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Keynote article

The new challenges of agricultural policy: new actors and redefined development paradigms

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Abstract. The role of the agricultural sector has had to evolve as our global social economic system has been changed by drivers such as climate change, demographics, ecosystem depletion, changes in dietary patterns and rising food demand. A key characteristic of 21st century agriculture is the reaffirmation of its primary function: producing sustainable food for a growing global population living in increasing inequality and political instability. However, the role of agriculture also goes beyond feeding the planet; it increasingly involves maintaining the environment. Meeting these challenges will require significant changes in the sector's organisational and operational boundaries and bold intervention from the research community and public sector alike to generate new knowledge and innovation systems. This paper aims to describe and analyse, where possible, the changes this transition will entail in terms of stakeholders, policy interventions, governance, development models and, finally, the role research should play in future scenarios.

Keywords: innovation ecosystem, stakeholder mapping, science-policy-society interface.

JEL codes: Q18, E61, O13.

HIGHLIGHTS

- The drivers of economic system transformation are social, political, and also environmental.
- The agricultural sector has redefined its role and scope.
- Multidimensionality of roles and development objectives can only be achieved through a systemic vision of the agricultural sector.

1. INTRODUCTION

Our economic system, and society are in a rapid state of change that shows no signs of slowing in the near future. The drivers of this transformation are social, political, and also environmental. The big issues facing society, referred to in the scientific debate as the Grand Challenges (Davidson *et al*., 2015; Bock *et al*., 2020; De Bernardi *et al*., 2020), include climate change, global demographic trends, the depletion of natural resources and ecosystems (Foley *et al*., 2011), changes in dietary patterns, and rising food demand. In addition to these elements, we must consider the recent shocks that have impacted both the developed and developing world, such as the COVID-19 pandemic and ongoing conflicts.

The Food and Agriculture Organization (FAO) (2022) has recently identified 18 interconnected drivers for the future Grand Challenges of agrifood systems that affect three interconnected systems: the environmental system (including scarcity of natural resources, ecosystem degradation, pandemics, climate change, and overfishing), the socio-economic system (including population growth, urbanization, economic growth, big data collection and data ownership, geopolitical instability, urban and rural poverty, and inequality), and the food system (rising food prices, science and innovation, capital intensity, investments, market concentration, and dietary patterns).

Within this context, the agricultural sector has redefined its role and scope. A key characteristic of 21st century agriculture is the reaffirmation of its primary function: producing food for a growing global population living in increasing inequality and political instability. Agriculture must meet this rising global demand whilst respecting sustainable development principles which are underpinned by ever more complex ethical values, including waste management, human rights protections, and the pursuit of circular production models.

The role of agriculture also goes beyond feeding the planet; it increasingly involves maintaining the environment. Climate change, fragile and marginal rural areas, increasing urban and peri-urban agriculture, farmland abandonment (even on the plains) and the consequent forest encroachment are all issues that can only be managed if agriculture is given a new role in territorial planning and protection, as well as in broader economic development models.

Knowing the precise future role and nature of modern agriculture is also complicated by its social and cultural functions, which have historically underpinned the European model of agriculture (Cardwell, 2004). Within this framework, the primary sector – recognized for producing positive externalities and providing a unique and resilient multifunctionality – must increasingly prioritize the needs of not only farmers and consumers but society as a whole. The expanded and diversified roles of modern agriculture make it uniquely positioned to create a "safe and just operating space for humanity" (Rockström *et al*., 2009; Rockström *et al*., 2023). Achieving this goal demands enhanced sustainability and competitiveness, a stronger contribution to food security and sovereignty, and greater resilience, elements that simultaneously present both synergies and conflicts. Furthermore, the new challenges and demands placed on the primary sector, in its broader and modern context, are driving agriculture and the entire rural world towards a transition that is not only ecological and digital (Brunori, 2022), but also social. This transition entails changes and adaptations in technology, and governance structures, as well as changes to the types and roles of stakeholders, including both long-established and newly introduced stakeholders (Gava *et al*., 2022).

In this context, the objective of this study was twofold. The first is to identify the needs and potential implications of change in the agricultural sector as it undergoes a complex process of transition. The second objective is to link these changes with new research needs, in order to better understand present and potential events and to implement tailored public intervention in future scenarios. The paper explores changes in different research topics. These are intervention policies, stakeholders in modern agriculture, governance structures and development models. The remainder of the paper is organised as follows. Section 2 outlines the role and characteristics that current and future public intervention should have. In particular, the need for policies based on an ecosystem approach will be discussed, which is essential when defining objectives and tools for ecological, digital and social transitions. Section 3 deals with stakeholders in the modern agricultural context, for which new mapping and new definitions of roles and dimensions are needed in order to better calibrate intervention policies. Section 4 analyses how policies and new stakeholders affect governance models in agricultural systems. Section 5 discusses how the described changes are changing development models and their theoretical frameworks. Section 6 provides discussions that stem from previous considerations, concluding with suggestions for future research needs.

2. POLICY INTERVENTION BETWEEN ECOSYSTEMIC APPROACH AND POLICY MIX

The current context requires agricultural and rural policy intervention that can meet ambitious environmental targets but also work towards social equality goals to ensure fairer and more inclusive development. In light of this, an analysis of the European policy framework, and in Italy in particular, reveals four main observations:

1. The scope of agricultural policies has widened as the domains and functions of the agricultural sector have expanded;

2. Policy interventions focus on the operational phase of guidance documents for long-term European economic development, including intergenerational goals;
3. Current policies were implemented or updated during a period marked by significant shocks, such as the pandemic and ongoing conflicts;
4. The central role of innovation as a cross-cutting strategy for all interventions

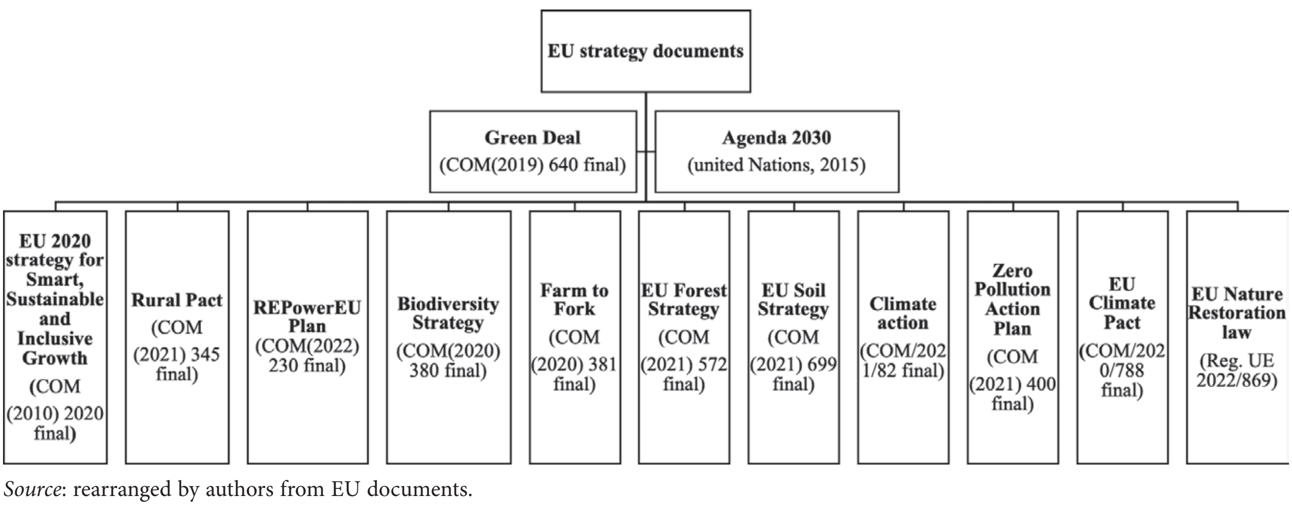
The first observation concerns the classification of policy interventions earmarked for agriculture or rural areas. As the domains and functions of the agricultural sector have expanded, an ever more diverse array of policy interventions has become available. A new categorisation of existing policies will be required if food policy is to meet the challenges of prioritising food safety, nutrition, and health, while also addressing the social and environmental dimensions of agriculture. This is essential to tackle environmental challenges, meet energy supply demands, and strengthen rural communities within a place-based framework (OECD, 2023).

The second observation is that most current policy interventions focus on the operational phase of guidance documents, designed to outline a path toward long-term European economic development, including intergenerational goals. The effectiveness of this approach depends on each Member State's ability to implement these interventions and the extent to which these principles and objectives are shared across nations. The central EU long strategy vision is described in two main documents: Agenda 2030 (United Nations, 2015) and the European Green Deal (COM(2019) 640 final). Many other intervention policies have been implemented to achieve the identified objectives. In addition to these, a myriad of other guidance documents that set out strategies for policy direct and indirect intervention for agricultural systems have been added, including the seven lighthouse initiatives under Europe 2020 "A Strategy for Smart, Sustainable and Inclusive Growth" (COM(2010) 2020 final), the Farm to Fork Strategy (COM(2020) 381 final), Biodiversity Strategy (COM(2020) 380 final), the EU Forest Strategy 2030 (COM(2021) 572 final), the REPowerEU Plan (COM(2022) 230 final) for the transition to clean energy, the European Soil Strategy 2030 (COM(2021) 699 final), the Climate Action Strategy (COM/2021/82 final), the Zero Pollution Action Plan (COM(2021) 400 final) for air, water and soil, the European Climate Pact (COM/2020/788 final), the Rural Pact (COM(2021) 345 final), the EU Nature Restoration law (EU Regulation 2022/869), and the upcoming EU Directives on sustainability (EU directive 2022/2464) (Figure 1).

The third observation is related to the timeframe of policy programming. Many of the current policies were implemented or updated during a period marked by significant shocks, such as the pandemic and ongoing conflicts. These events have profoundly altered our vision of development, political balance, globalization meaning, and the prioritization of contemporary societal needs, which often clash with the perspectives outlined in earlier documents. This observation applies to the broad range of interventions under the Recovery Fund, and especially to the new Common Agricultural Policy (CAP) 2023-2027, whose foundational regulations were established in 2018, before these shocks and before the introduction of the Farm to Fork strategy.

The final observation, and perhaps the most innovative aspect of the current intervention landscape, is the central role of innovation as a cross-cutting strategy for

Figure 1. Main EU strategy documents.



Source: rearranged by authors from EU documents.

all interventions aimed at transforming and transitioning the agricultural systems. Digitalisation, in particular, is highlighted as a key tool for enhancing the resilience and sustainability of the entire agricultural and rural sector. However, addressing the Grand Challenges requires innovation not only in terms of technology but especially innovation in social and institutional domains (Kok and Klerks, 2023; Herrero *et al*., 2020), therefore what is required is a socio-technical regime transition. This multidimensionality can only be achieved through a systemic vision. From this standpoint, Agricultural Innovation Systems (AIS) have emerged as the best approach to studying and building diverse stakeholder networks, bringing in actors from the areas of production, advisory services, research, institutions, and civil society (Klerkx *et al*., 2010). These networks are essential for co-producing research, innovation, and intervention policies that address increasingly complex needs (Annosi *et al*., 2022; Klerkx *et al*., 2012; Pigford *et al*., 2018, Vecchio *et al*., 2024). Recently, the scientific debate has shifted from a systemic perspective to an ecosystemic one, viewing innovation as a co-evolutionary process (Pigford *et al*., 2018; Maria *et al*., 2021). This shift acknowledges that in scenarios marked by high degrees of uncertainty and change, policies must exhibit a high degree of adaptive capacity (Folke *et al*., 2011).

Ecosystem approaches involve a complex network of interconnected actors (Wolfert *et al*., 2023). In essence, innovation systems focus on the types of interactions and governance mechanisms in operation between actors deriving value from innovation, while the ecosystem perspective highlights the co-evolution of innovation and the co-creation of value (Lioutas *et al*., 2021). Integrating dynamism into the theoretical framework makes the ecosystem a valuable tool for analysing the ecological and digital transitions of the agricultural and rural sectors, and for examining the synergies or conflicts that may arise between these processes (Wittman *et al*., 2020; Schnebelin *et al*., 2021). One of the most fitting definitions, which underscores the strong potential for empirical analysis, comes from Granstrand and Holgersson (2020: 3): "An innovation ecosystem is the evolving set of actors, activities, and artefacts, and of institutions and relationships, including complementary and substitutive relationships, that are important for the innovative performance of an actor or a population of actors".

Agricultural innovation ecosystems are integral to both planning a policy vision and the practical implementation of policy interventions. During the previous European programming period of 2014-2020, the European Partnership for Innovation, Agricultural Productivity, and Sustainability (EIP-AGRI) aimed to connect the agricultural and research sectors at regional, national, and community levels through the creation and funding of Operational Groups. In the new CAP 2023-2027, the Agricultural Knowledge and Innovation System (AKIS) serves as a transversal objective and a preferred approach in implementation procedures and interventions. This framework necessitates the involvement of all relevant actors, whether at the sectoral, problem-specific, or territorial level (CREA, 2023).

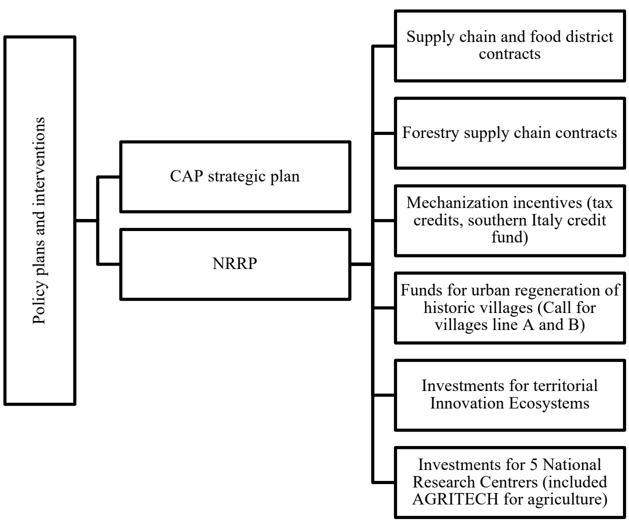
Additionally, both in Europe and in developing countries, there are established networks that facilitate knowledge-exchange networks and the creation of innovation ecosystems. Examples include the Strategic Working Group on Agriculture Knowledge and Innovation Systems (SCAR AKIS) from the European Commission (Poppe, 2012) and the Consultative Group on International Agricultural Research (CGIAR) with its "systems transformation approach for food, land, and water systems" which focuses more on developing countries (McIntire Dobermann, 2023).

From this analysis, two key observations emerge. The first is the sheer amount of policies and measures available to beneficiaries, some potentially leading to convergent or conflicting change pathways. Indeed, policy interventions are not limited to those cited as the CAP 2023-2027 (EU Regulation 2021/2115) itself, the New Delivery Model (EU Regulation 2021/2116) – namely the shift from a compliance-based to a performance-based system of the CAP – offers a wide range of measures. In Italy, the CAP Strategic Plan (PSP) for the 2023-2027 planning period includes a total of 173 interventions, including sector-specific ones. The national AKIS strategy is detailed in chapter 8 of the PSP, featuring 9 interventions – 3 under "Cooperation" (REG 2021/2015, art. 77) and 6 under "Knowledge and Information Exchange" (REG 2021/2015, art. 78). Additionally, there are intervention programs financed by the Italian government within the EU Recovery Fund- NextGenerationEU (e.g. the National Recovery and Resilience Plan – NRRP in Italy (EU Regulation 2021/241)), such as supply chain and food district contracts, forestry supply chain contracts, mechanization incentives (tax credits, Southern Italy credit fund, etc.), energy efficiency initiatives (Agrisolar Park 2023, etc.), funds for urban regeneration of historic villages (Call for villages line A and B), investments for territorial Innovation Ecosystems, and investments for 5 National Research Centres, among these AGRITECH focusing on agriculture (Figure 2). In details, AGRITECH is an innovation ecosystem composed by 28 Italian University, 19 research centres, 14 important and strategic companies. The main objectives are to combine the top multidisciplinary research expertise to develop and apply the most suitable technologies. Using a multi-actor approach, AGRITECH brings together universities, companies and farmers to co-design innovations, human capital and skills for the future of agri-food supply chains.

