestrial Ecotoxicity	kg 1,4-DB eq	3	389	393	495	0	0	0	0	0
Freshwater Ecotoxicity	kg 1,4-DB eq	175	1232	1261	439	16	23	48	23	26
Marine Ecotoxicity	kg 1,4-DB eq	153	6540	6546	4383	14	21	50	25	23
Ionizing Radiation	kBq U235 eq	505	1689	1701	135	36	64	138	61	28
Agricultural Land Occupation	in m^2 $year^{-1}$	366	805	785	364	102	162	169	107	43
Urban Land Occupation	in m^2 $year^{-1}$	1256	378358	378404	301	39	70	134	49	24
Natural Land Transformation	m^2	1	2	2	1	0	0	0	0	0
Water Depletion	m^3	119	9095	9088	20	4	6	237	6	9
Metal Depletion	kg Fe eq	–1253	–251	–57	1104	73	122	144	86	70
Fossil Depletion	kg oil eq	3539	5434	5069	–29	326	351	516	262	222

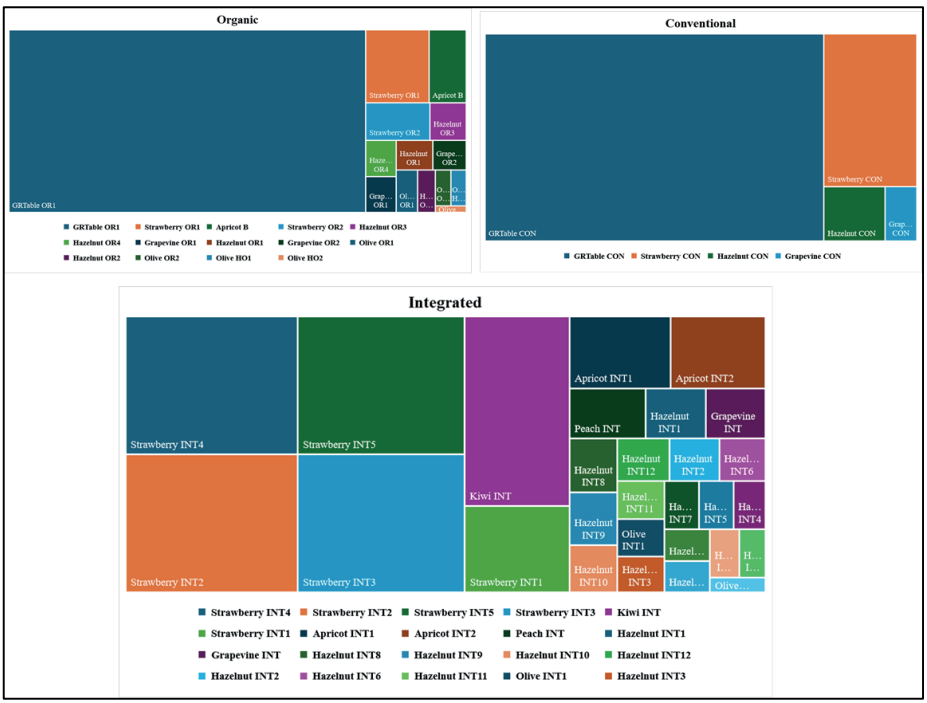
Table 3 - The environmental impact of conventional systems per *hectare*

Impact category	**Unit of measurement**	**Strawberry CON**	**Hazelnut CON**	**Grapevine CON**	**GRTable CON**
Climate Change	kg CO_2 eq	7046	2594	1384	63703
Ozone Depletion	kg CFC-11 eq	0	0	0	1
Terrestrial Acidification	kg SO_2 eq	54	51	10	456
Freshwater Eutrophication	kg P eq	2	1	1	12
Marine Eutrophication	kg N eq	3	2	1	26
Human Toxicity	in kg 1,4-DB eq	3998	1056	1512	26092
Photochemical Oxidant Formation	kg NMVOC	29	16	14	289
Particulate Matter Formation	kg PM10 eq	10	12	6	248
Terrestrial Ecotoxicity	kg 1,4-DB eq	379	1	0	96
Freshwater Ecotoxicity	kg 1,4-DB eq	437	230	321	524
Marine Ecotoxicity	kg 1,4-DB eq	5937	225	279	498
Ionizing Radiation	kBq U235 eq	1070	175	93	118
Agricultural Land Occupation	in m^2 $year^{-1}$	443	310	271	12179
Urban Land Occupation	in m^2 $year^{-1}$	836	203	125	27635
Natural Land Transformation	m^2	1	1	1	6
Water Depletion	m^3	1592	17	7	4573
Metal Depletion	kg Fe eq	–1621	549	922	1156
Fossil Depletion	kg oil eq	4522	689	305	–16339

Given the heterogeneity of the analyzed systems, the characterization phase allowed us to make only a few considerations. Indeed, the comparison just presented highlighted, among different crops, those which by their nature can be considered more sustainable than others (as olive and hazelnut systems) because linked to a management characterized by a low use of resources and inputs. On the contrary, other systems (like strawberries and table grapes) require the use of considerable quantities of items, especially support and covering structures. The system with the least impact was Olive OH2, a hobby system whose production was not intended for sale, but only for family consumption. On the contrary, in the panorama of farms that sold their products both on local, national and even international markets, the situation was more complex and did not allow the most virtuous or impactful system to be identified.

Therefore, to better compare the results, the normalization of them through the estimation of the total cost of pollution was very useful. Among the organic systems, GRTable OR1 was the most impactful system; among the conventional ones, the table grape system, while, among the integrated ones, strawberries, followed by kiwifruits, appeared the less sustainable systems (Figure 3).

Figure 3 - Comparison of the total impact (cost of pollution) of the systems analyzed divided by cultivation method



However, the comparison among cultivation systems (organic, integrated, and conventional) allowed us to highlight the greater sustainability of organic systems. This was clearly noticeable where it was possible to compare the cultivation of the same crop under organic and integrated/conventional management (as occurred for apricot, grapevine, table grapes, hazelnut, olive, and strawberry). The total cost of pollution of the different systems analyzed widely highlighted this finding (Table 4). Therefore, the first step for the ecological transition in agriculture is the conversion of cultivation systems to organic. Indeed, increasing the European Union's agricultural land dedicated to organic farming by at least 25% by 2030 is one of the objectives of the Farm to Fork Strategy (European Commission, 2020).

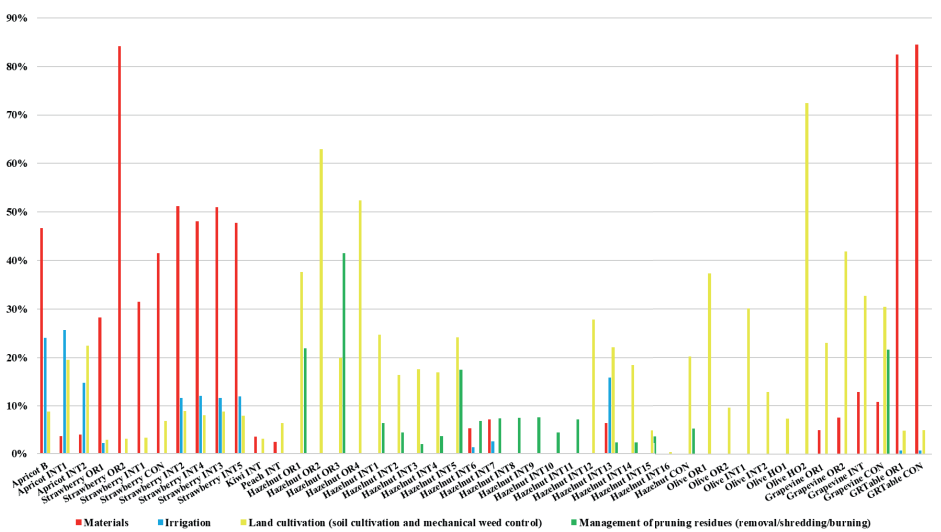
Table 4 - The cost of pollution of the cropping system analyzed

System	Euros	System	Euros
Apricot B	1240	Hazelnut INT4	444
Apricot INT1	2150	Hazelnut INT5	492
Apricot INT2	2013	Hazelnut INT6	577
Grapevine OR1	501	Hazelnut INT7	495
Grapevine OR2	454	Hazelnut INT8	754
Grapevine CON	621	Hazelnut INT9	745
Grapevine INT	875	Hazelnut CON	1204
GRTable OR1	25486	Olive HO1	253
GRTable CON	29732	Olive HO2	94
Hazelnut OR1	493	Olive OR1	414
Hazelnut OR2	345	Olive OR2	258
Hazelnut OR3	618	Olive INT1	514
Hazelnut OR4	506	Olive INT2	239
Hazelnut INT1	888	Strawberry OR1	2111
Hazelnut INT10	663	Strawberry OR2	1098
Hazelnut INT11	522	Strawberry INT1	2661
Hazelnut INT12	651	Strawberry INT2	6995
Hazelnut INT13	420	Strawberry INT3	6780
Hazelnut INT14	418	Strawberry INT4	7016
Hazelnut INT15	430	Strawberry INT5	6798
Hazelnut INT16	369	Strawberry CON	5155
Hazelnut INT2	627	Kiwi INT	5852
Hazelnut INT3	501	Peach INT	1126

At the same time, however, within the hazelnut systems, some integrated systems were found to be more environmentally sustainable than other organic ones. This was the case of INT16, INT14, INT13, INT15, INT4, and INT5 when they were compared to Hazelnut OR1 (Table 4). Consequently, from an ecological transition perspective, field management according to the principles of integrated agriculture has also proven to be a valid alternative. In fact, it is a production strategy based on the principles of awareness and analysis, guaranteed and maintained through technical preparation, constant updating of skills, technical adequacy of the tools, and "integrated" intervention strategies (which combine prevention, monitoring and targeted intervention). In this sense, the meaning of the term "integrated" combines the concepts of sustainable and safe.

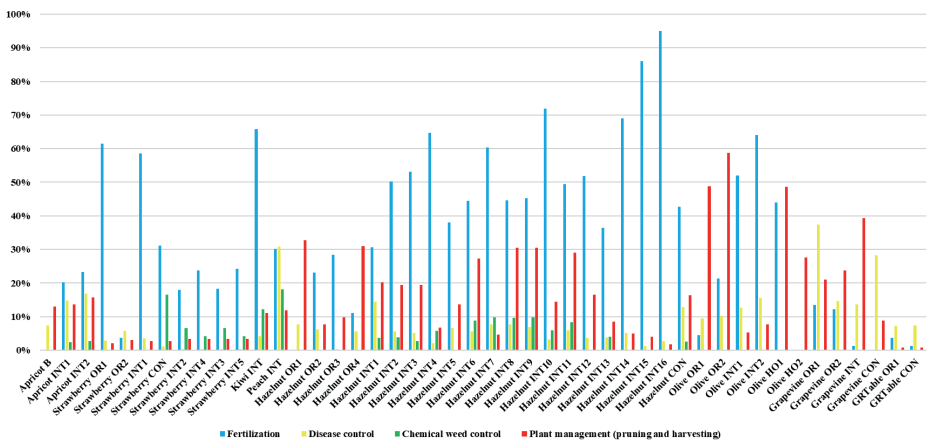
The disaggregation of the impacts by individual operation/item, reported in Figures 4 and 4bis, highlighted that materials represented the greatest impact in those systems adopting important support (such as the cultivation of table grapes) and coverage structures (such as the cultivation of apricot trees under greenhouse - Apricot B) and making use of significant quantities of packaging (for example plastic containers in the production of strawberries). Consequently, the impact of the production of the different materials used in the analyzed systems represented 84% of the total impact in GRTable CON and in Strawberry OR2, 82% in GRTable OR1, and 50% in other Strawberry systems (Figure 4).

Figure 4 - Contribution of the cultivation operations on the total cost of pollution in the different systems analyzed



On the contrary, in other systems (such as some olive and hazelnut systems) the greatest impacts were due to emissions from fuels, especially during the harvesting phase, while in others (Strawberry OR1, Strawberry INT1, Kiwi INT, Hazelnut INT2, Hazelnut INT3, Hazelnut INT4, Hazelnut INT7, Hazelnut INT12, Hazelnut INT14, Hazelnut INT15, Hazelnut INT16, Olive INT1, Olive INT2) the use of fertilizers and other disease control products caused 50% to 80% of impacts (Figure 4bis).