The second key observation, from a theoretical perspective, is that the current constellation of policy interventions requires a multi-faceted approach to policy analysis. Traditionally, the actions and interactions of all involved actors form "the policy market" and so also decisions (Lechi, 1993). Today's policy market is unique due to the complex nature of available interventions. Beneficiaries are not targeted on a single-issue basis, but instead are selected from a policy mix designed to address multifaceted needs (intangible benefits, investments, ecological transition, etc.). The composite nature of the possible intervention choices is identified, in scientific literature, as a policy-mix that highlights the importance of combining various policies to form a coherent strategy that coordinates the activities and roles of all involved actors (Flanagan *et al*., 2011; Lindberg *et al*., 2019).

To meet the types of challenges previously described and drive the necessary changes, the agricultural and rural sectors require models that can bring not only technological transformations, but also political and social ones. Furthermore, as previously mentioned, the approach must be multi-actor and ecosystem-based with a long-term vision (Geels, 2019). In this context, the policy mix concept is crucial. Achieving complex objectives such as climate resilience, social equity, or sustainability necessitates a combination of interventions that blend different existing policies into a unified strategy that can coordinate activities and roles across various actors (Mugabe *et al.*, 2022). To better define the concept, Rogge and Reichard (2016) described policy mixes using 4 characteristics: a) consistency captures the extent to which the elements of the policy mix are mutually synergistic in achieving the identified objectives; b) coherence refers to policy implementation processes able to achieve policy objectives; c) credibility is the policy mix degree of credibility and reliability; d) comprehensiveness of the policy mix refers to the exhaustiveness of its elements and to the extent of the decision-making process. Moreover, achieving common goals may involve integrating different action plans through governance that fosters cooperation across different decision-making levels.

Figure 2. Policy plans and interventions.



Source: Rearranged by authors from EU documents.

3. STAKEHOLDERS IN RURAL SYSTEM AND THE NEED FOR NEW MAPPING

An analysis of the current policy framework, as described in the previous paragraph, reveals a common theme: the ecosystemic approach, the socio-technical transition and the need for a policy mix all emphasise the involvement of stakeholders from various sectors and fields. The profound changes affecting the agricultural and rural world – such as digitalization, genetic innovation, new business models, and the unprecedented spread of services (organizational, logistical, digital, legal aspects) offered to the sector – have also impacted the actors involved, increasing their diversity and changing and expanding their roles and potential connections.

Given this, a new kind of stakeholder analysis has to consider stakeholders as integral parts of building knowledge ecosystems and to take into account different stakeholder roles and potential instances of synergies and/or conflicts in the context of profoundly dynamic and unpredictable future scenarios. Following the most recognized definition of stakeholder: "A stakeholder is defined as persons, groups, organizations, systems, etc., that have a 'stake' in a change effort (eg. a development project) and that are either likely to be affected by the change, whose support is needed or who may oppose the change" (Morgan and Taschereau, 1996: 4), it is clear that the first focus of analysis must be on farmers. The current scientific and political debate is focused primarily on exploring future scenarios for agriculture, including the challenges of food production and consumption patterns.

However, the changes that will directly affect the socio-economic characteristics of farmers in the medium and long term are still under investigation. This research gap is particularly significant given that only

Table 1. Farmer Profiles in 2040.

Farmer profiles	Keywords
Adaptive farmer	Diversification; systemic approach; innovative skills
Corporate farmer	Corporate; automatization; business unit; agricultural knowledge management
Intensive farmer	Intensive; Farm efficiently; production focused; specialisation
Patrimonial farmer	Tradition; family; heritage
Controlled environment farmer	Agritech start-up; indoor agriculture
Cell farmer	Biotech start-up
Social care farmer	Social and health sector; community; social inclusion
Lifestyle farmer	Farm as service; neo-rural; new entrant
Regenerative farmer	Planetary health; conservation; agroecology
Urban farmer	Entrepreneurial; micro-farm; local
Serious hobby farmer	Recreational; non profit; passionate
Community provisioning farmer	Subsistence

Source: Adapted from Bock *et al*., 2020.

11% of all farm holdings in the European Union are run by farmers under 40 (Eurostat, 2022), suggesting that discontinuity will play a major role in reshaping this group of stakeholders.

According to recent work by Bock *et al*. (2020), it is evident that future farmers will be much more diverse than those of today. The study identifies 12 profiles for farmers in 2040. The main characteristics of these profiles are shown in Table 1. The diversity of farmer profiles is a direct result of both the impacts of the sociotechnical transition on the world of farming and the expanding functions that define modern agriculture. The wide range of skills, objectives, business models, and the material and immaterial resources utilized, along with the intrinsic connection between farmer profile and their local territory, illustrate the complexity of future ecosystems in terms of actors, connections, and knowledge flows.

In the recent literature, stakeholder analysis has been employed as a methodological approach to address research questions relating primarily to future development scenarios or policy interventions. Analysts have long sought to understand how information, institutions, decisions, and power shape political agendas for interest groups within social networks. Stakeholder analysis represents an approach to deepen the knowledge of the actors in the system analysing their behaviours, interests, objectives and influences on the system processes. Specifically, stakeholder mapping proves particularly useful for assessing the interests, relationships, and conflicts among different actors within a given system of reference. In recent years, this type of analysis has gained widespread use across various disciplines and is now standard practice among businesses, policymakers, and international organizations (Friedman and Miles, 2006; Reed *et al*., 2009).

According to Grimble and Wellard's (1997: 175) definition, which is particularly relevant to this discussion, stakeholder analysis can be viewed as "a holistic approach or procedure for gaining an understanding of a system, by means of identifying the key actors or stakeholders and assessing their respective interest in the system".

In the new scenario of change for agricultural and rural systems, implementing innovative stakeholder mapping in order to find new actors and link these to the characteristics of ecosystems becomes a strategic element. From an analysis of the literature relating to the context of our interest, what emerges is still a strong focus on the production chain as a conceptual and physical boundary for the identification of relevant stakeholders. To give just a few examples, Graef *et al*. (2014) identify farmers, processors, traders, transporters and technical assistance services as relevant actors in a study of the cereal sector, as well as Benedetto *et al*., (2014) in the case of the wine supply chain, Vellema and Van Wijk (2015) in cases of agri-food certification, Lokesh *et al*. (2018) in cases of circular economy, Surucu-Balci and Tuna (2022) in managing food waste and losses. Other examples are Saint Ville *et al*. (2017) in the context of food security in a specific geographical area and D'Agostino *et al*. (2020) for water management.

The same ecosystem approach is also needed to map stakeholders in the rural and agricultural sectors if it is to adapt successfully to change and adopt suitable policies. This approach is already evident in other research fields, where the ecosystem defines the ideal boundaries for identifying key actors (Li *et al*., 2022; Del Vecchio *et al*., 2021; Nylund *et al*., 2021). However, many studies still provide a static view of stakeholders and their connections (Frooman, 1999; Friedman and Miles, 2002; Rowley and Moldoveanu, 2003), which does not reflect the co-evolutionary nature typical of ecosystems. An exception is the method suggested by Barquet *et al*. (2022), where stakeholders are mapped based on their involvement in the co-creation process.

Building a resilient agricultural system means encouraging co-creation processes in which actors learn to use each other's skills to develop new strategies aimed at grand and shared challenges (Voorberg *et al*., 2017). Considering the nature of the ecological and digital transition and the presence of a highly diversified structuring of policy interventions, it is reasonable to expect that stakeholders must include traditional actors endowed with both old and new functions and also new actors, with roles both already defined and yet to be identified. Examples are the different public institutions at different decision-making levels, the whole world of AKIS (production, research, consultancy, public institutions, civil society), all the new producers of digital and genetic technologies, providers of innovative services such as data management, marketing, traceability (blockchain, food passport, etc.), as well as all the producers of alternative technologies for energy production, third sector companies, the tourism sector, the material handling sector, etc.

Intermediate stakeholders must also be considered, such as those being developed and supported by specific intervention models like the Local Action Groups (LAGs) in the LEADER field, the European Innovation Partnership (EIP) – AGRI Operational Groups, the food districts in all their present forms (quality, food, rural organic etc.), the National Research Centers operating with RRNP funds, the European Startup Village Forum, the Regional Innovation valleys, the Living labs, the Lighthouse Initiative, the business Accelerators and Incubators, all the countless forms of international and digital networks, etc.

Deepening existing connections, and especially levels of cooperation between actors, is fundamental to lead the system towards a more equitable and inclusive development without making the mistakes already made during other important transformations (mechanics, chemistry, genetics, etc.) which have seen the agricultural and rural system worsen both in terms of economic and social performance.

4. GOVERNANCE: FROM SECTOR TO SYSTEM

The ecological, digital, and social transitions impacting the agricultural-rural system demand institutions and governance that are stronger, more transparent, and accountable, as well as highly adaptable and effective (FAO, 2022). In today's context, describing, analysing, and supporting the evolution and improvement of governance is crucial for both research and policy implementation (Dwyer, 2022). This is vital because crafting and implementing policies for sustainability and resilience involve complex interactions between government and society (Glass and Newig, 2019). Moreover, the long-term development perspective necessitates governance that fosters ecological transition processes that are not only efficient but also legitimate and socially just, tightly interweaving technical and economic evolution with social progress. In short, transitioning from a sector-specific or place-focused approach to a more holistic and multidimensional perspective in governance is the desirable path.

Theoretically, the concept of governance has evolved in this direction. According to Stoker (1998), governance encompasses a range of institutions and actors, both within and outside of government, that address social and economic issues in a framework where the boundaries between the state and society, as well as between the public and private sectors, become more blurred, as do the definitions of their respective responsibilities. However, the most recent literature (Lockwood *et al*., 2010; Glass and Newing, 2019; de Boon *et al*., 2022) characterizes governance by emphasizing values, power dynamics, sustainability, social justice, and legitimacy in relationships between actors.

The growing importance of networks and systems of actors, due to their ability to facilitate complex objectives like environmental goals and the adoption of composite innovations, is gradually transforming relationships between public institutions and local actors, as well as between elective and participatory democracy. This shift necessitates the improvement or development of linkage mechanisms that better integrate top-down public intervention with bottom-up local initiatives (Knickel *et al*., 2018).

Furthermore, it is important to emphasize that with the expanded functions of agriculture and the need for a mix of intervention policies, governance becomes crucial both within and outside agri-food systems, following the a forementioned transversal approach. The FAO (2022) continues to update the concept of governance by explicitly referring to formal and informal rules, as well as the organisations and processes through which public and private actors articulate their interests and implement decisions. Including rules within this concept addresses the need for agricultural and rural systems to establish not only adaptable governance but also clear regulations to manage new challenges such as climate change, risk management, digitalisation and data ownership, genetics and ethics, negotiating intangible assets (knowledge, skills, certifications, etc.), and the increasing involvement of the private sector in traditionally public services (e.g. natural resource management, advisory services etc.).

Developing new governance models is also made more complex by the evolving role of actors, particularly the evolving role and vast expansion in the functions of public institutions. In the European context, the already mentioned interactive and multi-actor model for innovation, known as AKIS, is central to the ecological and digital transition. This model assigns the public sector the role of a "*coordinating agent in an increasingly pluralistic innovation system*" (EU SCAR, 2015). Moreover, the new delivery model of the CAP, which requires national level strategic plans to tailor support instruments to specific territories, tasks public institutions at varying levels with choosing the appropriate policy mix, both within CAP interventions and among other potential policies.

Referring to the FAO definition of governance, the public sector also faces the challenge of adapting a large and highly specific body of legislation to an operational context where the boundaries between sectors, activities, and territorial zones are becoming less distinct. Complex interventions often cause different regulatory areas to converge and sometimes conflict (e.g., urban planning, agricultural, commercial, security, immigration, and training regulations). Resolving these conflicts necessitates a role for public institutions as administrative facilitators.

Another element shaping future governance is the increasing importance of knowledge and innovation on power (im)balances among key stakeholders. Some studies have highlighted the emergence of "expertification" processes, and the formation of a European lobby made up of professionals who gain legitimacy and power, by possessing specialized knowledge. This situation is particularly relevant in discussions about future governance given the roles of new service providers, advisors, and tech-experts in digital technologies in knowledge and innovation ecosystems.

Finally, it is important to emphasize once more that governance should have a transversal dimension that spans economic sectors, intervention programs, and development trajectories. The so-called "horizontal dimension of European governance", where civil society plays a significant role, has been extensively studied in literature (Eversole and Campbell, 2023). However, despite being a frequently highlighted necessity by analysts and policymakers, it has often been overlooked. In the new scenario, the involvement of private and public-private intermediary actors – such as well-known Local Action Groups (LAGs), districts, and networks of smart villages – offers an opportunity to enhance integration and address this gap.

5. DEVELOPMENT MODELS: NEW VISIONS FOR NEW ACTORS

It is now widely recognized that stakeholders of agricultural-rural systems care about aspects such as the quality of their environment and food, social cohesion, recognizability and autonomy not just because of economic benefits but because of improved quality of life (Riviera *et al.*, 2018; Knickel, 2018). This paradigm shift must, consequently, also affect the development models pursued by policy intervention in agricultural-rural systems. Giving space to a vision of the future that is not only multidimensional (environmental, social, economic, institutional), but is also dynamic because it evolves with the adaptive capacity of the stakeholders and related governance, means a move away from a singular focus on economic efficiency or the valorisation of only endogenous system resources.

The elements that help build strong connections between endogenous and exogenous growth models are closely connected with the ecological, digital and social transition and the central role played by innovation and knowledge in these processes, as well as the need to refer to systems of complex agricultural-rural actors and not only to individual supply chains or sectors (Cowie *et al.*, 2020). The ecosystems described above, in fact, present both exogenous and endogenous knowledge flows and actors. This feature is amplified by the type of innovation introduced, often by producers, advisors, and other operators who are external to the sector and the reference area. The changes described in the make-up and roles of stakeholders, as well as in the characteristics of the related governance structures, also translate into an approach to development where geographical and sectoral boundaries become blurred.

The Organization for Economic Cooperation and Development (OECD) has argued that "the opportunities in rural areas go far beyond agriculture" (OECD, 2019) and possible solutions to the challenges we face seem to reinforce this observation. Different studies have provided empirical evidence to support the long-held belief that the top-down development model that for the last 30 years has been so ardently pursued by the EU, and which is largely responsible for the model of agriculture we find in the EU today, is simply not capable of bringing about the change and growth needed for agricultural-rural systems. In response, a debate has opened up on a different form of development defined as "neo-endogenous development" (Ray, 2000) of which the LEADER community initiatives continue to spearhead (Chatzichristos and Perimenis, 2022). This model sees rural development as an action of change that starts from actors within rural areas and communities, since their on-the-ground knowledge makes them the best stakeholders to implement and guide strategies. The drivers and actors that influence the change process are considered external to the local context. However, the actions needed for change cannot feasibly be undertaken by local communities alone, either due to lack of funds or lack of knowledge. To fill this gap, policy action intervenes with a top-down process, giving rise to a neo-endogenous policy-driven development. Following this approach, the LEADER community initiative had the objective of valorising endogenous resources and encouraging local actors to innovate and network through policy intervention. However, recent studies have highlighted that the proposed model has encountered obstacles due to too much red tape, an insufficient transfer of decision-making power by institutions to the LAGs, and a poor uptake by local actors of the initiatives on offer (Navarro *et al.,* 2016; Cejudo and Navarro, 2020).

As discussed earlier, the foundation for policy intervention and the basis for creating growth strategies should be a community of actors that form an ecosystem. This vision should also be integrated into discussions on development models. Both the scientific debate and empirical analyses increasingly reveal development models that do not fit into these paradigms.

The challenges facing the agricultural-rural system necessitate a transition towards new social models, often explained within the framework of the so-called "Social Innovation". The European Commission (2010: 9) defines social innovation as "the development and implementation of new ideas (products, services, and models) to meet social needs and create new social relationships." This concept is increasingly prominent in discussions on development models (Bock, 2016; Bosworth *et al*., 2016; Neumeier, 2017; Arnold *et al*., 2022) because it encompasses all components of innovation systems, including institutions, universities, producers, and civil society, while emphasizing values such as responsibility for change, social cohesion, and co-creation. According to Bock (2016), this increasingly requires development models that facilitate connections with stakeholders that go beyond the local dimension. The need for exogenous actors becomes evident when considering the ecological and digital transitions. As described in the section on stakeholders, innovation and knowledge ecosystems involve actors beyond traditional geographical boundaries and zoning, transcending the urban-rural divide. Building an ecosystem with local and extra-local connections among various groups fosters a community united by shared cultural, scientific, and interest-based concerns.

Empirical studies (Gkartzios and Lowe, 2019) strongly indicate that a new model of rural development, termed "nexogenous" in its embryonic form (Bock, 2016), is emerging. This model's strength lies in linking and collaborating across spaces, accessing exogenous resources that, when combined with endogenous forces, enable revitalization. A defining feature is the "breaking down silos" process, not only geographically but also in areas of intervention. Often, the contributions of non-local actors are immaterial (knowledge, external networks, skills, interpretative tools), supporting the development of supra-local networks able to connect resources not available at the local level (Olmedo and O'Shaughnessy, 2022).

As discussed in previous paragraphs on new stakeholders, governance and development models, using a single theoretical framework, such as bottom up approach, to describe rural development could be no longer appropriate. This increased complexity is something public policy intervention will need to take into account. This scenario emphasises the growing importance of connections between research, policies, and society. This calls for a new interface between science, policy, and society. Significant attention has been given in the literature to the science-policy interface to support policymakers in implementing new and complex policies (Webb *et al*., 2022). However, the fundamental role of society in the ecosystem vision necessitates including this actor at the heart of connections. The science-policy-society interface must involve all key stakeholders to effectively address the challenges of designing and implementing complex policies. This approach ensures that the knowledge produced and transferred has political legitimacy, broad participation, equity, transparency, and democratic decision-making (Webb *et al*., 2022).

At both European and international levels, the effort to establish a science-policy-society interface has seen progress through the creation of various committees, expert panels, hubs, and networks by governmental and non-governmental bodies. However, this institutional dimension doesn't diminish the need for a constructive and operational interface at other decision-making levels – national, regional, and local (Singh *et al*., 2023). Particularly at these levels, a new science-policy-society interface can enhance the performance of the research community in co-creating knowledge that is more tailored to social needs and in effectively communicating results and potential strategies.

6. CONCLUSIONS

The aim of this work was twofold. The first objective was to describe and analyse the primary sector and its changes as it undergoes a complex transition process. The second one was to try to connect these changes with new research needs in order to bridge deep knowledge gaps. To do this, four areas of analysis were investigated: intervention policies, new and traditional stakeholders in modern agriculture, governance structures, development models and their evolution.

Polices for the agricultural sector have a reach that goes beyond the primary sector. To face the challenges ahead, the interventions models have to support not only technological transformations, but also political and social ones. This requires a policy-mix, that is an integration between the plans and the actions, following a multi-actor and ecosystem-based approaches. New and traditional stakeholders populate and design agricultural and rural ecosystems in which co-creation processes are becoming strategic to develop new solutions for ecological and digital transition. To manage new dimensions and actors, governance becomes crucial and more complex as well as the organisations and processes through which public and private actors articulate their interests, regulations and implement decisions. The role of a "coordinating agent in an increasingly pluralistic innovation system" (EU SCAR, 2015) is primarily up to the public sector. It is also facing the challenge of adapting a large and highly specific body of legislation to an operational context where the boundaries between sectors, activities, and territorial zones are disappearing. This scenario asks for a governance model characterized by a crossing-cut dimension that includes economic sectors, intervention programs, and development trajectories. The future vision is multidimensional (environmental, social, economic, institutional) and dynamic because it evolves with the adaptive capacity of the stakeholders and related governance, meaning a move away from a singular focus on endogenous system resources. These profound changes also shape the kinds of development models that emerge from rural and agricultural systems. What can be seen is that knowledge flows and actors are both external and internal to the local territory and also to the agricultural sector. This creates strong connections between endogenous and exogenous growth models, highlighting the need for theoretical and empirical studies on innovative processes of development.

As discussed previously, co-producing knowledge with all actors in the agricultural and rural ecosystem through a multidisciplinary approach is now crucial. This challenge is fully embraced by the model designed by the European Commission, known as "Science for Policy 2.0" (Šucha and Vladimir, 2020) which breaks from the traditional linear model of knowledge diffusion. In this new approach, science must provide practical answers for the implementation of intervention policies, moving beyond "comfortable, well-defined scientific boxes." Given this, the relevant question, which still remains partially unexplored, is what characteristics scientists should possess to be key actors in the scenario described and, in particular, what the role of agricultural economists should be in guiding the implementation of policies in agricultural-rural ecosystems in the Science-policy-society interface. Surely the current context requires new roles and skills from researchers in terms of scientific communication methods, co-planning and mediation in multi-actor groups in which knowledge takes on different forms and different languages (van den Hove, 2007).

In order to respond to the dynamism of the context, research in agricultural policy has also evolved. According to some authors (Matthews, 2021; Dwyer, 2022), there are at least three factors that describe the change: a broadening of the areas of analysis in relation to the differentiation of the objectives of policy intervention, an equal enrichment of the research questions deriving from the new tools used in policy intervention and the introduction of new methodologies deriving from the fields of economics, statistics and psychology, which has given space to new forms of analysis.

The profound change we are witnessing requires us, however, to reflect on how research must further evolve and with it the skills and roles of the scientists involved. The question becomes urgent when the following is noted in the literature: "the most cited papers that are driving the broader food systems and food policy agenda are not published in the traditional agricultural economics journals and often do not include economists among their authors" (Matthews, 2021: 197). There are several reasons why this is the case; a perceived lack of credibility, a lack of legitimacy of scientific knowledge (Cash *et al*., 2002), diversity of values, objectives and language between researchers and policy-makers, different time-scale perspectives (Eistrup *et al*., 2019), all of which relegate science and politics to separate worlds (Cash *et al.*, 2002).

There are various strategies to make the contribution of agricultural economists more impactful in the transition process affecting the rural-agricultural sector. In addition to an increasingly multidisciplinary approach, enhancing the ability to analyse the processes characterising the functioning of agricultural-rural systems of innovation and knowledge in order to achieve economic, environmental, and social objectives is essential. This requires embracing different analyses and evaluation approaches and engaging in a learning process that brings researchers closer to the transformation processes of agricultural and rural systems. This strategic choice is crucial for better understanding and analysing a reality that is becoming increasingly complex and multifaceted.

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Research article

Perceptions towards climate change, water scarcity and adaptation strategies: Case of the Zerafshan River Basin in Uzbekistan

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Abstract. Adapting to climate change under different agro-ecologies of Central Asian countries still remains a matter of debate. The present study aimed to explore the perceptions and key factors influencing adaptation strategies through the stepwise appraisal framework in upstream zones of the Zerafshan River Basin in Uzbekistan. First, a Severity Index (SI) was calculated to evaluate the perceptions of farmers towards climate change and water scarcity. Then, determinants of adaptation practices were investigated using a binary Logistic regression model with comprehensive farm-level survey data collected from 307 farmers. The highest value of the SI coefficient was attained for the perception "Water resource is getting scarce", which implies that most farmers already have worries about the potential risk of water shortages although they have been operating with an adequate water supply. Education of household head, extension, and farmer's perceptions on climate change and water were found to be positive determinants but land size and membership in agro-clusters were found to be negatively influenced factors to climate adaptation strategies. Therefore, we suggest policy implications to consider the land size, cooperation of farmers with clusters, extension, and water management systems to increase the resilience of farmers against climate change at national level.

Keywords: climate change, agriculture, water use, adaptation.
JEL codes: Q12, Q25, Q54.

HIGHLIGHTS

- Climate change impacts are becoming worse with particular effects on yield losses and water distribution among agricultural producers even in upland areas of Central Asian countries.
- Farmers' perception on water shortages is higher than climate change impacts in the study region.
- Education of household head and extension were found to be positive but land size and membership in agro-clusters were found to be negatively influenced factors to climate adaptation strategies.

1. INTRODUCTION

Climate change and its adverse consequences have already become a basic strategic concern of the 21st century while posing challenges not only to agro-ecological but to socioeconomic stability of the world society (Liu *et al*., 2020; Gosling *et al*., 2016). According to Nautiyal *et al*. (2022) climate change is a change in the global atmosphere that is directly or indirectly related to human activity, which leads to the melting of glaciers, an increase in floods and landslides, a decrease in the flow of rivers, and an attack on ecosystems. When we got the recent declaration by scientists about climate change and its expected consequences, it was thought that this phenomenon was far away and would not affect humanity. However, today we fully feel all aspects of these changes in our lives. Agriculture is the most climate-sensitive sector, in which many of the adverse influences of climate extremes are likely to occur and its players suffer (Ali *et al*., 2017). Increases in temperature and erratic patterns of precipitations have been altering the water provision and production possibilities of world agricultural producers with particular effects on crop yield and income. Along with this, the level of climate influence also depends on the adaptive capacity of agricultural producers (Gbetibouo, 2009). World rural societies with poor access and limited adaptive capacities are predicted to suffer more in the near and distant future from the potential and actual impacts of climate-driven changes (Liu *et al*., 2020).

As global climate change continues on the earth, its negative impacts on agriculture and global food security are becoming more acute. Developing countries are more vulnerable to climate change due to the vast number of rural livelihoods, dependency on an agriculture-based economy, and lack of assets (IPCC, 2014; Ali *et al*., 2017). Furthermore, with their rapid progress in industrialization, developing countries were already challenged in terms of food security, water scarcity, land degradation, and increased demand for agricultural production through the exacerbated threats posed by climate change (Mwongera *et al*., 2017). In this regard, adaptation is increasingly urgent for developing nations like Central Asia, where the livelihood of a vast number of the population is still predominantly related to agriculture (IPCC, 2014; Siegfried *et al*., 2012; Gosling *et al*., 2016).

Central Asian countries are more climate-sensitive due to the high level of uncertainty regarding precipitation and increased warming trends over the past decades (Babakholov, 2021; Muratov *et al*., 2023). Global warming and regional precipitation patterns have increased the rate of evaporation, and droughts have become more severe, impacting agricultural production and water use (Huang *et al*., 2016; Liu *et al*., 2020). In addition, several studies predicted that drought frequencies are becoming more severe and this might pose more glacier melting and subsequently high levels of water shortages in Central Asia. Downstream dry regions of Central Asia and little summer precipitation have already faced water shortages in their agricultural production, whereas seasonal runoff maxima have also been observed in some rivers (Sorg *et al*., 2012). In turn, those climate threats have damaged the livelihood and revenues of rural societies of the downstream and arid countries like Uzbekistan, where irrigated agriculture is still predominant in the national economy (Siegfried *et al*., 2012; Karthe *et al*., 2015).

The irrigated agriculture of Uzbekistan mainly relies on water sources, of which more than 80% originates outside the borders. Amu Darya, Syr Darya, and Zerafshan rivers are the major water sources for Uzbekistan, while less than 10% of water originates domestically (World Bank Group, 2021). A large number of studies have concerned climate change, water issues and agricultural production in the case of Central Asia and different geographic zones of Uzbekistan. The irrigation demand in Uzbekistan is predicted to increase by 16% by 2080, this would increase competition for water and impose risks on agricultural production with a potential reduction in crop yields (World Bank, 2018b). Additionally, Uzbekistan suffers from land degradation by secondary soil salinization in response to suboptimal irrigation/drainage management and shallow, saline groundwater levels (Sommer *et al*., 2013). Bobojonov *et al*. (2016) discussed the income and irrigation water use efficiency of agricultural producers under the climate change context in the western part of Uzbekistan. The results show that farmers' income could fall by 25% as temperature increases by 3.2 ^{0}C and a 15% decline in irrigation, while the share of revenue loss of farmers operating in downstream areas is even greater. Considering water use efficiency, 65.2% of applied water was used efficiently, and about 35% of total water was lost during irrigation of the crops. Babakholov *et al*. (2022) analysed the interactive effect of climate change and irrigation on farm output. Their findings indicate that farmers with sufficient water and improved irrigation techniques are more resilient and profitable, although a temperature increase is witnessed. As per the findings of Salokhiddinov *et al*. (2020) low-income levels, high dependency on irrigation, lack of technologies, adaptation measures, low yields, and land degradation were found to be the main vulnerabilities of rural inhabitants.

Meanwhile, studies by Reyer *et al*. (2017) and Sutton *et al*. (2013) indicated the likelihood of a 20-50%

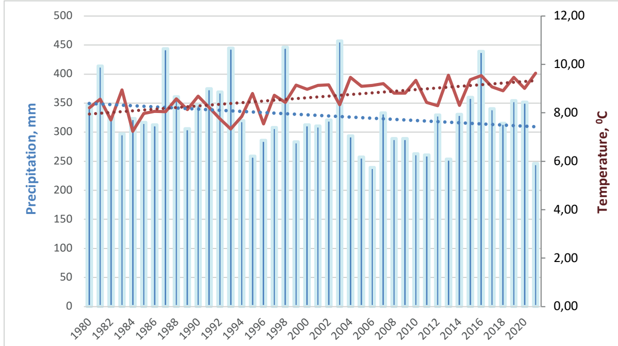
yield loss under the projected average temperature rise up to 2 ^{0}C by 2050 in Uzbekistan if sufficient adaptation measures have not been implemented. Despite the recent and current ongoing adaptation measures taken at regional and national levels in Central Asia, there are still noticeable gaps such as limited knowledge, insufficient technologies, poor infrastructure, climate-oriented techniques which pose barriers on implementing and underlying the accurate solutions for adaptation (Laws, Balance, 2016; Smit, Skinner, 2002). Furthermore, a large number of studies have already looked at reducing the risk and vulnerability level, while analysing the diverse frameworks of climate adaptation at national and international levels (Aleksandrova *et al.*, 2016; Arnell *et al.*, 2016; Garschagen, Romero-Lankao, 2015; Schlaepfer *et al.*, 2017; Liu *et al.*, 2020). Notwithstanding this, very few studies have considered the farmers' perceptions toward climate change and water scarcity jointly with adaptation strategies under the condition of sufficient water provision at basin scale.

The present study proposed to analyse the perceptions and determinants of adaptation practices in the case of farmers who fully use irrigation operating in upstream zones of the Zerafshan River Basin in Uzbekistan. The contribution of this research is threefold for the global context of climate change: first, it clarifies the perceptions of agricultural producers on actual and potential impacts of climate-driven changes and water resources in the case of farmers operating with sufficient water supply. Second, it identifies the main factors that influence farmers' decisions to implement adaptation practices. Finally, the findings enable us to draw the most important policy implications and regulatory frameworks that are needed to support agricultural water use and adaptation strategies in the study region.