Figure 4bis - Contribution of the cultivation operations on the total cost of pollution in the different analyzed systems



The results obtained by the LCA analysis could be useful for farmers, farmer associations, and technicians to identify the best cultivation techniques or the weak link in agricultural production, in order to reduce emissions and, consequentially, to make their contribution to the ecological transition. In particular, the analysis just conducted makes it clear to what extent the systems under study are more or less sustainable and how much there is still to be done. Surely today farmers cannot produce without having an impact, but they can intervene by bringing improvements in production processes and cultivation techniques, using, for example, digital innovations to make the various agricultural products more sustainable. Thus, satellite guidance technologies, the precision in cultivation operations and data management for the reduction of packaging, synthetic products, water, and waste seem to be the most widespread solutions at the moment, which could be widely applied in systems that make extensive use of plastic containers, fertilizers, pesticide and other chemical products. In this regard,

as reported in Abbate *et al*. (2023), precision agriculture techniques appear to be important for reducing resource waste, pollution and increasing quality of life, thus contributing to the achievement of sustainable development goals (Bhakta *et al*., 2019). The Internet of Things (IoT) is at the heart of smart agriculture and, according to Wu and Ma (2020), can convert and improve conventional agriculture by lowering costs, reducing emissions, and increasing efficiency and quality. Therefore, intelligent water management, smart temperature, humidity and lighting control system of greenhouses, based on various IoT, including sensors and cloud, can provide crops with the precise amount of resources they need, improving their fertility and avoiding waste and environmental pollution (Abbate *et al*., 2023). At the same time, there are several examples in the agricultural sector of cloud-based platforms for acquiring and managing data. Indeed, Manna *et al*. (2020) demonstrated how a new type of Decision Support Systems (DSS) built on the open-source Geospatial Cyberinfrastructure (GCI) platform could serve as a critical web-based operational tool for olive farming by better connecting productivity and environmental sustainability. In the viticulture sector, Terribile *et al*. (2017) showed that a new geospatial DSS, developed on a GCI platform, can provide a web-based operational tool for high quality viticulture providing operational support for farmers, farmer associations and decision makers involved in the viticulture landscape. At the same time, these digital technologies should be analyzed on a case-by-case basis in order to identify the best digital innovation to introduce into the farm, without neglecting a cost-benefit analysis that takes into account the real economic possibilities of the various farmers to understand whether they are able to bear these costs.

Conclusions

The research, through the analysis of different cropping systems, aimed to highlight the importance of conducting an LCA study to quantify sustainability of crop productive chains, identify the most impactful operations and find the best technical solution. In short, the results showed the greater sustainability of organic cultivation and how the production of materials (used in support and covering structures and in packaging), mineral nitrogen fertilization, fuel consumed during harvesting and the use of disease control products are the most impactful items, whose damage in some cases can represent up to 80% of the total impact. Hence the need to find less impactful alternatives. However, if mineral fertilizers and synthetic pesticides can be replaced with natural products (on-farm compost, biological control), it seems more difficult to replace the other items (materials and fuel), for the functions they must perform. The difficulty

of introducing digital technologies is demonstrated by the fact that, at the moment, of the farms analyzed, only two are in transition and are starting to adopt these technologies to be less impactful and consume fewer resources. Consequentially, the effect of this transition can only be verified in the coming years.

Furthermore, the results of the present research represent a contribution to the literature on LCA studies in agriculture, but at the same time they should be refined with economic analyses, to understand the profitability of farms, and social sustainability analyses, in order to have a complete picture and give the best operational indications to both farmers and policy makers. At the same time, there is the need to spread the use of the LCA methodology in the agricultural sector to quantify the impacts of the farms and consider it the starting point for the dual green and digital transition. For this purpose, it would be appropriate to increase the statistical base of the agricultural phase of the different analyzed systems for the creation of benchmarks to have elements of comparison for each crop and between cultivation systems. Only in this way the most virtuous farms, from an environmental, social and economic point of view, could be supported and rewarded, for example with more targeted CAP aids.

Finally, there is also the need to extend the evaluation to post-harvest and to the different types of processed products, with particular reference to small farms, and introduce carbon sequestration into the evaluation. This could help to think the agricultural sector in terms of carbon balance and not to evaluate it only through the "lens" of the impacts and damage it causes, but also from a more positive perspective.

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PDO Economy and Quality Agri-Food District in the wine sector: Blockchain and digitalization as tools for the twin transition

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Abstract

The twin transition has great potential for the development of the wine sector, although its benefits for the valorisation of the Protected Designation of Origin (PDO) economy and at the quality districts level are not explored in depth either in the theoretical or empirical literature. The study aims to contribute to this knowledge gap from a strictly conceptual perspective, by investigating benefits and obstacles that Blockchain and digital technologies can have to favour the creation and implementation of a quality wine district towards a sustainable path. Based on the literature background and a case study approach, the Vermentino di Gallura PDO Quality District, this study discusses the prospects and hypotheses of introducing Blockchain technologies and other digital tools at district level and the challenges and opportunities for fostering its sustainable transition. Preliminary results suggest that this transition could benefit the local supply chain and its territory over different pillars of sustainability, although obstacles can be expected along the implementation path. Obstacles can be in various areas – among which are the breadth and variety of processes included within the boundaries of the digital transition and the inter-organizational nature of the twin transition.

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Introduction

The concept of twin transition has received strong input from the current EU policy's priorities aiming at 'twinning the green and digital transitions in the new geopolitical context' (European Commission, 2022). As such, the term twin transitions "not only refers to two concurrent transformational trends (the green and digital transitions) but also to uniting the two transitions" (*ibidem*, p. 7, 2022) and coupling digital technologies with sustainable development, to focus on their interconnection and a simultaneous process of change towards two related but distinct goals (Müller *et al*., 2024). Anyway, separate, well-established research traditions on both digitalization and sustainability formed a major part of the literature, and only recently, a growing interest in investigating them jointly has emerged (Müller *et al*., 2024). Indeed, the twin transition implies considering how green and digital may enter a virtuous cycle in which the green/digital sphere is at the starting point of the cycle – as a driver – and at the end of it – as an outcome – producing an intersection that is mutually beneficial and creates room for further improvement.

Moreover, it should be noted that joining the green and digital world requires connections both in the various technologies, in the transition paths, outcomes and feedback, and for a systems approach in which they reinforce each other (Montresor & Vezzani, 2023).

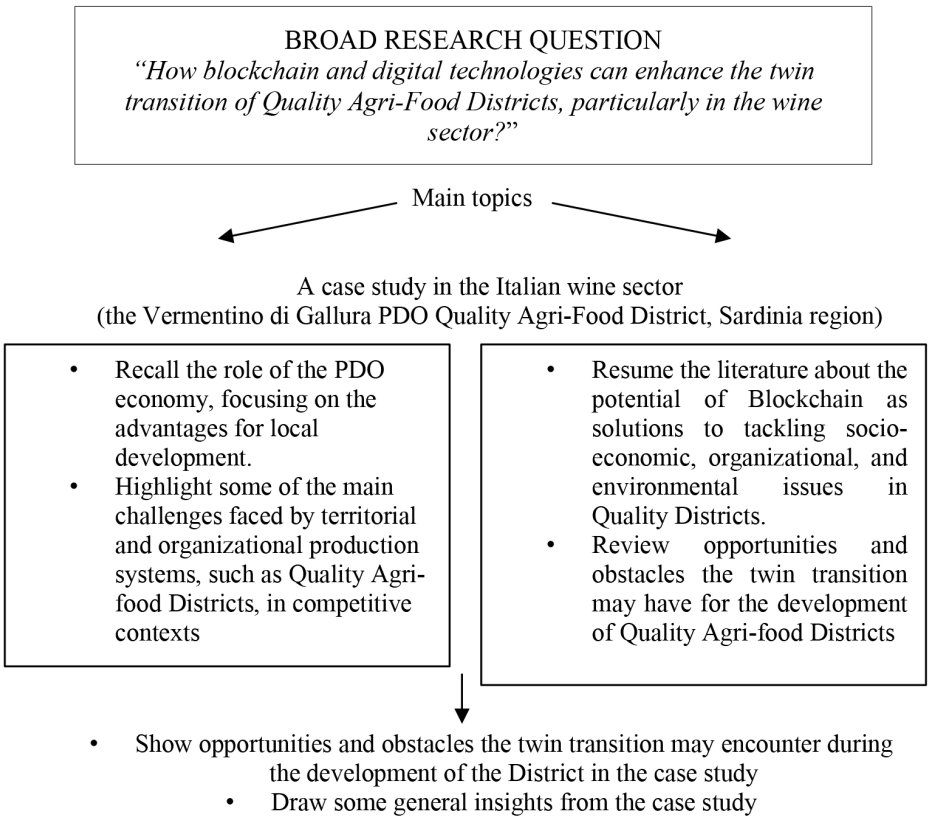
The growth of Information and Communication Technologies over the last decade has provided several opportunities to overcome some of the challenges faced in agriculture, although some side effects and digital divides have been signalled in the Italian case (Gnesi *et al*., 2022). Recent literature has devoted a lot of attention to applying Blockchain technology and other digital tools to the agri-food sector (Chiaraluce *et al*., 2024; Priya *et al*., 2024). The agri-food supply chain is considered among the most promising areas for the future development of digital technologies towards a sustainable transformation of the sector (Myshko *et al*., 2024; Rana *et al*., 2021).

The innovative contribution of the study compared to the existing literature is that in this case, it is not a question of applying Blockchain to a single company but to a (specific) Quality Agri-Food District. Furthermore, in the current literature, Blockchain technology has been analyzed as a tool capable of overcoming critical issues or facilitating production processes at the individual company level (Cuel & Cangelosi, 2020; Dicuonzo *et al*., 2021; Van Huy *et al*., 2024), at the consortium level (Agata *et al*., 2021; Zheng & Jiang, 2024), in the hospitality and tourism sector (Van Huy et al, 2024), for environmental sustainability (Myshko *et al*., 2024) and in the application of Social-Life Cycle Assessment (D'Eusanio & Petti, 2024) (just to mention a few). In this research instead, we focus on the use of Blockchain as a tool

capable of supporting the *districtisation* process (intended as a transition from a local production system to a Quality Agri-Food District) and at the same time, promote the digital and ecological transition.

Figure 1 summarizes the conceptual framework of the study.

Figure 1 - The conceptual framework of the study



The research uses the "case study" as a research method (Yin, 2009) which is applied in economics when "the structure of a given sector or the economy of a city or region is being investigated" (p. 4).

The paper is structured as follows: the first part of the work describes the PDO economy and the Quality Agri-Food District, and reports the literature background about Blockchain systems and digital tools for the wine supply chain; the second part describes the case study (the PDO

Vermentino di Gallura Quality Agri-Food District, Sardinia region); the third part discusses the role of Blockchain Technologies in supporting the District implementation, both along the wine supply chain and the non-winery actors, i.e. by enlarging its boundaries to the tourism valorization and the twin transition.

1. Background

1.1. *The Protected Designation of Origin economy and Quality Agri-Food District: advantages and criticalities*

The term "PDO Economy", which has now become part of the common language, has a very recent origin and was coined for the first time in the XVI Ismea-Qualivita Report on Italian agri-food and wine production PDO, Protected Geographical Indication (PGI) and Traditional Specialty Guaranteed (TSG) (Rosati, 2018). In 2021, it became part of the Treccani Vocabulary and was defined as a "Segment of the production and transformation of agricultural products intended for Geographical Indication food, which constitutes an important part of the national agri-food value".

The economic value of the Italian agri-food system reached 20.2 billion euros in production value by 2022, representing a 19% increase compared to 2020. In terms of export value, it amounted to 11.6 billion euros, marking a 22% growth since 2020. This growth contributed to a 20% increase in the overall turnover of the Italian agri-food sector (Ismea-Fondazione Qualivita, 2023). The system includes 853 PDO, PGI (Protected Geographical Indication), and TSG (Traditional Speciality Guaranteed) products. It supports approximately 890,000 jobs in the GI (Geographical Indication) supply chains, involves over 195,000 operators within GI agri-food and wine supply chains, and comprises 296 Protection Consortia authorized by the Ministry of Agriculture, Food Sovereignty, and Forestry (Masaf).

The wine sector is particularly significant, contributing to 62% of all PDO and PGI products registered in Italy. It accounts for 56% of the production value of bottled products within the total agri-food and wine market and 60% in terms of export value. The GI wine supply chain engages around 110,000 operators (including winemakers and bottlers), supports 340,000 employees, and consists of 128 Protection Consortia approved by Masaf.

While the PDO economy centered on the wine sector impacts the entire national territory, approximately 75% of the economic value of PDO/PGI wine is concentrated in five regions: Veneto, Piedmont, Tuscany, Friuli Venezia Giulia, and Trentino Alto Adige. Beyond the quantitative aspects,

the role of food as a driver for regional development is essential (Hall & Mitchell, 2004; Rachao *et al.*, 2018), particularly for products with designated origins and the associated territorial governance (Ciliberti *et al.*, 2024; Ismea-Fondazione Qualivita, 2023).

Most of the PDO economy is characterized by district-based production organizations. The legislation introduced in Italy in 2001 played a pivotal role in establishing quality agri-food districts. The Law for the Orientation and Modernization of the Agricultural Sector (Legislative Decree No. 228 of May 18, 2001) defined "districts" as governance tools that allow local communities autonomy to make decisions regarding suitable interventions on a limited territorial scale. Quality Agri-Food Districts are described as "local production systems, even interregional, characterized by significant economic presence and production interrelationships, with interdependence of farms and agri-food enterprises, and by one or more certified or protected products in compliance with applicable Community or national regulations, or by traditional or typical products" (Article 13).

In 2011, the National Institute of Statistics identified 141 industrial districts, predominantly situated in Northern and Central Italy. Notable examples include the Prosecco DOC district in Veneto, the San Daniele-Parma agri-food district in Emilia Romagna, the agri-food district of La Morra in Piedmont, the Pecorino district in Sardinia, and the fruit and vegetable district of Pachino in Sicily.