2. CLIMATE CHANGE AND WATER ISSUES IN CENTRAL ASIA

Central Asia comprises five former Soviet Union countries, namely Kazakhstan, Turkmenistan, Kyrgyzstan, Tajikistan and Uzbekistan, with about 4 million km^2 of total area and an arid and semi-arid climate with dry ecosystems and rainless environments (Lioubimtseva, Henebry, 2009; Zhang *et al.*, 2019). Only 20% of land in Central Asia is suitable for farming purposes and the rest are temperate deserts (Zhang *et al.*, 2017). Agricultural producers in Central Asia are vulnerable and suffer from climate threats due to several factors including heterogeneous geography, increased temperature and altered rainfalls, aridity and droughts, water scarcity,

Figure 1. Dynamics of annual mean temperature and precipitation in Central Asia, 1980-2020.



Source: Authors' own compilation based on data from the gridded time-series (TS) Version 4.01 (CRU, 2021) and the World Bank (2021b).

increased demand for agricultural production, and low-level investment and adaptive capacities (Seddon *et al.*, 2016; Zhang *et al.*, 2019).

The climate of Central Asia is semi-arid and arid continental, with summers being hot and dry and winters being cold mostly in the northern areas (Djanibekov *et al.*, 2015). The climate of the region has been changing at a greater rate than global averages since the 1950s (Mirzabaev, 2013). There are big uncertainties in the projections of potential impacts of climate change on the region, notably in terms of precipitation and irrigation water runoff dynamics. The annual mean temperature of the region ranges from 1.6 to 15 ^{0}C and receives on average about 250-300 mm precipitation annually (World Bank, 2018a). Temperature increase has been observed since 1970 and both summer and winter temperatures in Central Asia are predicted to rise up to +4.4 ^{0}C and beyond by the 2050s (IPCC, 2014). Numerous past studies on the assessment of climate-driven changes indicated different results based on the data and geographical conditions of the region. Findings explored by Lioubimtseva and Henebry (2009) show that the increase in warming on average is projected to reach +3 ^{0}C and will even exceed +5 ^{0}C in some arid and temperate regions of Central Asia by 2071-2100.

The dynamics of changes in annual mean temperature and precipitation amount in Central Asia for the period of 1980-2020 are illustrated in Figure 1. As we are able to see and judge from the above figure, there was a feasible increase in mean annual temperature in the region from the 1990s, while it was about +8 ^{0}C at the beginning of 1980s and reached almost +10 ^{0}C by 2020. There has been an observed decline in annual precipitation in the region over the past decades. Annual precipitation was about 350 mm in the last decades of the past century but it fell to 300 mm in 2020.

Water resources and water management are of central importance at the present time in Central Asia, where a large part of the population still relies on heavily irrigated agriculture and animal husbandry (Xenarios *et al*., 2019). Climate change impacts are believed to be strong and adverse not only to agricultural production and rural livelihoods but also to hydrological cycles and water availability in the downstream regions of Central Asia (Hill *et al*., 2017). Water levels of the Amu Darya and Syr Darya, which are the main sources of irrigated agriculture in the region have decreased by 20%-30% due to climate change impacts observed in past decades (Lioubimtseva, Henebry, 2009; Ososkova *et al*., 2000). The water sources that Central Asian societies use for domestic and agricultural purposes mainly depend on glacier meltwater (Pritchard, 2019). The tendency of glacier melt from Tien Shan mountains has intensified under the climate change context since 1970, while the precipitation and water amount from other sources have reduced (Narama *et al*., 2010). The glacier melting without snow cover in mountain regions of Central Asia has been accelerated via the increased annual surface mean temperature and the reserves for river basins have lost up to 30%-35% over the past five decades (Karimov *et al*., 2019; Harris *et al*., 2014; Zhang *et al*., 2019). Along with this, as per findings of studies by Hagg *et al*. (2013) and Punkari *et al*. (2014), CMIP3 model results projected a 22%-35% additional decline in water supply from Amu Darya and Syr Darya into downstream regions under the temperature rise dynamics of between 2.2 °C and 3.1 °C by the 2050s. More importantly, the increase in air temperature was slight in summers but a remarkable rise in warming was observed for the month of September over the past decades in Central Asia. This implies a prolonged glacier melting period with the potential risk of high-level water shortages together with ecological and political instability in the region (Bolch, Marchenko, 2006). Due to a lack of cross-border water management agreement among Central Asian countries, water use for agricultural irrigation in downstream countries like Uzbekistan largely remains dependent on the polices of upstream republics, whereas shortages are worsening with the increased demand for water (Aleksandrova *et al*., 2016).

By considering the above-highlighted issues related to climate change and water scarcity, adaptation measures such as policy responses at state level are vital for the region. A large number of studies show that climate impacts can be coped with through the implementation of various adaptation measures, although climate extremes are uncontrolled and detrimental to agriculture (Mendelsohn, 2008; Smit, Skinner, 2002). Regarding climate change adaptation, the governments of Central Asian countries have already shown a high sense of urgency in coping with climate change and have been actively participating in international projects co-funded by donors (Xenarios *et al*., 2019). On the political and economic side, a number of reforms and development projects have recently been included in national laws, strategies and management programmes of Central Asian countries, which mainly focus on climate adaptation and resilience activities. Despite several national climate action plans integrated into environmental policies, there are currently no national climate action plans in Uzbekistan. In the context of climate adaptation, improving irrigation and water use efficiency, developing a water monitoring system, and forest management policies are the strategies that are currently concerned at the state level in Uzbekistan. Notwithstanding this, a poor level of infrastructure in rural areas, worsened arid conditions, water scarcity, lack of input access, as well as the heterogeneous knowledge gap on environmental and socio-economic consequences of climate extremes are still determining the vulnerability of rural actors in the country (Xenarios *et al*., 2019). This in turn intensifies the necessity for research concerned with adaptation measures against future climate threats and boosting the resilience of agricultural producers in the country.

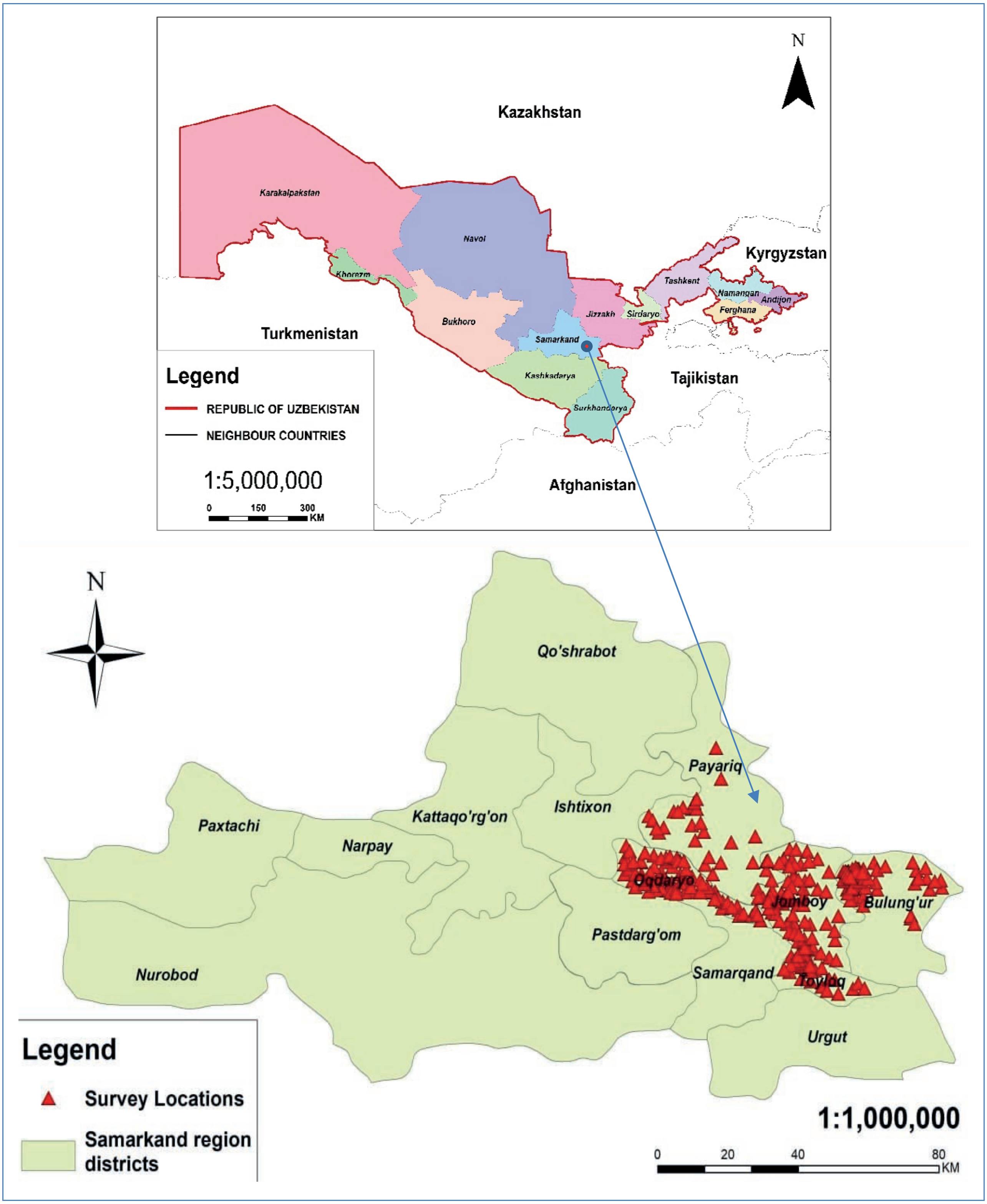
3. MATERIALS AND METHODS

3.1. Study site

An empirical analysis of the study was conducted in the case of farms operating with sufficient water supply in upland zones of the Zerafshan River Basin. Based on capacity and territory, the Zerafshan River Basin is one of the strategic places for Uzbekistan, which comprises two big administrative provinces, namely Samarkand and Navoi, with well-developed irrigated agriculture and industry (Khujanazarov *et al*., 2012; Babakholov *et al*., 2022).

Samarkand region lies in the main upland part of the Zerafshan River Basin. Located about 700 metres above sea level, the Samarkand region has a dry continental climate with hot summers and partly cold winters (Sommer *et al*., 2013; UzHydro-Met, 2018). The area of the region consists of 1677.3 thousand hectares, of which about 430 thousand hectares (irrigated and rain-fed) are agricultural cropland (SCRUz, 2022). Geographically, the region is surrounded by mountains and has suitable weather conditions for agricultural purposes and is the second main supplier of

Figure 2. Map of the study region and the location of surveyed farmers.

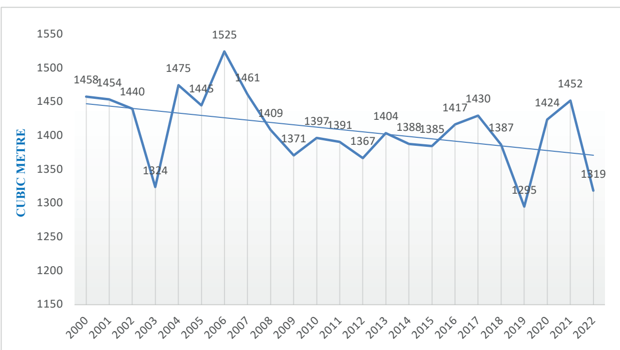


Source: Authors' completion using ArcGIS software 10.3.

gross agricultural output of the country (Babakholov *et al.*, 2018). A total of 14 districts are included in the administration of the Samarkand region, of which 4 districts are located in the upper tail of the basin and produce mostly cash crops, 5 districts are in the mid-tail and grow mostly cotton and wheat, 3 districts are in the lower tail and wheat, cotton as well as grapes are common crops for those zones. Rain-fed agriculture is common in only two districts, which are in the south and north-western parts of the region, and specialized almost entirely in livestock breeding. The map of the study region and the location of surveyed farmers is shown in Figure 2.

The Zerafshan River originates from the neighbouring republic of Tajikistan and flows through Uzbekistan with a total length of 780 km (Khujanazarov *et al.*, 2012). More than ¼ of the total population of Uzbekistan lives in the territory of the basin and their agricultural livelihood is entirely dependent on water sources from the Zerafshan River (Kulmatov *et al.*, 2013). Due to irrational water use, poor drainage and water management systems as well as exacerbated climate threats, the irrigation capacity of agricultural producers is worsening even in upstream areas of Zerafshan River Basin. A gradual increase in climatic water deficit per square metre has also been observed in the territory of the Zerafshan River Basin within the past decades (Figure 3). Based on statistics of the World Bank (2022), about 485 m^3 climatic water deficit per square metre was observed in the basin in 2022 compared to 2000. This intensifies the necessity and urgency of adaptation measures towards increasing the farmers' climate resilience, water management, and sustainable agricultural production in the region.

Figure 3. Dynamics of climatic water deficit per square metre in Zerafshan River Basin, 2000-2022.



Source: Author's completion based on data obtained from World Bank, 2022.

3.2. Data and variable description

Farm-level cross-sectional data was utilized for an empirical analysis of the study. The questionnaire was first designed following the objectives of the study and international standards. A total of 307 large-scale farmers who use irrigation were randomly selected and interviewed face-to-face through the structured questionnaire based on their outcomes in 2021. The survey was conducted in five upstream districts of the Samarkand region during the months of July and August 2022. Surveyed study districts are considered as the main producers of cash crops in the agricultural structure of the Samarkand region with sufficient water provision and fertile soil. The number of samples from each district represents roughly 10 percent of total farmers who mostly grow cash crops such as wheat, potatoes and vegetables. The summary statistics of the farm level dataset are illustrated in Table 1. The dataset includes the set of farm demographic, socio-economic, farm production, climate and water-related variables.

The descriptive statistics table gives detailed information about the response and explanatory variables obtained through the interviews. Starting from the dependent variable, a set of different adaptation strategies (water management, nutrition management, adjusting sowing time, drought and disease tolerant varieties, switching to new crop, crop rotation, and tree planting) encoded as a dummy, while 1 if the farmers have applied any of adaptation measures against climate change or 0 otherwise. A total of 14 independent variables were considered as main determinants that could encourage farmers to implement any of the adaptation activities, while those variables were also used globally in previous studies by Amfo and Ali, (2020), Makate *et al.* (2019), Ali *et al.* (2017), Abid *et al.* (2015), Bryan *et al.* (2013) and Deressa *et al.* (2009). The age of surveyed farmers is 45 years old on average and they have 12 years of farming experience. The land size of the farmers became bigger after the land optimization reforms were made in the country in 2019. Surveyed farmers own 39.1 hectares of land in 5.5 plots on average in study districts. It should be noted that farmers with financial and institutional assets are more eager and able to adopt and introduce innovations and new technologies to their farming activities.

Among the surveyed farmers 25.4% have higher education and 74.5% are operating at the secondary or primary school level. In addition, 17.5% of farmers have additional income from non-agricultural sources, while more than 80% of farmers' livelihood is directly related to agriculture. Those factors are important to adopting innovations and new technologies and have also been

Table 1. Summary statistics of dependent and independent variables.

Variables	Description	Mean	Std.Dev
Dependent variable			
Adaptation strategies	1 if the farmer has applied any of climate adaptation practices, 0 otherwise	0.60	0.4901
Independent variables			
Age	Age of the farmer in years	45	11.26
Education	Dummy, 1 if the farmer has higher education, 0 secondary or other	1.4	0.4902
Experience	Farming experience of farmer in years	12	6.3670
Off-farm income	Dummy, 1 if the farmer has another income source, 0 otherwise	0.17	0.3813
Livestock	Number of livestock owned by the farmer	9	7.3575
Land size	Farmland owned, ha	39.1	28.289
Credit	Dummy, 1 if the farmer has access to credit, 0 otherwise	0.12	0.3261
Extension	Dummy, 1 if the farmer has access to extension, 0 otherwise	0.34	0.4272
Market access	Dummy, 1 if the farmer has market access, 0 otherwise	0.72	0.4465
Weather information	Dummy, 1 if the farmer follows weather information, 0 otherwise	0.73	0.7328
Membership	Dummy, 1 if the farmer is a member of the cluster, 0 otherwise	0.38	0.4864
Climate change	Dummy, 1 if the farmer has experienced climate change, 0 otherwise	0.63	0.4812
Temperature increase	Dummy, 1 if the farmer reported temperature increase, 0 otherwise	0.44	0.4979
Water scarcity	Dummy, 1 if the farmer reported water shortages, 0 otherwise	0.33	0.4741
Farm outcomes			
Wheat yield	Harvested wheat yield in kg/ha	4181	721.63
Potato yield	Harvested potato yield in kg/ha	26000	6599.8
Tomato yield	Harvested tomato yield in kg/ha	30716	11204
Legumes yield	Harvested legume yield in kg/ha	2220	1624.8

Source: Authors' calculation based on survey data.

applied in a wide range of previous studies (Amfo, Ali, 2020; Ali *et al*., 2017; Alemayehu, Bewket, 2017). Sampled farmers own about 9 heads of livestock units on average. The rest of the variables contain more about environmental and institutional factors.

3.3. Empirical framework (Severity Index and Model specification)

There are different and broadly used methods in the world literature for assessing perception accuracy and the factors that have an influence on choice selection. In particular, farmers implement different adaptation practices based on climate challenges and their own resources and assets. In this study, we applied a stepwise empirical framework to meet the research objectives. Farmers' subjective perceptions of climate change and water issues were calculated using the mathematical technique, which is the Severity Index (SI). The index and its analytical criteria were introduced by Majid *et al*. (1997) and calculated using the following formula:

$$SI = \sum_{i=0}^{4} p_i \, q_i / n \sum_{i=0}^{4} qi \qquad (1)$$

where SI – is the coefficient of the calculated Severity Index (SI);
(p_0, p_1, p_2, p_3 and p_ (4)) are the response frequencies of the farmers (perceptions) with respect to the 5-point Likert Scale (q_0=0, q_1=1, q_2=2, q_3=3, q_4=4);
n – is the total number of observations against a 5-point Likert Scale.

Following Majid *et al*. (1997) and Ferdushi *et al*. (2019), Severity Indexes' analytical criteria were specified as follows:
q_0 = Strongly disagree, 0.00 ≤ SI ≤ 12.5;
q_1 = Disagree, 12.6 ≤ SI ≤ 37.5;
q_2 = Moderate agree, 37.6 ≤ SI ≤ 62.5;
q_3 = Agree, 62.6 ≤ SI ≤ 87.5;
q_4 = Strongly agree, 87.6 ≤ SI ≤ 100.

According to the above criteria, farmers' perception accuracy on climate change and water shortages has been analysed. Accordingly, climate change hasn't yet had a serious effect and there is no problem with water provision if the calculated value of the SI coefficient lies between 0.00 – 12.5 and 12.6 – 37.5. Meanwhile, farmers moderately agree with climate change influences and water shortages through the coefficients of 37.6 and

62.5. Moreover, climate change impacts and water problems were observed among agricultural producers if the attained value of SI coefficients were above 62.6 and 100 respectively.

The effect of predictor variables on adaptation was investigated in the second stage of analysis. After the perceptions on climate change and water scarcity, farmers were asked whether or not they implemented any adaptation strategies in their farming activities, with possible binary answers of yes or no. When the outcome variable is in binary classification, Logit and Probit models are most common in statistical analysis. These models are capable of predicting the probability of something occurring in the form of a binary outcome and are also better for controlling deterministic and heteroskedastic problems than linear probability models with maximum likelihood technique (Dougherty, 2011). Although both models are similar, they use different functional approaches, which are logistic and cumulative normal distribution to link the relationship between explanatory and outcome variables. Since the Logit model is more robust to outliers with its logistic function, we considered and applied the Logit model to our empirical analysis.

In general, Logit models have two types of forms, which are multinomial and binary logits. In our study, the binary form of the logistic regression model was used and specified as follows:

$$Logit\ (P)=\log\left(\frac{P}{1-P}\right) = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad (2)$$

where, the binary response has two possible outcomes Y, which 1 = farmers adopted any of practices, and 0 = otherwise;
α_0 – is the intercept;
X_n – is the set of explanatory variables, which are the factors that affect adaptation;
β_n – is the model parameters estimated through the maximum likelihood method;
P/(1-p) – denotes the odds ratio while implying the ratio of the probability of the factors that farmers have either successfully adopted or not adopted any of the adaptation strategies against climate challenges. From the statistical point of view, the influence of the predictor variables on adaptation is positive and significant if the value of the odds ratio is greater than one. In contrast, explanatory variables do not take a positive relation if the value of the odds ratio is less than one (Ferdushi *et al*., 2019; Alemayehu, Bewket, 2017).

4. RESULTS

4.1. Farmers' Perceptions (Severity Index)

Perception accuracy is one of the important indicators before drawing policy recommendations and related practical implementations. A set of climate change and water-related items were elaborated and asked to evaluate the perceptions of the farmers with respect to climate and water issues. The purpose of calculating the index is to better understand the perceptions of farmers on actual and potential impacts of climate change and water scarcities before analysing the determinants of adaptation practices they have currently been adopting on their farming performances. The coefficient of the Severity Index (SI) was calculated using the formula (1) explained in previous studies by Majid *et al*. (1997) and Ferdushi *et al*. (2019). The calculation procedure is implemented as in Table 2.

Where the sum of response frequencies of the surveyed farmers on each item with respect to climate change and water issues is multiplied with the order of Likert Scale coefficients and divided by the total number of observations respectively. Then derived coefficients were divided against 5 point Likert Scale order and Severity Index (SI) coefficients obtained for each perception related with climate change and water issues in the region. The results of the Severity Index (SI) are shown in Table 3.

Attained Severity Index (SI) values range from 50.1% to 81.3%. The highest value of SI was attained for the

Table 2. Calculation procedure of the Severity Index (SI).

a)	*SI* =	(0×0+13×1+7×2+176×3+111×4)/(0+13+7+176+111)=3.25;	SI = 3.25/4×100=81.35;
b)	*SI* =	(7×0+40×1+20×2+163×3+77×4)/(7+40+20+163+77)=2.86;	SI = 2.86/4×100=71.25;
c)	*SI* =	(12×0+79×1+34×2+130×3+52×4)/(12+79+34+130+52)=2.42;	SI = 2.42/4×100=60.5;
d)	*SI* =	(2×0+16×1+24×2+199×3+66×4)/(2+16+24+199+66)=3.01;	SI = 3.01/4×100=75.25;
e)	*SI* =	(30×0+86×1+32×2+154×3+1×4)/(30+86+32+154+1)=2.01;	SI = 2.01/4×100=50.1;
f)	*SI* =	(0×0+50×1+28×2+165×3+64×4)/(0+50+28+165+64)=2.81;	SI = 2.81/4×100=70.25;
j)	*SI* =	(0×0+48×1+16×2+134×3+109×4)/(0+48+16+134+109)=2.99;	SI = 2.99/4×100=74.75

Source: Authors' calculation based on survey data and the Formula (1).

Table 3. Farmers' perceptions toward climate change and water issues.

Description of the selected frames		SD (0)	DA (1)	MA (2)	A (3)	SA (4)	Severity Index (%)
Water resources are becoming scarce	NRS	0	13	7	176	111	*81.3*
	PRS	0	4.2	2.3	57.3	36.2	
Climate change has already affected agriculture and water resources of Uzbekistan	NRS	7	40	20	163	77	*71.2*
	PRS	2.3	13	6.5	59.1	25.1	
Climate change is a serious problem	NRS	12	79	34	130	52	*60.5*
	PRS	3.9	25.7	11.1	42.3	16.9	
Climate change effects my farm production	NRS	2	16	24	199	66	*75.2*
	PRS	0.7	5.2	7.8	32.2	54.1	
Precipitation is decreasing	NRS	30	86	32	154	1	*50.1*
	PRS	9.8	28	10.4	50.2	1	
Temperature is increasing	NRS	0	50	28	165	64	*70.2*
	PRS	0	16.3	9.1	53.7	20.8	
Adaptation is necessary for all of us	NRS	0	48	16	134	109	*74.7*
	PRS	0	15.6	5.2	43.6	35.5	

Note: NRS – number of respondents; PRS – percentage of respondents; SD – strongly disagree; DA – disagree; MA – moderate agree; A – agree and SA – strongly agree;
N – 307 farmers.
Source: Authors' calculation based on survey data.

perception "Water resources are becoming scarce". The next highest number of followers was attained for the perceptions "Climate change effects my farm production" and "Adaptation is necessary for all of us" with values of 75.2% and 74.7% respectively. Likewise, the perceptions "Climate change has already affected agriculture and water resources of Uzbekistan" and "Temperature is increasing" corresponding to 71.2% and 70.2% were calculated. The lowest values of SI were attained for the perceptions "Climate change is a serious problem" and "Precipitation is decreasing" corresponding to 60.5% and 50.1% respectively. The above attained Severity Index (SI) values indicate that farmers are sufficiently aware and agree with the overall and particular impacts of climate change events on their farming activities. Importantly, most farmers perceived the water shortages as a more problematic issue than other threats although they have been endowed with sufficient water in upstream zones of the Zerafshan River Basin. Furthermore, by taking into account climate change and the potential risk of water shortages, farmers considered the necessity for climate change adaptation practices for sustainable agricultural production and livelihood.

4.2. Determinants of farmers' adaptation practices

A set of explanatory variables were regressed upon farm adaptation practices. Selected factors were incorporated into the regression analysis based on their correlation statuses and economic theory. Detailed results of the Logistic regression model are given in Table 4. In this study, the dependent variable is the presence of farmers' adaptation strategies against climate challenges.

According to model results, farm socioeconomic variables such as age group of the farmer were found to have a negative but not significant relation with climate adaptation practices. It implies that younger farmers are more eager and faster than elders in terms of technological changes and adopting innovations for their better performance. Meanwhile, age and experience are interrelated factors that may have cumulative impacts on adaptation. In our results, farming experience was found to be a positively related determinant. The education level of the farmers also has positive and significant signs for adaptation strategies, while farmers with better education are more capable of adopting adaptation practices. In general, farmers with more assets are more successful in their operations, whereas additional income sources better encourage them to find solutions against challenges. In another case, farmers with a high level off-farm income source may quit agricultural activities. In our study findings present the negative relation between off-farm income and the positive relation of livestock ownership with adaptation practices. Agricultural land is a major livelihood asset and wealth indicator for the farmers. In this study, the sign of land size was found to have a negative correlation with adaptation practices.

Table 4. Determinants of farmers' climate adaptation practices (results of Logistic model).

Variables	Measurement unit	Odds Ratio
Age	years	- 0.97 (0.014)
Education	dummy	1.48 (0.538)*
Experience	years	1.04 (0.027)*
Off-farm income	dummy	- 0.47 (0.199)*
Livestock	number of heads	1.01 (0.018)
Land size	hectare	- 0.98 (0.004)***
Credit	dummy	1.81 (0.802)
Extension	dummy	2.02(0.573)**
Market access	dummy	1.32(0.377)
Weather information	dummy	1.05 (0.301)
Membership	dummy	- 0.48 (0.132)**
Climate change	dummy	1.56 (0.469)*
Temperature increase	dummy	1.06 (0.272)
Water scarcity	dummy	1.35 (0.364)

Note: *, **, and *** denote the significance of the coefficients at 0.1, 0.05, and 0.01 level.
Source: Authors' calculation based on survey data.

Institutional and market accessibility factors are important for coping with and mitigating climate threats. The investigated values of farmers' access to credit, market, and whether information is positively correlated with adaptation strategies. Agricultural producers with good access capacity are more capable of managing climate-related risks. In particular, the coefficient of extension was found to be highly significant and positive to climate adaptation strategies. Surprisingly, a negative correlation was found between membership of agricultural clusters and adaptation strategies. This may be because of the new system and inclusive transformation in the agricultural sector of the country. Moreover, farmers' perceptions of overall climate change, temperature increase and water scarcity were found to have a positive and significant relation with adaptation, while as climate extremes increase farmers intensify their efforts in order to adopt best practices.

5. DISCUSSION

Developing countries are more vulnerable and less resilient to the adverse consequences of climate change due to poor market and institutional accessibility and limited adaptive capacity. As per results of previous studies by Babakholov *et al.* (2022), Radchenko *et al.* (2017) and Bobojonov *et al.* (2016) climate change has already become acute to the agriculture of Uzbekistan, with particular threats to agricultural production, water resources, food security and rural income. Continued droughts and water shortages accelerated climate challenges even in irrigated areas of the country and this intensified the urgency and necessity of adaptation at local and national levels. In this regard, the present study attempted to investigate the farmers' perceptions on climate change and water shortages together with the main determinants of adaptation strategies in the case of farmers operating with sufficient water supply in the Zerafshan River Basin in Uzbekistan. The empirical analysis was implemented using farm-level survey data and a climate-oriented framework by corresponding previous literature (Ferdushi *et al.*, 2019; Delaporte *et al.*, 2018; Alemayehu *et al.*, 2017). At the primary stage of the analysis, the Severity Index (SI) was calculated using the data which included a set of climate and water-related items asked to farmers in order to measure their perception accuracy on observed climate events and water issues. The initial findings of this study on farmers' perception show that farmers in the study region are sufficiently aware of climate change consequences and confirmed the adverse impacts of climate threats on their production and water usage as well. Interestingly, farmers' perception on water shortages was found to be higher than the perception on climate extremes, while farmers have more worries about the potential risk of water shortages in the near future although they have been operating with sufficient water provision. As already mentioned by farmers involved in agricultural production the evidence of temperature rises and rainfall drop has occurred in their areas. Overall, farmers take both climate change and water issues as problematic concerns and give most consideration to the necessity for adaptation practices because these problems are directly and indirectly affecting their income loss and livelihoods respectively.

Meanwhile, this study explored the association between the farm's socio-economic, and institutional characteristics and climate adaptation strategies in the next step of analysis. Although the majority of findings of this study corroborate the results of other studies conducted globally, some results were found to be contrary and specifically study region-related. Age and experience are interrelated factors that may have interactive positive impacts on outcomes (Mulwa *et al.*, 2017). In this study experienced farmers were found to have more positive attitudes to take adaptation measures. Notwithstanding, the age of the farmer was found to be a negatively associated factor to adaptation and thus corresponds with the findings of recent studies (Yeo *et al.*, 2020; Ali *et al.*, 2017; Tesfaye *et al.*, 2016). While younger farmers are more likely to be innovative and active, the older generation is found to be negatively affecting the adaptation rate. This is because old farmers prefer to stick with their existing farming practices which are already not sufficient to overcome challenges. As confirmed in other studies across the continent Rahut *et al*. (2017), Alemayehu *et al*. (2017), Abid *et al*. (2015) and Bryan *et al*. (2013), the sign of farmers' education was found to be positive and significant for adaptation strategies, implying that educated farmers with good theoretical background could be sufficiently aware of climate change consequences and be more active and precise in adopting the best strategies against climate threats. Agricultural producers often rely on non-agricultural profits or assets to improve their outcomes or to combat challenges. In our study, there is a negative correlation between off-farm income and the positive correlation of livestock with adaptation. Theoretically, wealthy farmers with financial ability are more like to invest in innovations and technologies. At the same time having off-farm income may have either a positive or negative influence on farmers' decisions, while with good non-agricultural income, farmers may quit farming activities or be less motivated, especially under the condition of climate extremes and water shortages.