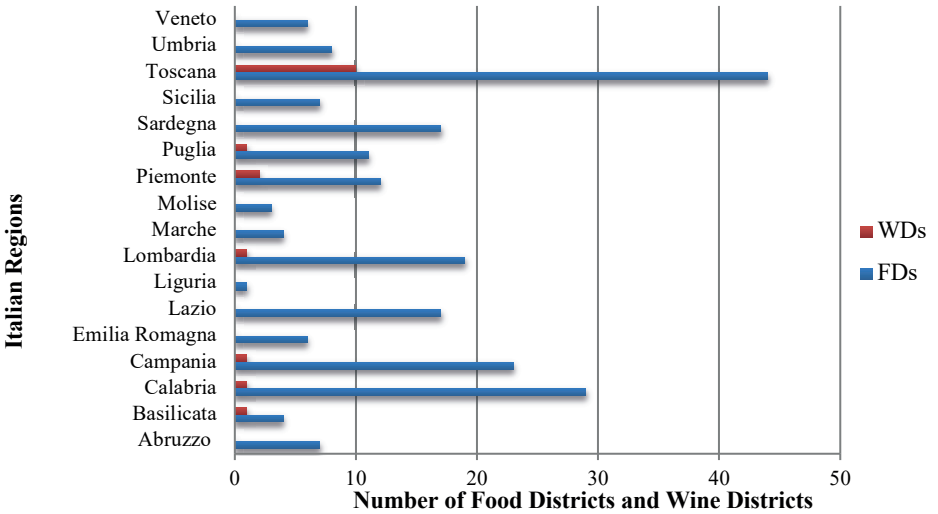
The National Law No. 205/2017 amended prior legislation on agri-food districts and introduced Food Districts (FDs) as a developmental model for the Italian agri-food sector. This law significantly propelled the formation and growth of new districts. As of April 5, 2024, there are currently 218 Food Districts in Italy.

The incidence of Wine Districts (WDs), which are areas where wine is the dominant industry, is relatively limited, making up only 8% of the total Food Districts (FDs), with the majority concentrated in Tuscany. In these regions, the territory plays a vital role as a "versatile integrator" among businesses, productive sectors, and the population. It is within the territory that local communities form through the integration of production, consumption, and the fulfillment of their needs (Sforzi, 2000, p. 186).

It is important to address some critical challenges that Protected Designation of Origin and Protected Geographical Indication (PGI) production systems face in order to maintain their competitive advantage, especially in the international arena.

Firstly, key issues include the need for protection against counterfeiting and the enhancement of traceability and transparency for consumers. Greater transparency throughout the supply chain allows for reliable product certification from the field to the table. This certification not only safeguards

Figure 2 - Distribution of Food Districts and Wine Districts in Italy (to 5 April 2024)



Source: Our elaboration on data available on www.politicheagricole.it.

producers but also protects consumers by reducing information asymmetry and enhancing the brand's reputation, as well as that of the Denomination of Origin and/or the Quality Agri-Food District.

From an institutional and organizational perspective, it is crucial to focus on the rationalization of territorial governance. As highlighted in the XXI Ismea-Qualivita Report 2023, this approach can lead to less conflictual governance, especially in areas where PDO and PGI products serve as the foundation of the local economy.

In designing a new production paradigm and overcoming the critical issues identified, useful support could come from a twin transition process of the PDO/PGI food and wine production systems favored by the implementation of Blockchain and other digital technologies. The following paragraphs will be dedicated to an examination of the literature that addressed these issues.

1.2. *Literature background: the twin transition in the agri-food chain*

The topic of twin transition in the agri-food supply chain has garnered significant attention in recent literature. Various reviews on the subject provide insights relevant to this study. According to Marvin *et al.* (2022), Artificial Intelligence (AI), big data, and digitalization possess great potential to support the transition towards a sustainable food system. This is especially

important given the complexity of agri-food systems and the vast amounts of data that require substantial computational infrastructure.

Myshko *et al.* (2024) offer a detailed overview of the literature concerning the digital transformation of the agricultural and agri-food sectors. They address several topics, including the characteristics and applications of technologies across the supply chain's nodes, environmental issues predominantly tackled by digital technologies, the identification of key stakeholders, and the sustainability outcomes of the digital transformation process. In their review, Myshko *et al.* ranked digitalization's contributions across four environmental areas: resource use reduction, environmental impact reduction, waste management, and ecosystem protection. Among the specific digital tools, the Internet of Things (IoT) was the most frequently mentioned technology in all areas, followed by Blockchain technologies.

The integration of digitalization and sustainability requires not only changes in functions and the inclusion of new actors but also improved coordination at all system levels, among networks of actors, and through their interaction channels. Checchinato *et al.* (2022) highlighted the intersection between digital applications and sustainability strategies within agri-food firms. They noted that while there is substantial academic and policy work investigating the pillars of sustainability in agriculture, only a limited number of studies link sustainability to digitalization. The primary drivers for implementing digital technologies in agri-food supply chains are largely found in the production stage (Checchinato *et al.*, 2022; Myshko *et al.*, 2024).

Specifically focusing on the support of Blockchain technology for sustainability in the food sector, Duan *et al.* (2020) pointed out that Blockchain's characteristics – such as decentralization, security, immutability, and smart contracts – have the potential to enhance sustainable food supply chain management and food traceability. However, they also identify several potential challenges, including a lack of understanding of Blockchain technology, technical difficulties, raw data manipulation, stakeholder involvement, and insufficient regulations.

Within the context of this study, Brunori (2022) discussed the twin transition towards sustainable rural digitalization, suggesting real-life experiments and emphasizing governance, rural strategies, and integrated policies. Lastly, Ciliberti *et al.* (2024) examined a case study of the Consortium for Parmigiano Reggiano, discussing the impacts of its digitalization strategy on natural resource management. They noted improvements in reducing inefficiencies and enhancing communication; however, the green pillar was not fully incorporated within a twin transition context due to limited integration of the digitalization strategy with ecological transition efforts.

1.3. *Literature background: Blockchain systems for wine supply chain and non-winery sectors*

Several reviews have connected Blockchain technology to the wine sector (Costa *et al.*, 2023; Bastard & Chaillet, 2023; Malisic *et al.*, 2023; Parry *et al.*, 2023; Luzzani *et al.*, 2021). The interest in applying Blockchain in this sector (OIV, 2021) can be attributed partly to the internal characteristics and needs of the industry and partly to the opportunities that Blockchain technology presents in addressing these needs.

Literature has primarily explored the opportunities and benefits offered by Blockchain technologies, focusing on transparency and traceability (Kramer *et al.*, 2024; Sun *et al.*, 2022; Gayialis *et al.*, 2022), as well as counterfeiting and building trust (Silvestri *et al.*, 2023; Tokkozhina *et al.*, 2022; Danese *et al.*, 2021). Some studies highlight the added value of Blockchain compared to other virtual systems and the advantages of integrating them (Pullo *et al.*, 2023; Popović *et al.*, 2021). Conversely, other literature – both in hypothetical scenarios and real-world cases – has examined the challenges of implementing Blockchain and the resources required, such as financial, human, and organizational resources (Adamashvili *et al.*, 2024; Silvestri *et al.*, 2023; Sternberg *et al.*, 2021).

Most studies adopted a case study approach, driven by the novelty of the phenomenon. These studies often link real-life experiences to theoretical frameworks developed across various disciplines. Additionally, several studies conducted surveys to gather the opinions of experts and stakeholders in the supply chain. These surveys aimed to assess the readiness for introducing Blockchain technologies, evaluate the diffusion of existing Blockchain applications among participants in the wine supply chain (Agata *et al.*, 2021), and investigate the potential benefits and obstacles (Sternberg *et al.*, 2021) when Blockchain was only anticipated or already applied in practical cases.

Most literature focuses on individual firms, particularly medium-sized enterprises and small- to medium-sized enterprises (SMEs), with integrated processes ranging from vineyards to wine production or simplified supply chains (Cuel & Cangelosi, 2020; Dicuonzo *et al.*, 2021; Longo *et al.*, 2023; Prencipe *et al.*, 2022; Richter & Hanf, 2021). These studies mostly employ a descriptive approach, which hinders the replicability of Blockchain design, structure, and procedures across different wine industries and supply chains. As Danese *et al.* (2021) noted, "the literature still lacks a clear operationalization of the Blockchain system construct, as well as a complete overview of all the relevant variables that can be used to design a Blockchain system" (p. 2).

Due to the early adoption of Blockchain technology and the limited number of real case studies available, there is no comprehensive assessment of its impacts on companies – regarding business models, effectiveness and

efficiency of inter-organizational processes, and overall performance – as well as on consumers. However, some studies have attempted to extrapolate impacts using qualitative methods (Cuel & Cangelosi, 2020).

Although the Blockchain case studies examined vary in context, they commonly consider extensive information to be digitized across the supply chain. This includes data on grape varietals used, origin areas, and cultivation processes (e.g., vineyard location, age, surface area, yield, climate, water and soil conditions, and pesticide and fertilizer applications); details about wine producers, cooperatives, integrated wineries, and transformation processes (e.g., type of winery, number of bottles produced, varietal composition, and chemical and organoleptic characteristics of the wine); as well as information on storage companies and market intermediaries (e.g., tank types, contents, storage/transportation dates, and transport distances). Additional content may include certifications and eco-labels, multimedia elements (e.g., videos and storytelling), and information about recipes, events, fairs, tastings, and wine tourism activities related to specific bottles of wine.

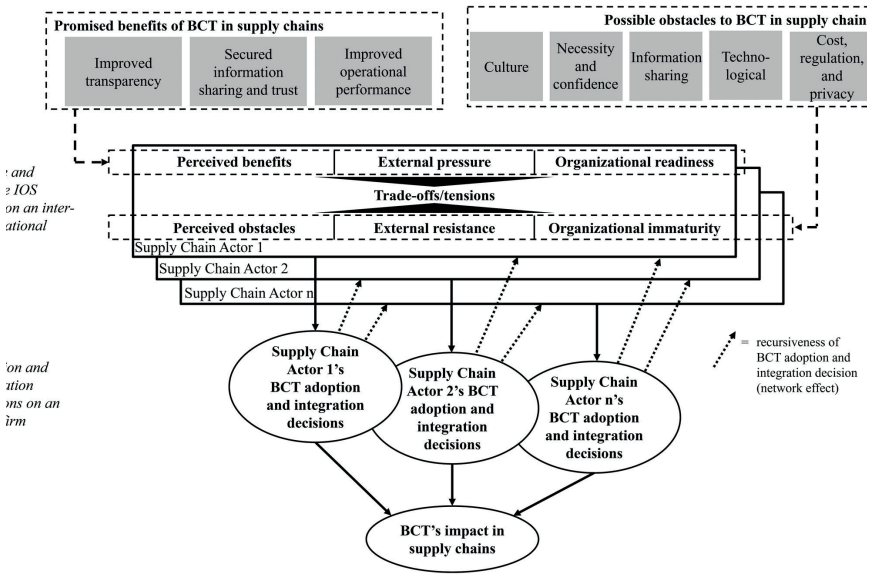
When shifting from a focus on the supply chain to considering the hypothesis of implementing Blockchain technology at the district level in the wine industry, Bastard and Chaillet's (2023) study is particularly relevant. It emphasizes the necessary prerequisites for fully leveraging the benefits of digitalization, such as establishing a strategic, collaborative, and forward-thinking approach alongside ongoing investment in technology and education. A model for inter-organizational adoption of Blockchain technologies, as proposed by Sternberg *et al.* (2021), serves as a valuable tool for exploring the hypothesis of Blockchain implementation throughout the entire wine supply chain in the case study presented below (Figure 3).

Focusing on the process of Blockchain implementation at the Quality Agri-Food District level, the work of Hacker *et al.* (2023) is particularly fruitful because it highlights the gradual progression that Blockchain consortia should follow when establishing collaborative relationship models (Figure 4).

A limited number of studies have explored the adoption of Blockchain technology within wine consortia, such as its potential implementation for the ETNA DOC wine (Agata *et al.*, 2021), or within the complex supply chains typically associated with wine production. The intricacies of the wine supply chain prior to consumer purchase arise from the many activities and actors involved, including grape growers, wine producers, bulk distributors, transit cellars, fillers/packers, finished wine distributors, wholesalers, retailers, and transporters or exporters, especially in international trade.

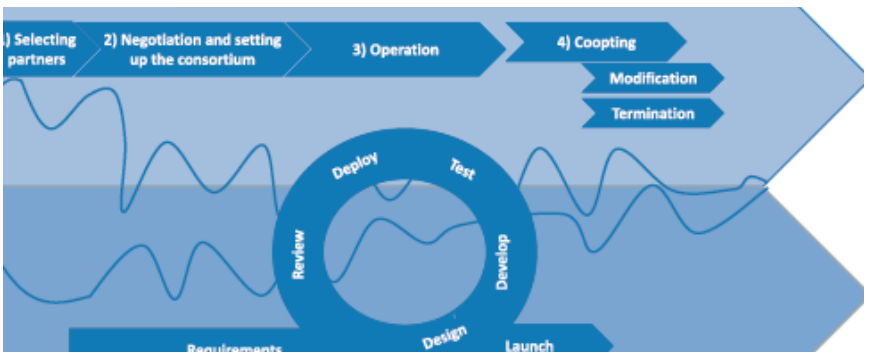
The adoption of consortium Blockchain is frequently utilized in cases where multiple organizations govern the platform, which is often accredited, to promote cooperation and address specific industry challenges (Zheng & Changmin, 2024). Additionally, consortium blockchains enhance transparency, accountability, and workflow among organizations that share

Figure 3 - Model of interorganizational Blockchain tecnologies adoption in supply chains



Source: Sternberg *et al.* (2021).

Figure 4 - Identification of staged progression of collaboration in Blockchain



Source: Hacker *et al.* (2023).

common objectives (Banerjee, 2024). In our context, as discussed below, the consortium Blockchain model appears particularly well-suited to support the management of wine flows within and beyond the Quality Agri-Food District.

Several studies have examined how technology can contribute to a more sustainable wine tourism experience among non-winery sectors within a district, as highlighted in a review by Zamarreño Aramendia *et al.* (2021). Festa *et al.* (2023) analyzed case studies of wine tourism in Italy and concluded that the level of digitalization – though limited to digital marketing tools such as websites, social media, and apps – was significant. They found that the more digitalized the wineries, the more sustainable and better performing they became; however, the opposite did not hold true. Van Huy *et al.* (2024) discovered that various factors, including technological and organizational elements (such as top management support, organizational preparedness, and employee knowledge of Blockchain technology), along with environmental factors (like competitive pressure, customer demand, and government support), positively influence the intention to adopt Blockchain technology in small and medium-sized hospitality and tourism businesses in China, where digital technology is widely utilized.

Insights from the aforementioned literature can serve as motivation for adopting Blockchain technologies within wine supply chains to facilitate the transition from a "local production system" to a "quality agri-food district," thus encouraging the dual transition of the wine sector and the district as a whole. The verification of this hypothesis will be explored through the analysis of a case study described in the following paragraph.

2. Materials and methods

The literature highlights that using a case study approach is essential for developing diverse perspectives on reality (Starman, 2013) and for understanding key characteristics of real-life events, such as the behavior of small groups, organizational and managerial processes, and the evolution of industries (Yin, 2009). Additionally, case studies offer concrete, context-dependent experiences that enhance the researcher's ability to comprehend relational dynamics, which may not easily connect to actions dictated by rules or theories (Starman, 2013). These points underscore the appropriateness of case studies in addressing our research question, which is primarily exploratory and descriptive. This method is particularly suitable for evaluating the potential application of Blockchain technologies within a specific local production context, beginning with a field analysis.

2.1. *The Case Study: Introduction*

Vermentino di Gallura DOCG is the only Protected Designation of Origin (PDO) in Sardinia that is controlled and guaranteed. It ranks among the white DOC/DOCG wines with the highest ex-cellar production prices, which stood at 215 Euros per hectoliter in 2023. This places it ninth in the national ranking, following prominent denominations such as Traminer, Franciacorta, Trento Pinot Noir, Roero Arneis, and Prosecco/Valdobbiadene, while surpassing other notable denominations like Trentino Chardonnay and Prosecco (ISMEA, 2023). The economic impact of Sardinia within the national PDO wine landscape places the region in 11th position, with an economic value of 149 million euros, 33 products, and 2,911 operators. Additionally, the local wine supply chain accounts for 26% of the agri-food economy in the region, second only to cheese, which accounts for 67%. The production system for DOP Vermentino di Gallura is characterized by a variety of players, including independent winegrowers, cooperative wineries, processing-only industries (without vineyards), pure bottlers, and fully or partially integrated industries. The Consortium for the Protection of Vermentino di Gallura consists of about 40 producers, overseeing an area of 2,500 hectares and an annual production of approximately 6 million bottles, with 80 different labels on the market. A complex regulatory framework, established in 1996 and modified in 2014, subjects all participants in the value chain – particularly those in the transformation industry – to strict compliance controls regarding wine production standards, including labeling. As of April 2024, Sardinia is home to seventeen Food Districts recognized by Masaf: fourteen rural districts, two quality agri-food districts, and one organic district, with an additional eighteen currently in the process of recognition (source: sardegnaagricoltura.it). This initiative is supported by Laore, the agency responsible for implementing regional programs in agriculture and rural development, in accordance with Regional Law 16/2014 and the related directives attached to Regional Council Resolution No. 11/8 (2020). The DOP Vermentino di Gallura Quality Agri-food District was officially recognized by the Sardinia Region in August 2024.

2.2. *Theoretical and legal aspects in the process of recognition of the Quality Agri-food District of Vermentino di Gallura DOCG*

The establishment of the Quality Agri-Food District of Vermentino di Gallura PDO was motivated by the belief that fostering strong relationships among local stakeholders is essential for wine production. This district aims to act as a catalyst for local development, a notion widely supported by

scientific literature that highlights social capital as a key factor in economic growth. Notable sources on this topic include Putnam (2000), Dasgupta and Serageldin (2000), Ostrom and Ahn (2003), and Svendsen and Svendsen (2009), as reviewed by Benedetto (2011) and Muringani *et al.* (2021). The competition among regions is influenced not only by market resources – such as tax policies, labor costs, and incentives – but also by social factors that enhance the networks of relationships within and outside companies. The creation of the district represents a natural progression in the evolution of the local wine production system, rooted in Marshall-Becattini's theory of industrial districts. While the traditional definition of an industrial district was crucial for assessing whether this specific wine-growing area could develop into a wine district, a study by Idda *et al.* (2007) confirmed that it does not entirely fit the classical Marshallian Industrial District model as defined by Becattini (1991). Nonetheless, several positive factors support the potential for the Vermentino di Gallura PDO production system to evolve into a recognized district. The theoretical framework used to identify this production system in the case study was narrower than the regulatory approach later adopted by the Sardinia Region for recognizing rural districts. While it offers a theoretical basis similar to the Marshallian District, regulatory recognition serves as a certification of a potential condition that is brought to fruition over time. Importantly, the primary goal of establishing the Quality Agri-Food District is to strengthen the network of values, associations, cooperation, and shared objectives aimed at promoting the unique qualities of the district's finished products. Access to funding from international, national, and regional sources is a secondary consideration. In accordance with the Regional Law, a multi-stakeholder approach was developed to engage a diverse range of public and private entities in discussing goals and challenges, as well as defining the programmatic interventions included in the district's first plan. The Protection Consortium of Vermentino di Gallura PDO is the leading partner and promoter of the Quality Agri-Food District, with significant participation from its wine producers, including fourteen prominent private wineries, three major social wineries operating at the regional level, a representative of winemakers, and other local institutions and associations.

2.3. *Participatory process description and its application to this case study*

The animation process involved a cycle of seven meetings between October 2022 and February 2023 and was preceded by the mapping of the stakeholders to be involved. It is not so much the number that is important, but rather the representativeness of each category of stakeholders involved:

these are actors who in various capacities are potentially interested, directly and/or indirectly, in establishing the Quality Agri-food District. In the selection process, therefore, the priority stakeholders were identified, i.e. those who could positively influence the implementation of this form of territorial governance. The first mapping allowed us to identify several key socio-economic figures involved in the participatory process, including a large number of wine companies.

The list of categories involved is reported below (Figure 5).

Figure 5 - Target groups of stakeholders invited in the animation process

The key values that guided the participatory process can be summarized as follows:

- Openness and Participation, with an approach oriented towards inclusion and listening to different needs and points of view, which was structured in a Participatory Planning process with the use of proven methodologies and widely adopted by Laore technicians.
- Representativeness: This principle emphasizes the importance of wide consultation involving economic, social, and institutional representatives from the territory.
- Inclusiveness: This involves actively engaging a diverse range of stakeholders, fostering participatory meetings that serve as platforms for discussion, listening, and learning.
- Transparency: Clear information and communication are essential to promote events and share the results achieved during work meetings.
- Co-planning and Result Orientation: The concrete outputs from each multi-stakeholder territorial animation meeting contributed significantly to developing the various sections of the Programmatic Plan. The

stakeholders alternated in leading the animation meetings, which were accessible both in person and online. Each meeting included a participant sign-in, with signatures collected through specific forms attached to a Descriptive Report submitted to the Sardinia Region. This was part of the required documentation under the implementing directives of Regional Law 7 August 2014, No. 16, to gain recognition for the District. Each meeting was structured like an extended focus group, tackling a specific theme that guided the discussions and helped identify strategies to address potential criticisms. During the third meeting, a participatory SWOT analysis was conducted with the assistance of Laore technicians. The fourth meeting focused on creating a participatory problem tree, while the fifth meeting analyzed participatory needs, allowing participants to suggest solutions to the identified challenges. By the sixth meeting, the results were summarized, and a draft of the programmatic plan for the district was presented. In the seventh meeting, a schematic Tree of Problems and Objectives was shared, along with the draft Statute and Regulations, and the collection of membership forms commenced. Laore Sardegna Agency facilitated the process by providing technical assistance and documenting each meeting to maintain transparency throughout the participatory process. Officials from the Autonomous Region of Sardinia play a crucial role during the animation days, offering vital information about relevant legislation, funding sources, the contents of the Regional Law on wine tourism, and the legal structures necessary for establishing the district.

3. Results and discussion

The participatory process highlighted the need for tools to support the districting of a local production system that requires a stronger network among local actors at various levels:

- Micro Level: Pertaining to the core producers of Vermentino di Gallura DOP.
- Meso Level: Connecting actors located upstream and downstream of this core.
- Macro Level: Considering public actors, such as agencies responsible for ensuring production compliance with established specifications. Additionally, there is a need to promote sustainable production techniques and enhance internationalization. Based on issues raised in the literature review, Blockchain technology and the digitalization process may offer solutions to some of these challenges.

The following discussion will explore the opportunities Blockchain presents for implementing the local District as it embarks on a twin transition path.

The introduction of a Blockchain combined with the digitalization of all phases of the production process could solve some of the internal problems of the system and respond to the purpose of allowing the intermediate and final consumer to verify the composition of each lot/bottle of wine along the entire supply chain from the grape growers to the retailers. The registration of the critical phases of the process within the Blockchain could make it more complicated, which causes failure to comply with production standards, and puts the consumer in a position to know the origin of the bottle as well as accessing production information. As previously reported, the type of Blockchain considered in the case study is the consortium, in which a group of members handles the control: the verification and addition of records to the Blockchain is based on a consensus mechanism by a pre-selected set of nodes.

Recently, Costa *et al.* (2023) focused on the digital transformation among family-owned low-tech SMEs operating in the Sicilian wine sector and showed that any of the investigated firms introduced a revolutionary business model innovation. These findings suggest that in the Sardinian case study, it could be useful to work on the promotion of disruptive digital business models at a single firm's level.

3.1. *The implementation hypothesis of Blockchain and digital tools of the Quality Agri-Food District of Vermentino di Gallura PDO*

The importance of expanding Blockchain boundaries is linked to its potential benefits, although for the "network effect" to occur and the benefits to be realized, a critical mass of supply chain actors adopting the technology and a disruptive socio-technical process are relevant issues (Rijswijk *et al.*, 2023; Sternberg *et al.*, 2021). The process of Blockchain and digitalization at the level of wine Quality Agri-Food District is far from being an easier and faster result.

All challenges that Bastard and Chaillet (2023) reported along the path of Blockchain implementation in the wine industry, are amplified in the reality and complexity of a District due to a wider range of interested stakeholders beyond the local wine supply chain actors who are central, but not necessarily the only ones. The need for interoperability between different systems and tools, such as various digital platforms, software, and devices to communicate and exchange data, becomes even more relevant at the Quality Agri-Food District scale. Another significant challenge in the digitalization hypothesis that is amplified within the District despite a single wine industry is the resistance to change and the lack of an innovative mindset among

all stakeholders involved within the inter-organizational system. Other challenges present in the case study are reflected in the literature (Banerjee, 2024): the lack of cooperation that impedes participants from reaching an agreement; the need for updating Blockchain structure and protocols, when the number and types of participants increase compared to the beginning.

To tighten control over the movement of grapes and wine in the case study, the hypothesis of Blockchain implementation at the district level requires adding inside the Blockchain platform a block represented by the Protection Consortium that could confirm the legality of the grape and wine production practice according to the PDO Disciplinary and the compliance with the specification for each producer.

Besides implementing a Blockchain system at the District level integrating it with other digital tools, such as electronic labels and QR codes whose benefits are envisaged at least in three spheres. First, the electronic label can be automatically translated into official EU languages known and preferred by the customer who scans the QR code. A further advantage is the possibility to update the provided information at any time: using this method, it is possible to always guarantee compliance with regulatory evolution, as well as add new content, thus avoiding the waste of physical labels and the related costs if information and data were to change. Furthermore, the QR code on the printed label does not take up much space and prevents "crowding" the back label of the wine, but it wins over the potential customer during the purchase, with certainly more captivating information. Finally, although no commercial or marketing information may appear on mandatory electronic labels to comply with the laws, wineries in the District could voluntarily choose other digital labelling and QR codes thereby opening up new engagement and marketing opportunities while maintaining the complete design of the brand/label with content linked to the QR codes (such as photos, videos, winery events, technical data sheets, awards and recognitions).

Indeed, electronic labels and QR codes provide a suitable solution for wine producers to meet the requirements of the EU Regulation. Also, the entry into force of the new EU Regulation on wine labelling (Reg. 2021/2117 amending Reg. 1308/2013) with the year of production 2024 pushes the wine industry towards greater transparency and communication with consumers. In particular, the above legislation permits that – for the list of ingredients and nutritional values – producers can choose between reporting them on the physical label or inserting them in a specific virtual space accessible via a QR code. To comply with this new regulation, wineries, as well as consortia, can exploit the potential of digital labelling and QR codes.

3.2. *Implementation hypothesis in non-winery actors within the District: the tourism valorization*

Blockchain technologies can be of great support for the involvement of non-winery operators located downstream of the production of Vermentino di Gallura PDO and provide assurance, most of all to distrustful actors, about the adoption of a common standard.

The creation of a network of relationships between the local wine and tourism sectors would make it possible to achieve a *governance of* the local system, aimed at creating an alignment between tourist supply and demand, and making the most of the wine tourism phenomenon, for the benefit of the two sectors. On the other hand, the Protection Consortium will play a fundamental role in GI tourism matters according to the reform introduced by Reg. UE 2023/2411. In essence, an institutional role is assigned to the Consortium in the promotion of "PDO tourism" by linking tourist accommodations to geographical indication products. Therefore, the Vermentino di Gallura PDO, an expression of local identity, would guide the ecological and digital transition path of the entire system that revolves around it.