Farm institutional and market accessibility are also paramount for better outcomes. Our findings indicated the positive association of credit, market, and weather information access in adaptation strategies although the coefficients were not statistically significant. Farmers with good market and credit access can improve their adaptive capacity, which enables them to implement climate adaptation measures on time in the study region. The results are consistent with previous research (Yeo *et al*., 2020; Adimassu *et al*., 2016; Abid *et al*., 2015; Yegbemey *et al*., 2013). Along with this, the positive and significant relation of extension access with farm adaptation practices was explored. Extension access could enhance farmers' ability, whereas farmers with good extension are more likely to have accurate information on climate-driven threats and be precise in coping with climate risk management (Ali *et al*., 2017; Deressa *et al*., 2009). Agricultural land is the main asset of the farmers, which enables them to survive and better develop their livelihoods. Owning a large amount of arable land implies more yield and more income respectively. On the other hand, it may pose some challenges in terms of management issues, as sampled farmers reported during the interviews. Even though the majority of previous studies Ferdushi *et al*. (2019), Ali *et al*. (2017), and Rahut *et al*. (2017) found a positive association between land size and adaptation, a negative-significant association of land size was found in the study area. In fact, private farmers own not less than 20 hectares based on their cropping pattern in Uzbekistan, particularly after the land optimization reform in 2019. This implies that the current amount of land given to farmers may pose managerial challenges with respect to climate adaptation practices in the study area.

Membership of the farming highlights the affiliation of farmers in any type of agriculture related communities, such as water users' association (WUA), farmers group (FG), and cooperatives, which generally also have a positive relation with agricultural output and adaptation strategies (Yeo *et al*., 2020; Piya *et al*., 2013). In this study membership denotes the farmers' affiliation in agro-clusters, which have recently been established in the country. Unlike the findings of other studies, the negative association of membership in adaptation practices is found in our study. As farmers reported, this may be due to the lack of mutual understanding and poor level of cooperation between the clusters and agricultural producers. Moreover, farmer's perceptions on climate change, temperature increase and water scarcity were found to have positively associated factors in adaptation practices. Similar findings were highlighted by the results of previous studies by Yeo *et al*. (2020) and Alemayehu *et al*. (2017). Overall, when agricultural producers perceive changes in climate patterns and face water shortages their willingness to adopt the best adaptation strategies would increase.

6. CONCLUSION

Climate change and its adverse consequences have already intensified the urgency of adaptation even in the irrigated zones of Central Asia. Climate change and water issues were reviewed and perceptions towards climate change and water shortages, together with determinants of adaptation practices, were investigated in the case of farmers operating in the upstream zones of Zerafshan River Basin in Uzbekistan. Farm-level survey data was collected through 307 interviews from 5 districts of the Samarkand region, which is located in the main body of the basin. In the first step, farmers' perceptions on climate change and water were measured using the Severity Index (SI) framework. The results of the index presented some interesting facts in the context of the study area, in which farmers perceive water issues as more problematic to their livelihood than climate extremes, although they have been endowed with sufficient water amount at present.

The effect of dozens of factors on the adaptive capacity of farmers and the influence of those factors may differ based on the context of the study region. Logistic regression was applied in order to investigate the main determinants of adaptation strategies. In line with other studies conducted globally, findings revealed some novel facts for the study region. Accordingly, education of household heads, extension, and farmers' perceptions on climate change and water were found to be positive determinants, but land size and membership in agro-clusters were found to negatively influence climate adaptation strategies. Based on the findings of this study, policy implications should concern the following aspects with respect to future climate extremes and water issues: i) land policy and cooperation between clusters and farmers should be strengthened; ii) awareness of agricultural producers on climate change and water issues needs to be increased; and iv) state policy should further concern extension and water management systems to increase the resilience of farmers against future climate challenges.

Despite the interesting findings that have been explored in the context of Central Asia, climate change adaptation processes still remain a matter of debate. Our study also has potential limitations due to limited data access and coverage issues. The estimations in the model are based on survey data and sampled farmers represent just one region. Therefore, we suggest further studies to make estimations with a broader dataset such as panel data, which enables better policies to be drawn in the context of climate adaptation.

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AUTHOR CONTRIBUTIONS

S.B.: Conceptualization, Methodology, Software, Data curation, Writing- Original draft version. S.H.: Supervision, Validation, Writing- Reviewing and Editing.

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Research article

A census-based sustainability indicator of agricultural holdings: the case of Italy

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Abstract. Sustainable agriculture is a critical issue globally. Evaluating it is often hindered by the complex, multidimensional nature of agricultural sustainability and the lack of statistical data at individual farm level. Ensuring the sustainability of Italian agriculture is vital for safeguarding both the survival of smaller agricultural holdings and the competitiveness of larger farms. In this context, the study proposes a methodology to estimate the degree of sustainability of Italian agricultural holdings. The methodology employs five indicators or *dimensions* – each representing a strategic farm feature related to sustainability – all derived from the Seventh Agricultural Census 2020. The number of sustainability dimensions each farm possesses forms the basis of the methodology. The findings indicate that, in 2020, 45% of holdings had at least one sustainability dimension; this share increases to 72% if the farm manager is under 40 years old. However, a significant sustainability gap remains between the north and south of the country.

Keywords: census, innovation, modernization, organic farming, sustainability.
JEL codes: Q10, Q12, Q15.

HIGHLIGHTS

- Survival and the development of agricultural holdings depend on their degree of sustainability.
- Agriculture's sustainability is a complex and multidimensional concept, and its measurement is not an easy task.
- Sustainability evaluation requires the availability of several statistical indicators at the single farm level.
- The results of the 2020 General Census of agriculture census were used to calculate a farm sustainability indicator.

1. WHAT IS SUSTAINABLE AGRICULTURE?

The goal of sustainable agriculture is to meet society's food and textile needs in the present without compromising the ability of future generations to meet their own needs. Practitioners of sustainable agriculture seek to inte-

Table 1. The 3 dimensions of agriculture sustainability according to FAO.

Economic	Environmental	Social
1. Farm output value per hectare	4. Prevalence of soil degradation	9. Wage rate in agriculture
2. Net farm income	5. Variation in water availability	10. Food insecurity experience scale
3. Risk mitigation mechanisms	6. Management of fertilizers	11. Secure tenure rights to land
	7. Management of pesticides	
	8. Use of agro-biodiversity supportive practices	

Source: Elaboration based on FAO (2023).

grate three main objectives into their work: a healthy environment, economic profitability, and social and economic equity. When measuring agricultural sustainability, two interconnected challenges arise: i) defining the indicators to be considered at farm level, and ii) identifying the data sources to be used in their calculation. Undoubtedly, the selection of indicators lies at the heart of the methodology, irrespective of whether it is feasible to calculate them or not.

In 2015, the United Nations adopted the *Sustainable Development Goals* (SDGs) as a call to action to end poverty, protect the planet, and ensure that all people enjoy peace and prosperity by 2030. The key issue raised by the *SDGs* system is that sustainable development is a complex and multidimensional concept, based on three pillars: economic development, social development, and environmental protection. In particular, the FAO promotes the calculation of the SDG 2.4.1: Proportion of agricultural area under productive and sustainable agriculture. The SDG 2.4.1 includes the 11 sub-indicators in Table 1 (FAO, 2023).

Although the FAO requires the calculation of these indicators annually, this calculation is difficult even in most EU States because it implies the availability of numerous statistical variables at the single farm level with a yearly update. Actually, only during the agricultural censuses – therefore every ten years – it is possible to collect data concerning some of the indicators in Table 1 for each farm. The only statistical source capable of annually collecting a wide range of indicators on economic results and agricultural sustainability is the FADN survey, which however, does not include the smallest farms in the field of observation[1].

The new Common Agricultural Policy (CAP) 2023-2027 supports the transition towards more sustainable systems of food and farming, in line with the European Green Deal. The main goal of the CAP is supporting agricultural holdings in the EU. An agricultural holding – or farm – is "*a single unit, both technically and economically, operating under a single management and which undertakes economic activities in agriculture within the economic territory of the EU, either as its primary or secondary activity. The holding may also provide other supplementary (non-agricultural) products and services*". This definition (FAO, 2017, 43) is the same as that applied in the last agriculture census, as stated in Article 2(a) of Regulation (EU) 2018/1091 on integrated farm statistics. The 2020 agricultural census was an important step towards increased knowledge about the structure of agricultural holdings in the EU.

In this context, the study deals with the following question: is the information collected with the last general agricultural census able to evaluate the degree of sustainability of Italian agricultural holdings, at least with a certain degree of approximation? Following a brief literature review (Section 2), the paper examines the power of data collected from the latest agricultural census (Section 3.1.) to describe five fundamental sustainability dimensions of Italian farms (Section 3.2.). Section 4 presents the proposed classification methodology, the key results, and a comparison between 2020 and 2010. Section 5 offers a concise discussion of the findings, while Section 6 provides concluding perspectives.

2. SHORT LITERATURE REVIEW

Several works commented on the need to focus on specific sustainability dimensions. Hansen (1996) underlined that agriculture sustainability can be interpreted according to two broad concepts: as an approach to agriculture developed in response to concerns about impacts of agriculture, or as a property of agriculture developed in response to concerns about threats to agriculture. However, even though interpreting sustainability as "an approach" should be useful for motivating change and improvements, conceptual and practical problems have

[1] The Italian FADN (Farm Accountancy Data Network) does not observe farms with a yearly standard output lower than 8,000 euro. Based on the census 2020 results, they were 611,067 (53.9% of the total).

limited its usefulness. In order for sustainability to be a useful criterion for guiding change in agriculture, its characterization should be quantitative and system-oriented. Blasi *et al.* (2016) showed that crops with negative environmental performances sustain farm income, while crops with a positive ecological balance bring a very limited contribution to economic profitability. Such results underline the *trade-off* between the economic and environmental consequences of farming activities in order to drive farmers towards more sustainable behaviour. More generally, evaluating farms' competitiveness may be a very different thing from evaluating their sustainability. Gilioli *et al.* (2020) analyse agriculture's sustainability from the point of view of biodiversity. Valorisation of agroecosystem biodiversity (spontaneous and cultivated flora, underground microbiota, habitat and landscape) support the transition of agricultural systems towards wider sustainability. Muie (2022) underlined that the use of novel approaches and practices such as smart agriculture, organic farming, biodynamic agriculture, sustainable intensification and regenerative agriculture has been proven to safeguard agricultural sustainability and should be implemented for ecological sustainability and food security. These goals lead to the keyword *innovation*, which is one of the indicators introduced in Section 3.2.

The complexity of the sustainability concept implies the need to define which indicators should be calculated at the single farm level to assess the degree of sustainability. Velten *et al.* (2015) conducted a structured literature review in combination with a cluster analysis in order to identify the overall ideas and aspects associated with sustainable agriculture. Within the three broad dimensions (economic, social and environmental) the authors identified 16 main themes, divided into goal themes, strategy themes and action themes. Latruffe *et al.* (2016) commented that in the latest literature, the environmental pillar has undergone an "indicator explosion", due to the multitude of themes covered and the attention given by society to this dimension of sustainability. By contrast, economic indicators target a relatively small number of themes. Social indicators typically cover two main sustainability issues: the farming community and society as a whole, their measurement being challenging as they are often qualitative and subjective. Bathaei and Štreimikiene (2023) identified a total of 101 indicators found in previous studies for the three broad dimensions. In order to measure sustainable agriculture, the paper proposes a reclassification of the wide set of indicators according to eight main types: technology, market access, prices (economic dimension), farm structure, pollution, soil (environmental), quality of products, and farmers' rights (social).

Beyond indicator selection, there is the need to identify reliable data sources useful for their calculation. Many works are based on the database derived from the FADN survey – which contains many more indicators than the census – from both the Italian and European perspectives. However, the FADN survey does not observe the smallest agricultural units, i.e., the farms, which are probably those most dramatically characterized by sustainability problems, such as staying alive first. Zahm *et al.* (2008) applied the IDEA method, based on 41 sustainability indicators covering the three dimensions of sustainability, using French case studies. They used the FADN network as a possibility to assess the sustainability level of different farming systems. The conclusion was that there is not just one farm sustainability model, and therefore the indicators must be adapted to local farming before using the methodology. Longhitano *et al.* (2012) built up a set of 26 sustainability indicators derived from the FADN database, some of which are monetary-valued, while others are social and environmental. Based on a multi-criteria matrix, a sustainability farm index was calculated at the farm level. The methodology was applied to the regional FADN sample of Veneto as of 2009. Buttinelli *et al.* (2021) assessed the financial sustainability of organic farms compared to conventional ones. Based on the FADN data, the analysis showed that financial sustainability is greater for organic farms than conventional farms, and in several cases, the level reached by the former is very high, especially in mixed types of farming. Turchetti *et al.* (2021) underlined how the goal of transforming the FADN system into the new FSDN is oriented to better incorporate the three sustainability dimensions and will permit objectives to be reached covered only in part by the current FADN. Coppola *et al.* (2022) proposed a principal component analysis in order to build an economic sustainability index applied to 6,000 FADN farms and based on three indicators: an efficiency indicator; an indicator of the ability of the farm to remunerate the entrepreneur's production factors; an indicator of the farm's income capacity.

As regards the usefulness of agriculture census data, Wrzaszcz and Zegar, (2014) presented proposals for measuring the economic sustainability of farms in Poland based on agricultural census data. They used the indicators of economic sustainability: land productivity, labour profitability (all these indicators are *not available* based on the 2020 Italian census), farm market activity, and sources of households' income and maintenance. The results show that economic and environmental goals are complementary at the farm level and that economically sustainable farms often conduct pro-environmental agricultural activities.

3. MATERIALS AND METHODOLOGY

3.1. Data sources: the census of agriculture

The 2020 Census was mandatory in each European Union country and was coherent with recommendations by the FAO (2017). The census had the purpose of updating the structural data collected with the 2010 Census and enriching the available information assets. The most critical feature was the actual state of activity of the farms, in a historical context characterised by the concentration of farms and consequent decrease of very small agricultural units. The census included questions concerned with the degree of modernization and sustainability of farms.

The data used for elaborations in the next sections are definitive and coherent with the data available on the ISTAT website[2] at the municipality level. In this context, common lands have been excluded from elaborations, because some relevant census questions, – such as those concerned with innovation and multifunctionality – could not be addressed to common lands. The census counted 1,133,006 farms, including common lands. The census results outlined the sharp decrease in the number of agricultural holdings between 2010 and 2020 (-30.1%).

Available data does not include revenues. However, based on census data, ISTAT calculated the *standard output* (SO) for each active farm. The SO of an agricultural product (crop or livestock) is the average monetary value of the agricultural output at farm-gate price, in euros per hectare or per head of livestock. The standard output can be used to classify agricultural holdings by type of farming and economic size. The 2020 census questions derived from the information needs that emerged at EU level, connected to multiple aspects of business management that are not always strictly concerned with sustainability. However, the main census value added is the capability of collecting several indicators at the level of each active farm (*microdata*), without a relevant size threshold. On the other hand, the main limitation of agriculture censuses is periodicity (ten years in the EU, five in the USA).

Most of the works based on census microdata deal with the typological classification of agricultural holdings. Russo and Sabbatini (2005) were among the first researchers to point out the usefulness of census data in order to classify farms. Even if not in close connection with the theme of sustainability, Arzeni and Sotte (2014) proposed a methodology based on the 2010 agricultural census data. They highlighted how the majority of Italian agricultural units are not "businesses" in a strict sense, but pseudo-family entities with low economic size. The authors considered: altimetry, technical-economic orientation, self-consumed production, days of work, sub-contracting, age and education of the farm manager, other gainful activities beyond agriculture production, and share of direct payments from the EU on revenues.