In this larger implementation hypothesis, the idea would be to build a Blockchain of the Quality Agri-Food District that includes within the boundary of the system operations/operators outside the vine-wine supply chain but related to it, that remains the nucleus of the Blockchain district. The hypothesis refers to all the players that use Vermentino di Gallura wine to promote it in tourism and gastronomy, first of all in typical restaurants and agri-tourisms located in the area. All companies involved in the local wine tourism valorization should be profiled within the common platform and agree to sign the Blockchain, recording all the information necessary to trace back the wine chain; if so, they will be allowed to use a common brand of the Quality Agri-Food District.

In addition to typical restaurants and agri-tourisms located within the geographical area of the District and offering its wine, there is the possibility of including other food producers that are based on Vermentino wine as an ingredient for other types of high-quality food products. This could be the case for those pasta factories located in the territory of the Vermentino District that produce special products.

Lastly, fairs and festivals in the wine sector could be somehow linked to the District platform. This could be the case with the annual event "Benvenuto Vermentino" which aims to create awareness and promote Vermentino di Sardegna PDO through meetings and guided tastings.

In addition to extending the digital traceability and valorization of Vermentino di Gallura thanks to the Blockchain platform, a further

possibility is to introduce a Quality Agri-Food District certification, in which, as reported below, rigorous environmental, social and economic protection criteria – the pillars of sustainability are satisfied.

Therefore, the positive influence may be more difficult in a context, such as the one under study, where technology is less widespread, and knowledge and skills, technological infrastructure and Internet access are limited. However, it provides a point of reference regarding the factors on which to intervene in the study context to positively orient local non-winery actors towards digitalization.

3.3. *The twin transition: the support of Blockchain and digital tools for the sustainability of the Quality Agri-Food District*

Blockchain technology is still in its early stages and faces several challenges, particularly the significant amount of energy consumed by the technology itself and the associated implementation costs. Given these environmental impacts and economic concerns, the digital innovations achieved through Blockchain would be further justified if a broader and multifunctional application of the technology were possible, especially in environmental and social areas. One promising application of Blockchain is its potential to serve as a sustainability management tool in the wine industry, as indicated by various studies. For instance, Luzzani *et al.* (2021) reported in their exploratory study that Blockchain enables the collection of data and information crucial for monitoring and enhancing sustainability. However, to fully leverage the technology, it is essential to integrate the data collected by Blockchain with the indicators used in wine sustainability programs and certifications. Pullo *et al.* (2023) emphasized, within the context of increasing production and water footprints, the importance of integrating Blockchain with the Internet of Things (IoT) to address scalability and transaction cost challenges inherent to Blockchain.

From a political standpoint, there may be pressure to use digital tools for sustainability due to the recent EU Regulation 2024/1143, which reforms and unifies existing laws concerning the European Geographical Indications system. This new regulation recognizes and promotes sustainable practices that encompass environmental, economic, social aspects, and animal welfare. It outlines rules (Article 7) related to sustainability and allows producer groups to agree on sustainable practices for producing designated geographical indications or for other obligatory activities specified in the regulations. Moreover, this regulation grants greater autonomy to producer groups, enabling them to establish a voluntary system that strengthens their position within the supply chain. Finally, Regulation 2024/1143 supports

the digitalization of the sector, stating that "the Commission may establish and support a digital system for the inclusion of optional quality claims and schemes to promote awareness of products and schemes across the Union" (Article 79).

Additionally, according to national law (D.Lgs. 116/2020), starting from January 2023, it is mandatory for wine labels to include three environmental indications: an alphanumeric code regarding packaging materials (under Decision 129/97/EC), the specific materials used in the packaging, and guidelines for proper disposal at the end of the packaging's life cycle. Integrating VIVA indicators (air, water, vineyard, and territory) within a Blockchain platform could fulfill the goals of Blockchain technology. Given these factors, the case study presents an opportunity to advance digital and sustainable innovations within the local wine sector, beginning with the regional adherence to the VIVA Program, which currently includes only one Sardinian wine producer. Moreover, implementing the VIVA Program at the district level – which requires participation from at least 75% of the wine marketed under its umbrella – represents another pathway for assessing the district's overall sustainability performance through the combination of sustainability and digitalization. From an environmental perspective, integrating sustainability and digitalization can also be explored through a circular economy approach within the studied district. The vine and wine sectors generate several by-products, such as vine pomace, grape stalks, and wine lees, which can be utilized in various ways. In this case study, key sectors interested in utilizing these waste products include natural cosmetics, nutraceuticals, textiles and fibers, as well as natural coloring for food and fibers. The digitalization of these circular processes is considered extremely beneficial not only for tracking material flows but also for enhancing the overall environmental efficiency of the circular system.

Lastly, concerning the boost that digitalization can provide for exporting Italian wine, the ICE (Agency for the Internationalization and Promotion of Italian Companies) launched the TrackIT Blockchain project in 2022. This project aims to offer Blockchain traceability services for Made in Italy products in the textile/clothing and agri-food sectors. So far, 45 companies in the wine sector, including several from Sardinia, and 198 products have benefited from the project's support. Although only individual firms can participate in the TrackIT program, consortia could play a crucial role in facilitating the involvement of local businesses.

Conclusions

This study aimed to enhance the discussion surrounding the twin transition in the agri-food sector by examining its potential for valorizing a wine

product with a designation of origin within a Quality District. Although still a work in progress, the study provides insights for future research and its application in other sectors.

Preliminary results suggest that both environmental and digital transitions could benefit various aspects of sustainability, the local supply chain, and the surrounding territory. However, challenges are anticipated during implementation. Among the projected benefits are improved traceability of wine supply chains, which ensures the origin of production and enhances transparency for consumers. Additional advantages include the protection of the Protected Designation of Origin (PDO) supply chain from counterfeiting and the use of digital tools for the sustainable promotion of the territory. Numerous obstacles exist in this context, particularly those related to the broad and diverse processes involved in the digital transition, as well as the inter-organizational nature of tools like Blockchain.

The Blockchain consortium approach considered in this study fosters trust among enterprises and facilitates collaboration on a common standard. This represents an innovative contribution to the literature, as few studies have explored the adoption of Blockchain at the district level, rather than focusing solely on individual firms. This shifts the focus from the core of a Quality Agri-Food District – the wine supply chain – to its peripheral activities, phases, and sectors.

Future research could explore various perspectives that are valuable both in this case study and on a broader scale. One key area of investigation could involve examining the digital orientation and openness of both core and peripheral stakeholders, as well as their engagement in the twin transition process. The case study method is particularly suitable for exploring novel and complex issues and for calibrating the application of new tools in specific contexts using a place-based approach. Qualitative research methods and tools, such as those applied in this case study, are useful for understanding new phenomena, collecting primary data, and gaining experience with field techniques. Continued research in this case study may provide guidance on structuring a standard protocol that could be replicated in other settings.

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The role of EIP-AGRI Operational Groups as a driver towards innovation in viticulture

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Abstract

European policies play a crucial role in helping farms and stakeholders in the agri-food sectors to proactively engage in digital and environmental transitions. Among them, the European Partnership for Innovation in Agriculture (EIP-AGRI), which was established in 2014, has proven significant in promoting sustainable production models and value chains in Europe. Operational Groups (OGs) within the Partnership provide "interactive innovation" platforms in which research institutions work with farmers, advisors, businesses, NGOs and other interest groups to co-create innovative solutions for agriculture and forestry as well as rural communities; the rationale is that when farmers and foresters are engaged in the process, the solutions are more likely to be based on their concrete reality and thus relevant. While the benefits of the participatory, multi-actor and bottom-up approach of OGs have been widely acknowledged, little is known about the drivers and barriers influencing the process. This contribution explores their role in the wine sector, applying a mixed methods approach to analyse the perceptions of OG stakeholders from different Italian regions. Interviewees have been asked to what extent they believe the EIP-AGRI OGs serve as drivers of innovation and provide a network able to foster knowledge exchange, and what they perceive to be their barriers to innovation. By addressing this knowledge gap, this study will provide some insights and good practices to improve EIP-AGRI policies at regional, national and European levels.

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Introduction

European policies play a crucial role in helping farms and related stakeholders to engage proactively in the "twin transition" that fosters environmentally sustainable practices through the adoption of digital innovation (JRC, 2022). In the sphere of food production and agriculture, the EU Common Agricultural Policy (CAP) seeks to foster more sustainable production models and value chains. To this end, in 2012 it launched the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI)[1] to encourage the spread of Agricultural Knowledge and Innovation Systems (AKIS), a multi-actor collaborative way of producing and sharing knowledge to promote innovation and the use of new technologies (EU SCAR, 2012). In addition, since the 2014-2020 programming period, the EIP-AGRI has also been supporting the creation of Operational Groups (OGs), which are innovation-oriented projects to foster regional cooperation strategies to address specific agricultural issues. By pairing research institutions with farmers, foresters, businesses, advisors, NGOs and other environmental and interest groups, OGs draw upon the complementary knowledge of different stakeholders to co-create practical solutions and drive competitive, sustainable, and inclusive growth of the agricultural and forestry sectors as well as of rural communities[2] (Arzeni *et al*., 2023; Giarè & Vagnozzi, 2021; Parzonko *et al*., 2022)especially to innovation brokers working there. The aim of the study was to determine the role of the innovation broker in the formation of EIP-AGRI operational groups. Mechanisms of innovation support in the agricultural sector were presented, paying particular attention to the tasks of the National Network for Innovation in Agriculture and Rural Areas (NRN. Therefore, the OGs complement the collaborative systemic approach promoted by the AKIS to encourage technological solutions for place-based sustainability (Collini & Hausemer, 2023).

OGs serve as intermediaries of innovation by fostering demand articulation for the innovation needed, promoting and assisting the institutional change, working on knowledge and network brokering, capacity building and providing a structured management process for innovations in terms of coordination and negotiation (Piñeiro *et al*., 2021; Kilelu *et al*., 2013). They are designed to be challenge-driven, and to provide conducive environments for obtaining better and quicker outcomes than those offered by top-down

1. EU CAP NETWORK, Innovation & knowledge exchange: https://eu-cap-network.ec.europa.eu/support/innovation-knowledge-exchange-eip-agri_en (last retrieved 24/07/2024).

2. EU CAP NETWORK, Operational Groups: https://eu-cap-network.ec.europa.eu/operational-groups_en (last retrieved 27/03/2024).

approaches (Collini & Hausemer, 2023). However, it has been observed that the place-based nature of this tool has led to uneven development of projects across European regions. Generally, funding opportunities to prepare and implement OG projects among the European member states are provided by the current CAP programming period (2023-2027) via national CAP Strategic Plans[3]. They are supported by a dedicated EIP-AGRI Network to ensure that the "interactive innovation model" is used to find solutions to the needs of farmers and foresters, that the relevant stakeholders are brought together and that a co-decision and co-creation approach is central throughout the project (EU Regulation 2021/2115, Art. 127, 2021).

In Italy, the Italian Regional governments have established different modalities for setting up OGs, as well as different regulations for actors to participate and cooperate in OGs. This came about during the 2014-2022 period, with measure 16 of the Italian national Rural Development Programme (RDP). For example, some regions required that only farms take on the coordination of OGs, while others assigned a higher score in their project evaluation if the lead partner was a farm, and still others did not impose any constraints. Similarly, the required minimum number of farms within the individual project, the duration and the maximum budget differed from one Region to another. In addition, not only have innovation needs been addressed differently across the regions, but also the participatory approach has not been uniformly embraced, which had an impact on the results and on the innovation outputs themselves (Giaré & Vagnozzi, 2021). Indeed, according to Molina *et al*. (2021), when focusing on the innovation process, it is important to consider how the different social actors participate in the co-creation activities and to what extent, as well as the factors influencing their participation, such as motivation, commitment, interaction, communication, networking, and trust, in order to create a solid working structure, reinforced by tailored policies and engaged stakeholders acting as knowledge and innovation brokers. An innovation broker is an intermediary whose primary role is to create suitable connections within innovation systems and facilitate interactions among multiple stakeholders involved in the innovation process (Klerkx *et al*., 2009). According to Howells (2006, p. 720), an innovation broker is defined as "an organization or body that acts as an agent or broker in any aspect of the innovation process between two or more parties".

Strong national involvement in the innovation processes of the entire agricultural sector resulted in a plethora of regional OGs, whose information is collected on a specific web platform entitled

3. EU CAP NETWORK, Operational Groups in EU Member states: https://eu-cap-network.ec.europa.eu/operational-groups-eu-member-states_en (last retrieved 27/03/2024).

"INNOVARURALE"[4]. Up to February 2024, the OG-related measures have involved 20 agri-food sectors (including multisectoral projects covering two or more chains) within 717 projects, for about 258,7 million euros in total investment. The viticulture and wine sector have been prominent, only second in terms of funding received (over 36 million euros)[5]. Agricultural production is estimated to be one of the main causes of greenhouse gas emissions. In particular, the production of greenhouse gasses during the agricultural phase of winemaking process accounts for 17% to 40% of the emissions of the whole national wine supply chain (Bosco *et al.*, 2011; Rugani *et al.*, 2013; Tezza *et al.*, 2019). Indeed, the viticulture and wine sector must make short and long-term changes to address the challenges related to sustainability, climate change and a more competitive and diversified market (Costa *et al.*, 2022). Therefore, promoting both a green and digital transition is crucial for helping this sector.