According to this path, based on the 2020 agricultural census, we have identified five main *behaviours* of the farms – five *sustainability dimensions* – which can determine, even with some approximation, how many farms are sustainable and which are their main features. Broadly speaking, being sustainable means choosing a management model that is oriented to the principles of sustainable agriculture, integrated with the surrounding territorial and entrepreneurial context, able to guarantee a minimum economic well-being to those who manage the farm, and which can offer services additional to the basic agricultural production. The methodology proposed is founded on three main pillars.

1. It is applied to all farms active in Italy. This is an important peculiarity of census surveys, which collect microdata for each unit of the population and not just for those belonging to a sample. The vast majority of applications known in the literature are based on a larger number of indicators, but are calculable only for a small subset of farms. Furthermore, they are not always representative samples of the entire population of existing farms.
2. The agricultural census guarantees the high quality of the data collected, which derives from the direct measurement of the indicators through a skilled data collection network. Estimates were used only in a few cases (outlier observations).
3. As explained in Section 3.2., the census-based indicators employed are constructed from a dichotomous perspective (i.e., whether a requirement is met or not). This approach is deliberately simple and helps to reduce information asymmetries arising from the particular distribution of the original variables, which are often highly concentrated in a few large units.

3.2. The five dimensions

The degree of sustainability of agricultural holdings depends on multiple factors, as outlined in Section 1. One of the major critical issues consists of the trade-off between the number and consistency of available statistical indicators and the availability of these indicators for the greatest possible number of agricultural holdings. In this context, five dimensions have been identified, probably not all those that could be listed, but all meas-

[2] https://esploradati.istat.it/databrowser/#/it/censimentoagricoltura.

urable through the agriculture census. Only part of the fourth factor was mandatory based on EU legislation. The indicators selected are focused on particular managerial strategies and do not directly concern structural features of the farm (as hectares of surface or geographical localization) or the farm manager (as gender or age).

Crops diversification

According to CAP 2023-2027, crop diversification is one of the three good practices for the climate and environment that must be respected by farmers in order to receive the ecological payment, or *greening*[3]. Greening considers diversification only for farms whose arable land exceeds 10 hectares. In particular:

- farms with an arable land area between 10 and 30 hectares must cultivate at least two crops, the main one of which does not occupy more than 75% of the arable land;
- farms with arable lands area exceeding 30 hectares must cultivate at least three crops, the main one of which does not cover more than 75% of the arable land and the two main ones together do not cover more than 95% of the arable land.

If more than 75% of the arable land is occupied by grass or other herbaceous fodder plants or by land left fallow, the number of crops based on the arable land area must still be respected, but there are no maximum limits. The diversification commitments do not apply, in addition to farms with arable land of less than 10 hectares, in the following cases:

a) if the arable land is entirely covered by a submerged crop (rice);
b) if more than 75% of the arable land is used for the production of grass or other herbaceous fodder plants and/or is kept fallow, provided that the total area of arable land not subjected to such uses does not exceed 30 hectares;
c) if more than 75% of the eligible agricultural area consists of permanent grassland, used for the production of grass or other herbaceous fodder plants or for the cultivation of submerged crops (rice) or a combination of such uses, provided that the total area of arable land not subjected to such uses does not exceed 30 hectares.

The census collected the data necessary to evaluate which farms would have met the requirements to access the greening contribution because of diversification just in 2020 (diversification binary variable = 1). However, based on this criterion, we could not assign any diversification score to: 1) farms with arable land areas of less than 10 hectares; 2) farms that fall into the particular cases from a) to c) mentioned above; 3) farms without arable land; and 4) farms with livestock only. Therefore, the diversification indicator for farms of types 1), 2) and 3) was equal to 1 if these farms had at least 5 different crops of any kind, and equal to 0 otherwise. As regards farms with livestock only (type 4), the indicator was equal to 1 if the farms had at least two different animal species among those observed by the census.

Organic farming

Organic farming is a method of production that places the highest emphasis on environmental protection and, with regard to livestock production, on animal welfare. It avoids or largely reduces the use of synthetic chemical inputs such as fertilizers, pesticides, additives and medicinal products. The production of genetically modified organisms and their use in animal feed are forbidden. It is a part of a sustainable farming system and a viable alternative to the more traditional approaches to agriculture.

A sustainable food system is at the heart of the European Green Deal. The European Commission set a target of at least 25% of the EU's agricultural land under organic farming and a significant increase in organic aquaculture by 2030. The area used for organic agricultural production in the EU keeps on increasing: it passed from 14.7 million hectares in 2020 to 15.9 million in 2021, which is 9.9% of the total utilized agricultural area (UAA) in the EU. In Italy, in 2022, organic agricultural areas were 2.35 million hectares, or 18.9% of the whole UAA.

Even though organic farming is not the only dimension able to measure the attention to the environment by farmers, it is an important variable measured by the census. Therefore, the second indicator taken into account is expressed through the binary variable, equal to 1 (yes) if the farm was organic (crops and/or livestock) and equal to 0 (no) otherwise.

Other gainful activities (OGAs), or multifunctionality

The gainful activities of the farm include activities beyond basic agriculture production that have an economic impact on the farm. The census questionnaire took into account other gainful activities where either the resources of the holding (area, buildings, machinery, etc.) or its products are used in the activity.

[3] The other two practices are: the maintenance of permanent pastures on the farms where they are present and the maintenance or establishment of an Ecological Focus Area.

OGAs constitute an additional source of income to basic agricultural production. The diversification of income sources is important, especially in the presence of economic shocks or other undesired events such as climate change, natural disasters, or wars (Van der Ploeg *et al.*, 2009). OGAs respond to new demand needs and allow the valorisation of a territory's characteristics and traditions. According to the census results, in 2020, 65,126 farms had at least one OGA, or 5.7% of the total. This percentage had increased compared to 2010 (4.7%).

In this context, only some particular OGAs have been taken into account. Assessing sustainability means evaluating the propensity of agricultural holdings to offer services to customers, such as a) agritourism, b) educational farming, c) care farming, which express the degree of social and economic sustainability of the holding. Furthermore, from the point of view of environmental sustainability, it is important to verify whether the farms self-produce energy from renewable sources: d) wind, e) biomass, f) solar, g) hydro energy, and h) other renewable energy sources. Therefore, the third dimension is expressed through the binary variable, equal to 1 (yes) if the farm had at least one OGA from a) to h) and equal to 0 (no) otherwise. In 2020, there were 33,881 farms with at least one OGA from a) to h), or 3.0% of the total.

Innovation

Innovation in the agricultural and forestry sectors can be described as the introduction of something new (or renewed) that turns into an economic, social, or environmental benefit for rural practice. Innovation may be technological, non-technological, organizational, or social, and based on new or traditional practices. Moreover, innovations are often related to agriculture's sustainability (Fontana, Fiorillo, 2023). The trend towards increasing support for innovation was reinforced within the CAP 2023-2027. Introducing innovation is a cross-cutting goal that must be integrated into priorities adopted by Member States in their rural development plans.

The last agriculture census collected two kinds of information related to innovation. The first one consists of the answers to the question: "*In the last three years (2018-2020), has the farm made investments aimed at innovating the technique or production management?*" The second information source derives from the record linkage between census microdata and AGEA microdata. AGEA is the Italian authority that manages EU subsidies to farmers. Among the wide set of subsidies, we selected those more concerned with sustainability issues, based on the assumption that many rural development measures can have a positive impact on the sustainability of agricultural holdings (Moulogianni, Bournaris, 2021), The rural development measures selected are: quality regimes for agricultural and food products; investments in tangible assets; aid for starting up entrepreneurial activities for non-agricultural activities in rural areas; aid for starting up entrepreneurial activities for the development of small agricultural businesses; support for investments in the creation and development of non-agricultural activities; agro-climate-environmental payments; biological agriculture; Natura 2000 payments and payments related to the Water Framework Directive; animal welfare.

The fourth feature taken into account is expressed through the binary variable, equal to 1 (yes) if the farmer answered "Yes" to the question on innovation, and/or if the farmer received at least one of the EU subsidies listed above, and to 0 (no) otherwise.

Economic size

The economic size is a basic indicator for each agricultural holding. The basic rationale is that each farmer has the right to ensure food security for himself and his household (Rocchi *et al.*, 2012). Even though the agricultural census did not pick up economic data, census data can be used in order to calculate the standard output (SO)[4]. The SO takes into account land and livestock but does not consider other sources of income, such as EU subsidies and other gainful activities. The SO is a *proxy* for the true (but unknown) economic revenues of farms.

The economic dimension of farms is fundamental in the framework of FAO Sustainable Development Goal 2.3: by 2030, double the agricultural productivity and revenues of small-scale food producers (FAO, 2019). Even though small-scale food producers should be identified according to the combination of the three dimensions given by agricultural land, livestock and net revenues, Gismondi (2024) showed that very similar results could be obtained using the SO in place of the three above-mentioned indicators.

Each modern farm must have a yearly SO larger than a given threshold. Of course, thresholds may be determined in different ways. In this context, we preferred not to use subjective thresholds, or to refer to percentiles of the SO cumulative distribution, which is strongly influenced by very large farms. Instead, we used the concept of *poverty threshold*, strictly connected with the old question about poverty and the richness of rural households. ISTAT updates this indicator annually; it represents the

[4] https://rica.crea.gov.it/APP/documentazione/?page_id=2153

monetary value, at current prices, of the basket of goods and services considered essential for each family to avoid serious forms of social exclusion in the reference context[5]. In this framework, the threshold T used depended on the territorial area in which the agricultural holding was located, and was based on the standard household composition of three adults. On average, the poverty threshold was found to be T=17,562 euro. So, the fifth dimension taken into account is expressed through the binary variable, equal to 1 (yes) if the farm had SO≥17,562 euros and equal to 0 (no) otherwise.

4. RESULTS

4.1. Sustainable and not sustainable farms

The core idea is to classify agricultural holdings based on the number of sustainability dimensions they possess, ranging from 0 to 5. Of course, this means that two farms may receive the same score even if their sustainability features differ partially or entirely.

For each reference domain, n is the number of agricultural holdings, while $n(i)$ is the number of agricultural holdings that have i sustainability dimensions (binary variable = 1) – e.g. i "Yes", for i=0,1,2,3,4,5. Moreover, we define:

number of sustainable farms: $n(1) + n(2) + n(3) + n(4) + n(5) = n - n(0)$ (4.1)

number of "high sustainability" farms = $n(4) + n(5)$ (4.2)

number of "medium sustainability" farms = $n(2) + n(3)$ (4.3)

number of "low sustainability" farms = $n(1)$ (4.4)

number of not sustainable farms = $n(0)$. (4.5)

Table 2 summarizes the $n(i)$ frequencies defined above and the main results of the farm classification based on the number of sustainability dimensions they possess (*sustainability score*). In 2020, 45 farms out of 100 were sustainable (more than 508,000). High sustainability characterized 2.1% of farms, while low sustainability farms were 22.2%. On the other hand, 55 farms out of 100 were not sustainable at all (more than 622,000).

In detail, the scores in Table 3 summarise the frequencies with which the individual dimensions examined characterise agricultural holdings. Economic size is the most frequent sustainability dimension, since it is present in 358,133 farms, or 31.7% of the total. The second most important sustainability dimension is diversification (20.4% of farms), while the least common dimension is multifunctionality (3.0%). The contribution provided by each dimension to the general level of sustainability can also be measured based on a second indicator. It is the number of farms with "yes" for that particular dimension and with "no" for all the remaining 4 dimensions (*exclusive "yes"*).

For instance, the economic dimension was the only sustainability dimension for 125,267 farms. We define *exclusive effect* as the percentage ratio between the number of exclusive "yes" and the number of "yes" for that particular dimension. As regards the economic dimension, the exclusive effect was 35% (125,267/315,133x100). The larger the exclusive effect is, the greater the relative importance of that dimension for the overall sustainability level, because without that dimension, the farm would not be sustainable at all. Even though innovation characterizes 188,827 farms, more than double compared to organic farming (79,053), the exclusive effects of these two dimensions are almost the same (18.0% and 17.9%, respectively).

The degree of sustainability of agricultural holdings is quite correlated with their main dimensional charac-

[5] https://www.istat.it/it/files//2023/10/REPORT-POVERTA-2022.pdf

Table 2. Degree of sustainability of farms by number of "Yes" (from 5 to 0) – 2020.

Number of "Yes"	Classification	Number of farms	%
Total	Whole population	1,130,513	*100.0*
>0	Sustainable	508,303	*45.0*
4 or 5	High sustainability	23,862	*2.1*
2 or 3	Medium sustainability	233,905	*20.7*
1	Low sustainability	250,536	*22.2*
0	Not sustainable	622,210	*55.0*

Source: Elaboration on ISTAT data – Census of agriculture 2020.

Table 3. Number of farms with certain sustainability dimensions (5 dimensions) – 2020.

Dimension	Number of "Yes"	% of total farms	Exclusive "Yes"	Exclusive effect
Diversification	230,716	*20.4*	72,983	31.6
Organic farming	79,053	*7.0*	14,178	17.9
Multifunctionality	33,881	*3.0*	4,063	12.0
Innovation	188,827	*16.7*	34,045	18.0
Economic size	358,133	*31.7*	125,267	35.0

Source: Elaboration on ISTAT data – Census of agriculture 2020.
Number of "Yes" %: % ratio between number of "Yes" and the whole population (1,130,513).
Exclusive "Yes": number of farms with "Yes" for that particular dimension only.
Exclusive effect: % ratio between exclusive "Yes" and number of "Yes".

Table 4. Dimensional indicators by degree of sustainability (average per farm) – 2020.

Number of "Yes"	Classification	Standard output (1)	Utilized agricultural area (2)	Adult livestock units (3)	Annual working units – AWUs (4)
Total	Whole population	49,740	10.6	8.3	0.67
>0	Sustainable	105,474	20.6	18.2	1.23
4 or 5	High sustainability	253,617	52.6	44.3	2.71
2 or 3	Medium sustainability	147,928	28.9	27.0	1.58
1	Low sustainability	51,729	9.8	7.5	0.76
0	Not sustainable	4,209	2.5	0.1	0.22

Source: Elaboration on ISTAT data – Census of agriculture 2020.
(1) Euro. (2) Hectares. (3) Indicator that summarizes in a single number the different animal species present on the farm. (4) AWUs have been obtained by dividing the overall amount of hours worked by the standard daily work length (8 hours) and by 225 yearly working days, as recommended by EUROSTAT.

teristics (Table 4). Not sustainable farms have on average 2.5 hectares of UAA, 0.1 adult livestock units, 0.22 annual working units, and slightly more than 4,000 euros of standard output. On the other hand, as regards sustainable farms (those with at least one sustainability dimension), these figures rise to 20.6 hectares, 18.2 adult livestock units, 1.23 annual working units and more than 105,000 euros of standard output.

4.2. Post-stratification criteria

Features of the farm manager

According to the data collected by the census, it was possible to verify which factors most influence farm sustainability. These *post-stratification factors* belong to three main types: manager characteristics, type of production (crops and/or livestock), and territory (plains/hills /mountain and disadvantaged or not disadvantaged municipality). The use of data on disadvantaged municipalities[6] was possible through the linkage with the census database at municipality level. The main control indicator is the percentage of sustainable farms out of the total. The main difference with respect to Section 4.1. is that, in this context, the sustainability level is calculated within the particular sub-population identified through each post-stratification factor. For instance, as regards the *management* factor "How long have you been running the farm?" the farms can be distinguished between those with management of less than 3 years and those with management of at least 3 years. Farms managed for less than 3 years (Table 5) are more sustainable (54.9%) than those managed for a longer time (44.5%). The larger the difference in sustainability referred to strata identified by the post-stratification factor, the greater the importance of that factor for influencing farm sustainability.