From the digital point of view, beyond the aspects related to the organisation of production, the major innovation-related challenges of the wine sector concern the definition of suitable business models, the need to provide an efficient offer in response to the changing needs of international markets, and the readiness to the use of the latest information and communication technologies to enhance the competitiveness of the businesses involved (Dressler & Paunovic, 2021). The adoption of innovations by wine companies is influenced by their resources, positioning, and size, and by other factors as well: the value of knowledge exchange and a synergistic approach to innovation as a strategy for improving the innovation ecosystem should also be acknowledged (Dressler, 2022). Similarly, the evolution to develop innovation ecosystems is also affected by territorial factors, for example the presence or absence of relational networks among actors and institutions and related knowledge sharing may promote or deter change (Chaminade & Randelli, 2020). It is important to observe OGs not only on the EU and national level, but also on the regional level, in order to understand the mechanisms of knowledge transfer and innovation co-creation that they foster, and to identify the most effective strategies for promoting the twin transition towards environmentally sustainable practices through the adoption of digital innovation.

Starting from the analysis of OGs in the viticulture and wine sector, this research article explores the role of OGs as intermediaries of innovation

4. INNOVARURALE, Operational Groups Database: www.innovarurale.it/en/pei-agri/gruppi-operativi/bancadati-go (last retrieved 27/07/2024).

5. INNOVARURALE, Statistics from the Operational Groups Database in Italy - costs per thematic area: www.innovarurale.it/it/pei-agri/gruppi-operativi/bancadati-go-pei/statistiche (last retrieved 27/07/2024).

and as creators of knowledge networks within different Italian regions. The objective of this article is twofold: to provide an understanding of the role played by the RDP OGs in the innovation processes, and to identify OG strengths and weaknesses in co-design and innovation transferring strategies supported by the EIP-AGRI.

1. Innovation in the viticulture and wine sector: what are the needs and main challenges?

In response to the evolution of agriculture and its interconnectedness with other productive sectors in rural contexts, there is a need for information and learning networks that engage not only farmers, but also a wider range of stakeholders, inside and outside the agricultural sphere. Given the intricate and diverse local settings of today's agricultural concerns, along with the multitude of functions that agriculture must perform, stakeholders need more inclusive and participatory approaches to managing the creation, integration, and dissemination of information (Šūmane *et al.*, 2018).

The innovation process can offer beneficial solutions for the actors involved, and thus help to address sustainability trade-offs. Initiatives such as the OGs from the EIP-AGRI espouse a bottom-up approach to innovation that helps create win-win solutions as stakeholders compare, share, and reflect on their knowledge and innovation efforts (Brunori, 2023).

An added benefit of adopting innovations to foster a green and digital transition in agriculture is that innovation ecosystems at different levels may profit from the socio-technical and ecological processes, with changes that go far beyond the technological, material, and organisational dimensions to engage socio-cultural, economic, institutional, and policy-related dynamics (Kivimaa *et al.*, 2019).

Italy is one of the biggest players in the wine sector worldwide, and produces more wine than any other European country (ISMEA, 2022). Thus there is great interest in developing knowledge and innovation in the Italian wine sector. Innovations may have significant effects on different stages of the value chain. Farmers are facing unprecedented challenges from climate change and associated fluctuating weather patterns, shorter growing seasons, heat waves and droughts. In addition, they also deal with labour shortages and increased production costs (Soar *et al.*, 2008; Tardaguila *et al.*, 2021).

In the viticulture and wine sector, various reforms of the EU Common Agricultural Policy have led to differentiated sectoral regulations regarding income support for farmers and ways to enhance their competitiveness (Pomarici *et al.*, 2021). Moreover, the financial support of the first and second pillars is complemented by sectoral interventions confirmed in the new CAP

programme (ISMEA, 2019). There is an ever stronger emphasis in European policies to encourage member states to boost innovation that enhances sustainability. Specifically, in the Strategic Plan Regulation concerning the wine sector, member states are invited to pursue the common objective of facing climate change by improving the sustainability of their production systems. To this end, "tangible and intangible investments in innovation consisting of the development of innovative products […] processes, and technologies for the production of wine products […], as well as other investments adding value at any stage of the supply chain, including for knowledge exchange […]" are suggested (Waye *et al.*, 2023).

As a result, the new CAP framework may provide potential changes in the viticulture and wine sector policy, with consequent impacts on the European and international wine markets. The complex regulatory modifications do not address changes in the amount of funds to be distributed, but instead, focus on raising the sector's sustainability levels, which could better align the EU wine supply with market demand and make it competitive with non-EU producers (Pomarici & Sardone, 2022).

2. Materials and methods

With the goal of clarifying the role played by the Rural Development Plan's OGs in innovation processes, and to identify the strengths and weaknesses of OGs in co-design and innovation transferring strategies supported by the EIP-AGRI, this research collected data and interviewed members of a number of OGs in different Italian regions:

- as a first step, the authors carried out desk research using the OG database on the INNOVARURALE portal, extracting and analysing data about the OGs implemented in the viticulture and wine field;
- as a second step, authors collected quantitative data through a questionnaire submitted to OGs coordinators to identify whether or to what extent RDP measure 16 contributed to the innovation intermediation by OGs;
- as a third step, the authors collected qualitative data, by interviewing OG members to gather insights about their involvement and participation in OG projects.

2.1. *Desk research in the Innovarurale OG database*

An initial introduction to OG projects in the viticulture and wine field took place in February 2024. The Innovarurale portal was searched by

selecting 'viticulture' as one of the production sectors, while leaving empty all the other fields, including the project start and the end date. The results yielded a total of 96 OGs implemented in the viticulture and wine field all over Italy, with grants of over 36 million euros since 2016. Background information on each OG project was extracted, specifically, the keywords, the funding region, the year of start and end, as well as the duration and the total budget allocated. With these results, we created our own database and added information on the actors involved and the lead partner, as well as the project's objectives, topic, and focus area. In order to provide a situational overview by region, the authors adopted descriptive statistics to identify the concentration of OGs in the viticulture and wine sector, and to analyse the average budget granted for each OG, as well as the themes and the targeted focus areas.

2.2. *Gathering quantitative data*

To identify the contribution of RDP measure 16 on OGs in terms of innovation intermediation, a questionnaire was submitted by email to the lead partners. The information requested was based on the dimensions provided by Piñeiro *et al*. (2021) and on the functions defined by Kilelu *et al*. (2013). Table 1 lists the topics addressed in the survey, to provide data for quantitative analysis of how OGs in Italian viticulture and wine production support the technological transfer of innovations, investigating the dimensions concerning the articulation of the demand, the institutional support, the network brokering, the capacity building, the management of innovation processes, and the knowledge brokering.

Out of the 96 OG coordinators who received the surveys, 24 responded, a response rate of 25%. The authors aggregated answers by region, to highlight regional differences or similarities in the perception of OGs as innovation intermediaries. For each respondent, the item values for each dimension listed in Table 1 were summed. Due to the limited number of observations, the median was chosen as the index of central tendency to attenuate the effect of possible outliers. The median values for each dimension were then normalised to allow for cross-regional comparison. Coordinators were also asked dichotomous questions to find out the number of OGs they had already been part of, and the number of partners for each OG. In addition, they were asked to indicate their satisfaction or lack thereof with the results achieved by their OG, and whether they believed the OG strategy was a success of the EIP-AGRI policy.

Table 1 - Description of the functions that OGs may provide as intermediaries of the innovations proposed by Piñeiro et al. (2021)

Dimensions of OG Functions	Description
Demand Articulation	Assisting the process of determining innovative possibilities and problems as seen by the many stakeholders through needs assessment, visioning, and diagnostic exercises. A few examples of the needs are access to information, technologies, funding, and institutional gaps.
Institutional support	Promoting and assisting institutional change by fostering new business models and encouraging interactions with new actors.
Network brokering	Identifying and connecting many actors.
Capacity building	Fostering and bolstering novel organizational structures.
Innovation process management	Coordinating communication, promoting negotiation, and fostering learning amongst several actors.
Knowledge brokering	Determining the knowledge and technology requirements, mobilizing, and sharing the information and technology from many sources.

2.3. *Gathering qualitative data*

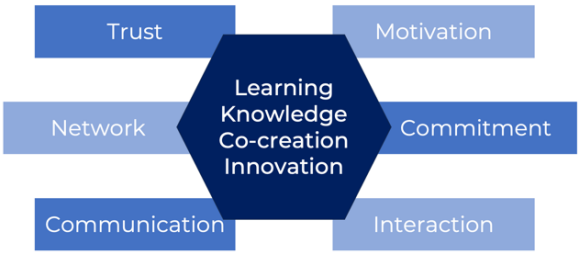
The quantitative investigation was also paired with qualitative interviews, structured according to the qualitative approach developed by Molina *et al.* (2021): OG members were asked to explore the relational dynamics among stakeholders, and the role of farms within the OG partnerships. In addition, 9 key informants, as coordinators or intermediary partners in one or more OG, were interviewed to identify the factors influencing the interactive process of innovation. The 9 key informants took part in a total of 15 OGs in the viticulture and wine sector, and a total of 25 OGs considering all production sectors.

Participants were asked to answer a few open-ended questions to reveal how the different OGs were organised, the role of each partner, their motivations, the overall partnership approach and the relations that they had developed.

Interviews were conducted online, recorded and machine transcribed. Two researchers conducted thematic analysis on the results (Gibbs, 2018; Saldaña,

2021), adopting the dimensions from the framework of Molina *et al.* (2021) (Figure 1).

Figure 1 - Factors that influence the participatory innovation process. Source: Our own elaboration based on Molina et al. (2021)



This qualitative methodology made it possible to extract relevant information from the interviews, summarize it according to specific labels for the emerging topics and categorise it under the main themes.

To do so, researchers first familiarised themselves with the content of all the interviews. Second, they separately conducted the qualitative analysis. Third, they agreed on the results emerging from the analysis conducted separately. Lastly, they provided an overview of the results according to the main codes, categories and related themes.

3. Results

The descriptive analysis of the data showed the main trends regarding the innovation pattern and the orientation of the different Italian Regions. Since 2016, Emilia-Romagna (25 projects) has been the region with the highest number of OGs in the wine sector, followed by Veneto and Tuscany. The wine sector projects covered 19 of the 36 topics included in the set-up of OGs. The highest number of investments addressed precision agriculture, disease and pest control, protection of biodiversity and farm management. In particular, Emilia-Romagna focused on biodiversity, Tuscany and Piedmont on precision agriculture and Veneto on disease and pest control, while other regions have a more uniform distribution of topics.

The thematic area of precision agriculture has the greatest amount of funding followed by disease and pest management, and farm management. Under the topic of farm management, the projects cover a variety of issues

such as agronomic management of soil, water, and vineyards by means of monitoring systems and Decision Support Systems (DSS) for pest and disease control, grape monitoring in the cellar and during shelf-life.

Analysing the 96 projects revealed by the Innovarurale portal query, we found that the average budget per project is €368,894.53; the region with the lowest average budget per project is Calabria (below €100,000), while in regions such as Piedmont, Lombardy, Sicily, and Apulia the average funding per project exceeds €450,000.

This reflects the different policies and funding regimes adopted by the regions, which diverge from one another regarding cooperation and innovation measures (Giarè & Vagnozzi, 2021). Similarly, leadership varies among the regions. In some, agricultural enterprises, cooperatives, business associations, and producers lead the projects, while in other regions research institutions have taken the leadership role.

3.1. *OG functions as intermediaries of innovations*

Analysis of the surveys conducted among the OG coordinators revealed that 96% are satisfied with the results achieved by at least one OG of which they are a member and 88% consider this RDP measure of the EIP-AGRI policy to be a success.

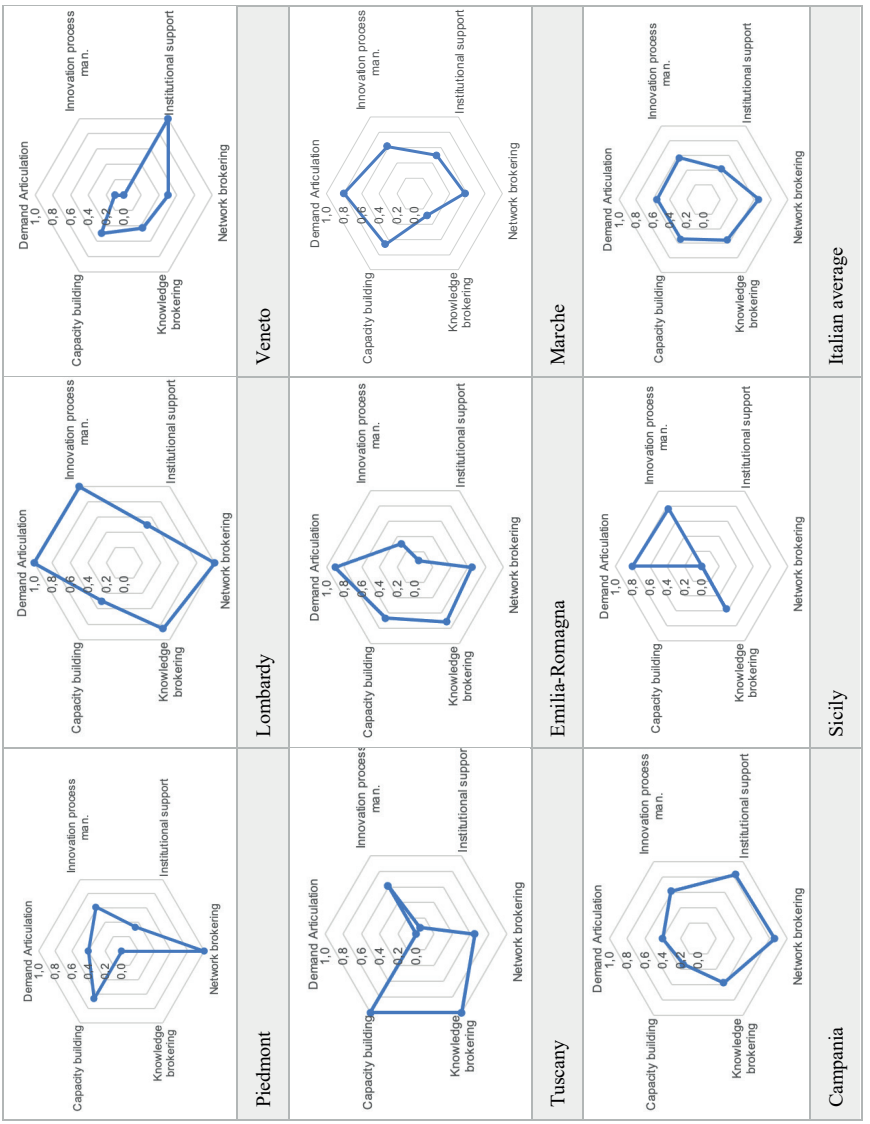
As shown in Figure 1, the respondents from Lombardy, Emilia-Romagna, Sicily, and Marche consider OGs to be significant in *Demand Articulation* and therefore in facilitating the process of understanding the needs of the various actors, identifying and studying new solutions and opportunities, and integrating the different approaches of the actors involved.

Regarding *Innovation Process Management*, the respondents from Lombardy, Sicily and to a lower degree Piedmont, Campania and Marche recognised the value of OGs in facilitating collaboration between different actors to develop projects in support of innovation, favouring information exchange among partners about specific actions, and promoting their control and assessment mechanisms.

Respondents from Tuscany, Marche and Emilia-Romagna also expressed a positive opinion about the *Capacity Building* function of OGs in promoting new forms of organisation to support projects and objectives within the same groups.

Concerning *Networking Brokering*, respondents from Lombardy, Piedmont, and Campania and to a slightly lesser extent Emilia-Romagna, Tuscany, and Marche deemed that OGs are important for spreading and promoting cooperation between internal and external actors through platforms, workshops, or other projects with common aims.

Figure 2 - Overview graphs of the perception of the role of OGs as innovation intermediaries by region



The respondents from Lombardy and Tuscany especially recognised the *Knowledge Brokering* function of OGs and their potential to spread knowledge and information about new technologies as practical solutions.

Finally, respondents in Veneto and Campania judged that OGs are useful in supporting the institutional function. They indicated that OGs have been helpful in assisting partners in the consolidation of their economic activity and acquiring funding for the team's professional training, facilitating institutional and economic support in the proposal of legislation useful for problems identified by the group, and increasing policy maker awareness about suitable solutions.

3.2. *Factors influencing the participatory innovation process in the OGs*

This section presents the results of the qualitative analysis of the interviews carried out with different OG members. Results are based on the framework provided by Molina *et al.* (2021), who describe the factors influencing stakeholder participation in co-creation activities (motivation, commitment, interaction, communication, networking, and trust), and impacting the innovation process and outputs.

Nine interviews were conducted with OG members from different regions of Italy (Northern, Central-northern, Southern Italy, and one of the islands), 6 of whom are OG projects coordinators. This provided the research with a systemic perspective on the engagement and participation of different partners.

Table 2 presents the characteristics of the OGs considered by the research.

The following sections describe the factors influencing the innovation process, according to the dimensions identified by Molina *et al.* (2021).

3.2.1. Motivation to engage and participate in OG projects

The main motivation for partners to engage in OG project initiatives arises from the need to increase knowledge on topics that are still poorly addressed legally and scientifically (OG1, OG2) and to foster innovative agricultural practices by going beyond what is known so far and experimenting new methods, tools and processes (OG8). Often, the project idea itself comes from a bottom-up shared need from businesses, which increases the probability that the project will be successful (OG6, OG7, OG8, OG9).

Moreover, partners recognise the concreteness of the OG projects, and the tangibility of the innovative solutions for practitioners in the viticulture and wine sector. Indeed, small and medium-sized enterprises (SMEs) in

Table 2 - Characteristics of the OGs involved in the study

Resp. ID.	Type of organisation	Role of organisation	N° of OGs in viticulture and wine sector in which they participated	N° of OGs in other sector in which they participated	Other partners	OG Region	Solution category
OG1	Protection and valorisation consortia	Coordinator	2	0	Research body University Institutional body Association Wineries	Lombardy	Climate change, Pest and disease control, Landscape and land management, Agricultural practices
OG2	Research body	Coordinator	1	0	Research body University Wineries	Sicily	Agricultural competitiveness and diversification, Fertilisation and nutrient management, Soil management, Biodiversity management, Agricultural practices, Agricultural production systems
OG3	Tech company	Coordinator	1	0	Research body University Trade Association Wineries	Campania	Agricultural practices/ Agricultural machinery and equipment; Climate change; Plant pest control/disease; Soil quality control
OG4	RDI consulting company	Scientific partner	1	5	Research body (coordinator) University Consulting companies (RDI) Wineries	Emilia Romagna	Plant pest control/disease; Farming systems; Soil quality control

OG5	Winery	Coordinator	2	0	Research body University Consulting companies Trade association Wineries	Veneto	Agricultural practices; Agricultural machinery and equipment
OG6	Research body	Coordinator	3	1	Research body (coordinator) Consulting company (ICT) Wineries	Tuscany	Agricultural machinery and equipment Agricultural practices Agricultural production systems
OG7	Research body	Coordinator	3	0	Research body (coordinator) University Consulting companies Trade association Wineries	Piedmont	Agricultural and forestry competitiveness and diversification Fertilisation and nutrient management Agricultural production systems
OG8	RDI consultancy company	Technical-environmental partner	1	3 (1 of which in Sicily)	Research body University Trade association Wineries	Marche	Climate and climate change Soil management Agricultural Practices Natural resource use Organic regenerative agriculture
OG9	Consulting company	Innovation broker	1	1	Research bodies University R&D Consulting-Tech company Wineries	Apulia	Agricultural and forestry Competitiveness and diversification Supply chain, marketing and consumption Biodiversity management

particular see the concrete value of these projects, because they give them access to technological advancements normally not within their reach, due to infrastructural limitations, lack of knowledge and limited financial resources, in comparison with bigger companies, which find it easier to engage in such investments and collaborations with tech companies and research institutions (OG3, OG9). Therefore, it is very important to create consortia that can manage and sustain this kind of project (OG8).

OG partners feel motivated to have a role in the process of innovation development: here, research institutes and universities serve to transfer knowledge, providing research and scientific data for the development of specific solutions (OG3), while capitalising on their participation through publications and similar scientific products (OG5). Like research institutes (OG5), tech companies also engage in the process of innovation co-creation by helping to prototype new products and services, and benefit from their collaboration with the opportunity to launch these products and services on the market (OG3, OG5). One organisation (OG8) said the main motivation to engage in an OG was the opportunity to disseminate regenerative agriculture practices as a form of innovation, while others were motivated by the opportunity to make such innovations accessible to SMEs (OG8, OG9).

Regarding barriers to participation, several OG partners expressed scepticism about projects funded and managed by regional governments (OG3, OG4). Particularly, engaging farms and SMEs in a consortium to apply for a specific call might result difficult for different reasons. First, they perceive that public initiatives often fail to drive positive changes for farmers (OG4). Second, strict bureaucratic obligations demand too much time and expertise (OG4, OG5, OG9). Third, they cannot rely on financial resources from a Region-managed project, because the project budget is delivered after the submission of the activities report, and it might be reduced compared to the agreed amount, should one of the partners fail to complete their part of the project (OG3, OG8, OG9). Moreover, in some cases the Region delays delivery of the final balance of the funds, and thus farms cannot participate in future projects, due to the lack of guarantees in the funding reception within an adequate timespan (OG9).

3.2.2. Commitment towards project objectives

Generally, members are highly committed when there is a common perception of the shared benefits from the innovative output (OG5) and when the consortium is based on existing and previous collaborations (OG8). Small farms showed high commitment, proactivity and enthusiasm, as OGs make the application of innovative solutions in their farms accessible (OG9).

Instead, competition among similar partners, especially research bodies, can slow the project run (OG3, OG9). Moreover, when research bodies are committed to more than one project at a time, their level of engagement decreases, thus producing delays in the delivery of the project outputs, with negative impacts on the farms (OG9).

Commitment can be promoted or harmed by partner actions or attitudes. Defining feasible goals (OG7) and a common vision, as well as the roles and responsibilities for different tasks is crucial for ensuring successful project implementation (OG1, OG2, OG7, OG8). This should be done since the very establishment of the consortium and must be consistent with the actual effort that each partner could ensure (OG6). In general, there is heterogeneity in the efforts of the participants: while some partners show great initiative, others might demonstrate lower commitment or even prove to be a liability. Although project initiatives are based on unanimous cooperation (OG2), partners with a "pioneering" attitude towards the innovation could lack a sense of collaboration. Also, companies may be reluctant to release data collected over the years, and this can hinder the whole collective learning experience (OG1). Moreover, some negative consequences may occur when the specific interests of some partners lead to divergent views on the project. For example, in one case (OG8), the Region cut the budget because one of the topics declared in the application was neglected by partners who chose to prioritise other topics.

Some of those interviewed stressed the importance of the commitment of the project manager. For some respondents, the coordinator should oversee the different roles throughout the project, making sure that all partners accomplish their bureaucratic duties (OG3) and ensure transparency about their contributions in the financial reporting (OG4), since it is the coordinator who bears the economic and legal responsibility to the funding agency and the project partners (OG2). Others stressed that an experienced and committed project manager in the consortium might ensure positive results for the project (OG8).

The coordinator is responsible for ensuring partner commitment towards the project goals and the specific task assigned (OG1, OG2). One partner suggested that this role could be covered by the innovation brokers (OG9), acting as an intermediary among partners, the OG and the regional officers, and responsible for the communication and dissemination of the project results (OG9).

The commitment and motivation of farmers and SMEs could be boosted when coordinators/innovation brokers support their project activities, provide them with clear indications at each step, and show the tangible benefits from the solutions. In such cases, the farmers would likely offer to engage in extra activities and experiments, and speak well of the project to their

acquaintances, which can have positive economic implications on the project (OG3, OG9).

There is no doubt that face to face and even online meetings encourage the commitment of participants. Field visits and brief technical meetings in person not only help the implementation of the project (OG9) and serve for practical purposes of installing and maintaining technological tools, testing, and data collection from the experiments (OG7) but they also help create personal connections among stakeholders (OG4, OG7). Online calls advance project implementation and coordination (OG4), but can also foster team building with partners from different provinces in the same region or different regions altogether (OG3, OG9). Also in this context, coordinators must acknowledge partner commitments and keep the meeting and communication schedule feasible for everyone (OG6).

Moreover, availability of additional funding resources allows to tackle challenges that are similar in OGs operating in different regions or areas of the same region, and support further experimentation at different levels, with a common ground for the analysis and comparation of results (OG4, OG9).

Several respondents also indicated that regional officers are usually committed to solving OG bureaucratic issues, checking the overall project procedures and functions (OG3, OG6, OG8), and providing networking opportunities at the regional level, by connecting different projects to share practices and solutions (OG3). In one case, disorganisation and lack of punctuality was highlighted (OG9).

3.2.3. Interaction throughout the project

To provide efficient space for interaction and set up a strong partnership it is helpful to establish consortia based on pre-existing collaborations (OG7, OG8), and to choose partners who can face budget anticipation (OG8).

In this context, mainly the coordinator or, in one case, the innovation broker (OG9) is perceived as having a decision-making role, not only because this person has "a broad view of the project topic" (OG2) but also to avoid assigning this role to some participants who may work on specific tasks and therefore be less responsive when it comes to making decisions for project management and coordination (OG3).

It is essential from the very outset of the project idea to organize "key meetings to explain the nature of the funding call and give guidance on participation" (OG2, OG7), whether the project involves partners from the same region or collaborators from different territories, chosen for strategic reasons (OG1).

Diplomacy is important (OG2) to make sure that everyone's voice is heard when speaking about the project progress and outlining solutions in line with principles and aspirations of each (OG2, OG5). However, when organisational or relational problems occur, the coordinator/innovation broker must safeguard the integrity of the consortium and find feasible solutions, perhaps by re-assigning tasks among the partners (OG3, OG9).

In addition, coordinators oversee the overall management process of the project. Previous experience in project management might be a bonus, but acting strategically in setting up the partnership and knowing partners' commitments is of extreme importance for running the project smoothly (OG6, OG7).

Coordinators and innovation brokers play a key role in the cohesion and effectiveness of operational groups. Coordinators intervene with their decision-making power, especially in situations of conflict (OG2). Innovation brokers also are known for their contribution to partnership cohesion. In one case, the innovation broker supported the creation of the consortium by identifying partners from different areas of the region that were connected to producer organisations; this made it possible to establish of a consortium that officially counted on 3 farms but that actually connected a huge network of farms, where the innovations could be experimented throughout the project (OG9). Instead, the poor engagement of coordinators and innovation brokers negatively affects the development and diffusion of innovation, the engagement of partners and other key stakeholders (e.g., consumers or opinion leaders) and the consistency of feedback received about the innovation output (OG2, OG9).

Interactions in the project involving project management agencies and scientific partners also influence the success of the initiative. Some respondents felt that the former do not help the operational groups, because of their project-oriented nature (OG6, OG7).

According to some (OG2), the scientific partner also contributes to the process, to "dictate the intensity of the [different] […] actions", together with the innovation broker, "who should create connections between businesses potentially interested in the topic […] and research centres" (OG2).

There can be many barriers to innovation co-creation. First and foremost, the short duration of the project (OG1, OG2, OG4, OG7) could yield data of little significance (OG1, OG2, OG4), unrepresentative of the entity of the efforts made (OG1). Secondly, regional projects often are bureaucracy heavy, "full of formalities" (OG2) and restrictive budgeting and reporting rules, with up-front demands for specific information on activities before it is possible to provide this information (OG6), thus creating delays in the project timeline (OG2, OG9).

Interactions might be difficult also when the partners have different educational backgrounds, values, willingness to share information (OG7) or vision for the type of innovations and activities to be implemented (OG2, OG8) and when businesses have internal disagreements (e.g.: entrepreneur vs. employees/workers) on the experiments to be conducted (OG8).

Moreover, in the wider local context in which the OG operates, there could be "jealousy" and "egocentric" attitudes due to established power-interest relationships, sometimes "political" and often related to a "fear of change" (OG3). This could result in the lack of recognition of the OG results (OG3) by other local actors. In some other cases, instead, regional policy makers have shown a collaborative approach regardless of their political affiliations (OG8).

Overall, respondents would engage in future collaboration, although the terms and conditions are not clear for the follow-up activities (OG7). They are willing to pair old and new partners to engage in new funding opportunities. Trade associations might have a role in creating new connections to broaden the networks since, due to time constraints and other overlapping commitments, few efforts have been made to convert potential contacts into concrete partnerships for future collaborations (OG3). Many projects have produced a great impact on the local area, and the organisation of workshops attracted the interest of potential new entrepreneurial generations who are "perhaps culturally […] sensitive to environmental and […] sustainability issues, and who naturally see […] innovative solutions as a possible economic outlet" (OG2). Nevertheless, it is difficult to involve other farmers in projects adopting innovative and sustainable agricultural practices. It takes time to change people's minds, but some respondents said that these OGs activities have recently begun producing some impact in this direction (OG8).

Future collaborations could involve other OGs, to allow knowledge exchange […] and the development and adoption of innovation (OG1, OG2). However, identifying someone who could develop this collaborative activity is essential (OG6): this could be done by coordinators (OG1) or regional governments, which should act to connect different project coordinators (OG1, OG2) through dedicated services like instant messaging platforms and training days (OG2, OG3, OG4).

3.2.4. Communication

Communication within the operating group and also the sharing of information and results outside the partnership is of key importance. Within the OG, coordinators and partners responsible for project communications (OG9) seek to provide effective, transparent and balanced communication

among partners by circulating meeting information and providing an overview of further steps to ensure the attention and commitment from all partners (OG1). Especially for partners from different areas, internal communication can be ensured by online meetings (OG7) and, periodically, by technical face to face meetings (OG9).

However, the excess of meetings, emails and messages can impact negatively on the consortium, especially if members deem them superfluous or not of equal interest to all the partners (OG2). In this context, coordinators might consider an alternative communication language, according to the frequency and level expected by each of them (OG3). Moreover, issues may arise due to the willingness of some partners to pursue their own interests, giving priority to aspects of the project that the other partners do not perceive as a shared need (OG8).

Coordinators should also oversee the sharing of information and results from the projects outside the OG partnership, for example through workshops, newsletters, articles in the national press, etc. (OG2, OG7, OG9), by participating in conferences that would favour further knowledge exchange (OG7) throughout the entire viticulture and wine sector (OG4) and by involving producer organisations and their networks within the consortia (OG9). For example, OGs have organized thematic dissemination meetings to share the project results and even storytelling seminars hosted by farms to present their innovative solutions (OG9). Generally, effective sharing of information and results could strengthen the existing network and help establish new relationships, especially if OG partners succeed in communicating a shared vision and showing coherence and common values, although one respondent indicated that this does not always happen (OG8).

Here, local agricultural agencies involved in the OG projects (OG7) or regional governments can play in important role by publicizing OG projects and their positive results for the viticulture and wine sector and providing new opportunities for the OG members to increase their knowledge and build relationships inside and outside the OG through AKIS programme activities (OG3). This could result in new collaborations and an enhanced reputation beyond the regional context. Word of mouth and informal communications are also important during the dissemination events to foster networking. Here, presenting good practice examples from farms participating in the OGs could stimulate other farmers (OG3) to invest in the developed solutions.

3.2.5. Ensuring a strong and collaborative network

The establishment of relationships of trust among participants is essential for running experiments and ensuring on-site applications of the solution

developed. Training activities might foster understanding of roles among participants and relevance of the solution for business activities (OG3), although the age of the manager and the business size might impact the responsiveness towards the technological product. Indeed, senior managers of SMEs have proven to be more oriented towards implementing the technologies developed than have the younger managers who run bigger farms (OG3).

In general, when partners face highly urgent problems together, for example, floods or other natural disasters, or parasite damage to fields, they tend to have a strong collaborative and "problem-solving" attitude. Instead, when bureaucracy hampers the activities, partners are less open to collaborating (OG3, OG8, OG9).

To broaden the consortium beyond the official partners, one OG invited representatives of producer organisations with a high number of farms, from other parts of the region. This allowed more companies to benefit from the experiments and enhanced sharing of the project results (OG9).

Often external relations with other OGs in the viticulture and wine sector are established by coordinators and innovation brokers themselves. This is easy when they manage more than one OG or create contacts with OGs working on similar innovations domains, to gain an overall understanding of the OG results produced regionally (OG4). This action is very important because to date no particular attention has been devoted to creating opportunities for networking at an extra-regional level, beyond the "Innovarurale" online database for retrieving information about viticulture and wine OG projects, and some national initiatives organised by the Ministry of Agriculture with some selected OGs to promote exchange among OGs from different regions (OG3, OG8). Collaborative relationships with regional officers and policymakers potentially impact policy implementation and project success (OG3, OG8) with increased awareness of and knowledge about the innovations (e.g. Agriculture 4.0) implemented by the OGs, resulting in following more punctual and pertinent measures and call for funding (OG3).

3.2.6. Building and encouraging trust

Trust lies at the core of successful project implementation. The perception that the different partners are working with equal engagement in the project reinforces a sense of cohesion. Opportunities for bonding among participants happen when partners carry on activities together and engage in periodic meetings (OG3, OG4).

Coordinators and other intermediaries (OG7), such as innovation brokers (OG9), should ensure a space of trust in order to address innovation barriers.

They should help partners overcome administrative obstacles (OG2, OG3, OG4, OG7) and carefully choose business partners to involve in the project, with the awareness that the involvement of many business partners is certainly a positive aspect for the project, but that a small group also has its advantages, allowing for better and faster identification of solutions to address issues that arise in the project (OG2, OG4, OG9). However, "roles and actions also depend a lot on people" (GO2). Indeed, besides the proactive partners engaged in project objectives and sharing of results (OG2, OG7), there could be other companies that are "silent," even during meetings (OG1). In general, partnerships built with acquaintances or previous collaborators would certainly

Table 3 - Drivers and barriers to participatory innovation process

Drivers to the participatory innovation process	The coordinator plays the role of connector, facilitator, motivator. This role can also be played by innovation brokers
	Pre-existing collaboration patterns in the consortium
	Partners grasp the concrete benefits from application of the innovation based on real needs
	The coordinator and the regional government work cooperatively
	The regional government is open to listen to partners about issues that arise during the project and acknowledge them, and to support a smooth work flow
	The OG can create present and future interconnections with other regional OGs
	Good dissemination of the project objectives and results, including through peer-to-peer interactions, positively impacts the commitment
	Frequent online and in-presence meetings enhance trust among the project members
	A transparent and useful subdivision of roles and activities
	Trustworthy intermediaries monitor the development of different activities
Barriers to the participatory innovation process	Pressing bureaucracy
	Delays in receiving funds
	Ineffective communication about the concrete results of the project
	Resistance to sharing data and information
	Different interests and divergent visions among partners
	Power-interest dynamics, sense of jealousy or competition diffused in rural contexts
	Poor dissemination of information and portals related to the OG activities and projects

set the ground for a relationship of trust (OG6, OG8, OG9). Instead, when partnerships have new members with whom there are very few personal interactions, having trustworthy intermediaries who ensure the accomplishment of different roles and activities might help to develop a good relationship among the partners (OG2, OG7, OG9).

Heterogeneity in membership (OG7), and clarity on roles are perceived to positively influence the project outcomes. When roles and tasks are allocated clearly, so that all members know their primary responsibilities, the project activities are more transparent and partners can help each other in achieving the project goals (OG1, OG2). Transparency on the specific tasks could be supported by the establishment of deadlines (OG7) and detailed rules, both internal to the partnership or external, for reporting and dissemination of the activities (OG1).

Based on the results of the qualitative data, Table 3 provides a synthesis of drivers and barriers to the OG innovation-oriented projects.

Conclusions

This study sought to understand the role played by OGs in the process of adopting innovation, and to identify the strengths and weaknesses of co-design and innovation transfer strategies supported by the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI).

The innovation process is multifaceted and can be influenced by a number of variables that are sometimes complex to identify and generalise. However, as highlighted by Costa *et al.* (2022), given the great challenge of the twin transition towards environmentally sustainable practices through the adoption of digital innovation, more effort is needed to improve the dissemination of innovations in the viticulture and wine sector, facilitating the culture of innovation and the orientation of operators towards a digital and sustainable production system.

The quanti-qualitative research presented in this contribution highlights some useful aspects for strengthening the instruments of OGs and fostering their dissemination. The research shows that OGs work better when they are based on innovation needs and interests shared by the participants. In line with the previous study of Piñeiro *et al.* (2021), OGs can be a tool for developing and applying concrete innovations from farmers' recognised need for knowledge or the willingness to move to more sustainable production systems.

According to the literature on the topic, the dynamics that foster the success of an OG are closely linked (Giarè & Vagnozzi, 2021; Molina *et al.*,

2021)the most important initiative of the European agriculture innovation policy is the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP AGRI, and a common vision and shared objectives positively influence the management of the innovation process, favouring coordination and communication activities and the climate of trust among participants.

Here, the role of coordinators in project management is crucial: they keep participants reminded of the overall vision of the OG, manage transparent and balanced communication among the participants, support and listen to individual partners, deal with conflicts, facilitate project activities and work with the authorities on administrative and bureaucratic aspects. The expertise required to coordinate an OG is crucial, and regional agencies should take this into account when they define calls for proposals. For example, if the coordination role is restricted to farmers, the project may not have a coordinator with the expertise needed. Given the limited strength and availability of smaller farms, in the latter case, it would be useful to encourage the presence of innovation intermediaries who can assume the facilitation tasks and the absorption of administrative bureaucracy that is sometimes too burdensome for companies as early suggested by Parzonko *et al*. (2022). Other strategic decisions assigned to the Regions concern the timing and funds made available for projects, which should also be calibrated with the objectives set by the Region and the practical aspects concerning project implementation.

Communication, as pointed out by Molina *et al*. (2021), emerges as a decisive factor in the co-creation processes of innovations and knowledge transfer mechanisms. Communication skills are essential in interactions within and also outside the group, for example, in strengthening relations and contacts with other OGs nationally and internationally or with stakeholders facing similar issues.

Although the local government's institutional support in the design and setting up phase of the OG is acknowledged, the respondents indicated a lack of trust in managers of public funding, because of bureaucratic aspects and problems with excessively long waits for reimbursements.

Implications for practitioners

Although this contribution is more focused on management aspects of OGs than on analysis of specific innovations, important considerations emerge on managerial aspects that could involve practitioners.

Engaging actively in OGs offers practitioners an opportunity to access and share cutting-edge knowledge and innovative practices. This collaborative

environment not only helps to address existing gaps in the viticulture and wine sectors but also fosters a culture of continuous improvement and innovation. SMEs can benefit from active participation in consortia because it helps them overcome infrastructural and financial constraints and provides access to technological advancements that might otherwise be out of reach. Disseminating project results can significantly enhance the visibility and impact of the innovations developed, benefiting the entire sector, but primarily, farms could benefit internally from a diversified partnership for the training of their employees and the development of a stronger innovation culture through knowledge-spreading.

Implications for policymakers

Focusing on the operating mechanisms by which the EIP-AGRI supports innovation and knowledge exchange in agriculture, with particular attention to the viticulture and wine sector, this contribution offers significant insights for policymakers about the enabling factors and potential barriers to innovation development forward a twin transition.

Policymakers should support and enhance bottom-up initiatives that emerge from common stakeholder needs. What could increase effectiveness and adherence to OG projects is the simplification of bureaucratic processes and the reduction of administrative tasks. Clear and accessible guidelines for project management, budgeting and reporting could facilitate the effective participation and contribution of all partners. In addition, investing in the training of skilled project coordinators could be a contributing factor to improving the management of the project. Finally, local and national governments can play a pivotal role in supporting the dissemination of results and providing national and international networking opportunities among stakeholders to ensure that the innovations introduced by the OGs are widely disseminated and adopted, leading to sustainable growth and development of the viticulture and wine sector.

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