The most important factor is the age of the farm manager: 71.8% of farms managed by a "young" manager (with less than 40 years) are sustainable, compared to 42.5% of farms with a "not young" manager. These results confirm the fundamental role played by new generations in modernizing agriculture (Proctor, Lucchesi, 2012). Young managers develop organic farming and innovation more than twice that compared to not young managers: these sustainability dimensions characterize, respectively 15.3% and 37.2% of farms managed by young managers, against 6.2% and 14.8% of farms managed by not young managers.

Further factors discriminate significantly against different sustainability levels: farms with both crops and livestock are much more sustainable (73.4%) than those with only cultivations (39.4%) or only livestock (34.5%); farms whose manager has a diploma or degree are more sustainable (53.8%) than those whose manager has only basic education (40.4%).

It is undoubtedly comforting to note that the gender of the manager does not discriminate too much in the sustainability level, although for female-run holdings, the sustainability is lower than for male-run ones (37.8% versus 48.2%). In particular, the gender gap is almost null as regards other gainful activities and organic farming.

As regards territory, it is not surprising that the sustainability level of farms located in disadvantaged municipalities is lower than that of those operating in non-disadvantaged municipalities (39.2% against 46.7%). On the other hand, the higher sustainability level of mountain farms (51.0%) is surprising, at least in part. This may be due to the fact that the lower accessibility of mountain sites may lead to the need to organize their

[6] https://www.istat.it/it/files//2022/07/FOCUS-AREE-INTERNE-2021.pdf

Table 5. Sustainable farms according to some post-stratification criteria – 2020.

Breakdown	Sustainable farms (1)	Farms with the dimension (2):				
		Diversification	Organic farming	OGAs	Innovation	Economic size
Management < 3 years	*54.9*	*23.1*	*9.2*	*2.8*	*21.4*	*38.7*
Management ≥ 3 years	*44.5*	*20.3*	*6.9*	*3.0*	*16.5*	*31.3*
Young (< 40 years)	*71.8*	*30.4*	*15.3*	*5.3*	*37.2*	*57.4*
Not young	*42.5*	*19.5*	*6.2*	*2.8*	*14.8*	*29.3*
Male	*48.2*	*21.4*	*7.2*	*3.0*	*18.9*	*35.2*
Female	*37.8*	*18.3*	*6.6*	*2.9*	*11.9*	*24.0*
Basic education	*40.4*	*18.0*	*4.7*	*1.9*	*13.2*	*28.1*
Diploma/degree	*53.8*	*25.0*	*11.4*	*5.0*	*23.4*	*38.6*
Crops and livestock	*73.4*	*33.5*	*10.4*	*7.2*	*34.4*	*60.0*
Only cultivations	*39.4*	*18.0*	*6.4*	*2.2*	*13.2*	*26.1*
Only livestock	*34.5*	*0.1*	*3.8*	*1.2*	*17.1*	*22.7*
Plains	*44.0*	*17.7*	*4.9*	*2.4*	*15.0*	*36.4*
Hills	*43.5*	*21.8*	*7.7*	*2.8*	*15.4*	*28.8*
Mountain	*51.0*	*21.4*	*8.8*	*4.6*	*23.8*	*31.0*
Disadvantaged	*39.2*	*21.2*	*7.6*	*1.0*	*12.6*	*24.2*
Not disadvantaged	*46.7*	*20.2*	*6.8*	*3.6*	*17.9*	*33.9*

Source: elaborations on ISTAT data.
(1) % ratio between sustainable farms and total farms. (2) % share on total farms.

own production according to schemes that are basically sustainable and integrated with the surrounding area. This profile is confirmed by the larger propensity of mountain farmers to practice organic farming, carry out other gainful activities and introduce innovations.

Regional aspects

The geographical breakdown represents one of the most important post-stratification criteria. The persistence of geographical gaps in the degree of evolution of Italian agriculture is well known. In 2020, while in the north-west area the percentage of sustainable farms was 64.2%, it was only 34.6% in the south (Table 6). Sustainability decreases from north to south, even though the average sustainability of the two major islands (Sicily and Sardinia) is more similar to that of the centre than south. Compared to other areas, southern regions are penalized above all by their small economic size and poor propensity to introduce innovations. In the south, other gainful activities are also not very widespread, being practiced by only 1% of farmers, a share that is very close to that of the islands (1.2%). In the south only organic farming shows diffusion similar to the national average (6.5% of farms against 7.0%).

The territorial heterogeneity of sustainability is further highlighted by regional analyses. Figure 1 shows the ranking of Italian regions based on the percentage of sustainable farms on the regional total (horizontal axis) and the ISIC indicator (vertical axis). ISIC[7] is a synthetic indicator of regional agro-food competitiveness, which summarizes the four competitiveness dimensions: cost competitiveness, gross profitability, foreign markets and innovation. Both indicators have been calculated with reference to their national averages (equal to 100).

ISIC considers parameters such as economic performance and openness with respect to international markets not available from the 2020 census and therefore not included in the sustainability indicator proposed here. On the other hand, even though ISIC is a competitiveness and not a sustainability indicator, it also takes into account some aspects related to sustainability. Joint analysis of the sustainability index and ISIC leads to the identification of four regional clusters.

1. Regions with levels of agro-food competitiveness and agricultural sustainability close to their respective national averages. Most of the regions belong to this cluster; in order of increasing sustainability, they are Sicily, Abruzzo, Basilicata, Lazio, Molise,

[7] The ISIC indicator (*Indicatore SIntetico di Competitività*) taken into consideration refers to the agricultural component only (with the exclusion of food manufacturing). It is the synthesis of aggregate data on a regional scale and could not be calculated starting from data referred to each active agricultural holding, such as occurs instead for the sustainability indicator (ISMEA, 2021).

Table 6. Sustainable farms by geographic area – 2020.

Geographic area	Sustainable farms (1)	Farms with the dimension (2):				
		Diversification	Organic farming	OGAs	Innovation	Economic size
North-West	*64.2*	*27.9*	*5.3*	*5.9*	*26.6*	*50.1*
North-East	*57.8*	*22.3*	*7.2*	*5.7*	*27.6*	*45.9*
Centre	*46.4*	*24.7*	*9.0*	*5.7*	*15.9*	*28.9*
South	*34.6*	*16.5*	*6.5*	*1.0*	*10.3*	*22.3*
Islands	*45.7*	*20.0*	*7.1*	*1.2*	*17.0*	*33.1*
ITALY	*45.0*	*20.4*	*7.0*	*3.0*	*16.7*	*31.7*

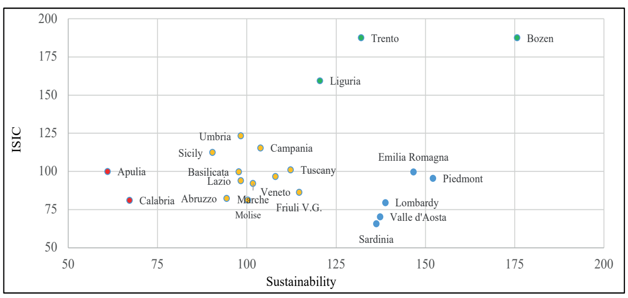
Source: elaborations on ISTAT data.
(1) % ratio between sustainable farms and total farms. (2) % share on total farms.

Marche, Campania, Veneto, Tuscany and Friuli Venezia Giulia.

2. Regions with ISIC index and agricultural sustainability significantly higher than the respective national averages: Liguria and the autonomous provinces of Trento and Bolzano.
3. Regions with high agricultural sustainability but levels of agro-food competitiveness equal to or lower than the national average: Sardinia, Valle d'Aosta, Lombardy, Emilia Romagna and Piedmont.
4. Regions with low environmental sustainability and ISIC index levels equal to or lower than the national average: Apulia and Calabria, which are the Italian regions with the lowest sustainability levels.

These results confirm that economic competitiveness is important, but does not necessarily imply sustainability, and vice versa. At regional level, the linear correlation between ISIC and sustainability is poor ($r = 0.33$) and 7 regions out of 21 (those belonging to clusters 3 and 4) are characterized by very discordant levels of the two indices.

Figure 1. Sustainability and agriculture competitiveness by Regions – 2020.



Source: elaborations on ISTAT and Rete Rurale Nazionale data. Italian average = 100.

4.3. Comparison with 2010 Census

Each census includes partly or entirely new questions. Therefore, the 2020 census collected data that was not available with the 2010 census. For example, the propensity to introduce innovations, which is one of the dimensions used for assessing the sustainability level as regards 2020.

Overall, the 2020 data are substantially comparable with those of 2010, even though the two censuses used different size thresholds. In order to estimate the changes in the degree of sustainability of Italian farms over the decade, we applied a classification methodology similar to that described in Section 4.1., even though the innovation dimension has been excluded. Both for 2020 and 2010, starting from the availability of data for each farm, the other four dimensions (diversification, organic farming, multifunctionality and economic size) are measurable.

The main consequence is that, to allow comparison between 2020 and 2010, the sustainability classification of farms changes as follows: according to the symbols introduced in Section 4.1., $n(i)$ is the number of agricultural holdings which have i sustainability dimensions (binary variable = 1) – e.g. i "yes", for i=0,1,2,3,4. Moreover, we define:

number of sustainable farms: $n(1) + n(2) + n(3) + n(4) = n - n(0)$ (4.6)

number of "high sustainability" farms = $n(4)$ (4.7)

number of "medium-high sustainability" farms = $n(3)$ (4.8)

number of "medium-low sustainability" farms = $n(2)$ (4.9)

number of "low sustainability" farms = $n(1)$ (4.10)

number of not sustainable farms = $n(0)$. (4.11)

Of course, the results referring to 2020 reported in Tables 7 and 8 are slightly different from those already seen in Section 4.1. because they are based on four sus-

Table 7. Degree of sustainability of farms by number of "Yes" (from 4 to 0) – 2020 and 2010

Number of "Yes"	Classification	2020		2010	
		Number of farms	%	Number of farms	%
Total	Whole population	1,130,513	*100.0*	1,620,884	*100.0*
>0	Sustainable	474,258	*42.0*	525,817	*32.4*
4	High sustainability	3,593	*0.3*	5,322	*0.3*
3	Medium-high sustainability	32,317	*2.9*	31,254	*1.9*
2	Medium-low sustainability	152,112	*13.5*	160,477	*9.9*
1	Low sustainability	286,236	*25.3*	328,764	*20.3*
0	Not sustainable	656,255	*58.0*	1,095,067	*67.6*

Source: Elaboration on ISTAT data – Censuses of agriculture 2020 and 2010.

tainability dimensions rather than five. With reference to 2020, the exclusion of the innovation dimension led to a reduction in the share of sustainable farms: 42.0% (Table 7), compared to 45.0% obtained including innovation (Table 2).

The main result deriving from comparison with 2010 is that, over the decade, farms' sustainability increased significantly, since it was only 32.4% in 2010. While the share of "high sustainability" farms remained the same (0.3% both in 2010 and 2020), the relative importance of "medium sustainability" farms increased: from 1.9% to 2.9% as regards "medium-high" and from 9.9% to 13.5% as regards "medium-low". Even "low sustainability" farms increased: they rose from 20.3% to 25.3%, probably because over the decade a share of non-sustainable farms have become sustainable, albeit at a low level. A comparison between 2010 and 2020 shows that the share of farms with at least one sustainability dimension increased for each dimension (Table 8). The largest increase characterizes the economic dimension (8.1 percentage points, from 23.6% to 31.7%), while the share of farms adopting organic farming has more than doubled (from 3.1% to 7.0%).

Table 8. Number of farms with certain sustainability dimensions (4 dimensions) – 2020 and 2010.

Classification	2020		2010		Difference 2020-2010
	Number of farms	%	Number of farms	%	
Diversification	230,716	*20.4*	255,798	*15.8*	4.6
Organic farming	79,053	*7.0*	50,092	*3.1*	3.9
Multifunctionality	33,881	*3.0*	27,424	*1.7*	1.3
Economic size	358,133	*31.7*	382,195	*23.6*	8.1

Source: Elaboration on ISTAT data – Censuses of agriculture 2020 and 2010.

Overall, the results confirm that Italian agriculture is becoming more sustainable over time, emerging from the essentially rural context that characterized it at least until the 1990s. However, sustainability levels still depend too much on farm size and location.

5. DISCUSSION

As already mentioned in Section 3.2., the main limitation of the methodology proposed is the low number of sustainability indicators available. This limit derives from the characteristics and purposes of the agricultural census, which was carried out in Italy, having to respect the rigid constraints imposed by the EU regulations on the matter. The census collected a lot of data on production tools, but only a few indicators strictly related to sustainability. Each of the indicators used (Section 3.2.) is connected with specific sustainability dimensions (Table 1).

- Crop diversification and organic farming refer to the environmental dimension.
- Economic size refers to the economic dimension.
- Other gainful activities refer to the economic dimension (because they represent a source of additional revenue), but also to the environmental dimension (regarding the production of energy from renewable sources) and the social dimension (educational and care farming).
- Innovation is a transversal characteristic connected to all three sustainability dimensions.

We used the five above indicators for these main reasons. 1) They are available for 100% of farms. 2) As just seen, they are connectable to SDG 2.4.1. 3) They can be easily expressed through binary variables (possession or not of the characteristic).

A potential limitation of the methodology is that the dimensions have the same weight in the synthesis procedure that allows the classification of agricultural holdings. This choice derives from the intrinsic multidimensional nature of the sustainability concept, which attributes the same importance to environmental, economic and social dimensions. Moreover, based on the analysis of the exclusive effect of each dimension (Table 3), the five indicators do not have the same relative importance: diversification and economic size are much more relevant indicators than the others. This evidence largely derives from the fact that in 2020, there were still relatively few farms dedicated to organic farming or multifunctionality.

The proposed methodology considers the five dimensions individually and therefore analyses them separately. Even though the advantage of this approach is the possibility of easily understanding why a certain farm is more or less sustainable, the main risk is to lose pieces of the correlation between the variables and the dimensions themselves. Gómez-Limón and Sanchez-Fernandez (2010) proposed a methodology applied to two Spanish agricultural systems based on calculating 16 sustainability indicators that cover the three main components (economic, social and environmental), and their subsequent aggregation into nine different types of composite sustainability indices. Reig-Martínez *et al.* (2011) built up a composite indicator at the farm level to assess social, economic and environmental issues, combining Data Envelopment Analysis and Multi-Criteria Decision-Making methods. Dos Santos and Ahmad (2020) proposed a cluster analysis of EU countries based on 22 indicators derived from the FADN, founded on the calculation of composite indicators, where the weight of each original indicator is derived from a factor analysis. In our context, the number of basic indicators is quite low (5). Their normalization consisted of the use of binary variables equal to one if the farm possessed that particular feature and to zero otherwise. The aggregation criterion was the not weighted sum of indicators because of two main reasons. First, the main goal was to assess whether the farm reached each target (yes or no). Second, the degree of linear correlation among the five indicators is quite low: the average correlation between each couple of indicators is 0.167, and the highest correlation referred to the couple 1 (diversification) and 5 (economic dimension) is still rather low (0.308). Both these pieces of evidence and the very low number of indicators taken into account discouraged the use of composite indicators.

Among the studies on agricultural sustainability, at least partly comparable with the one examined, we consider the results obtained by Longhitano *et al.* (2012), referring to the Italian case. The two analyses are not fully comparable because the authors used a much broader set of indicators derived from the FADN network and applied the methodology to the Veneto region for the accounting year 2009. One of the main results was the identification of three sustainability classes: low (44% of companies), medium (44%) and high (12%). It is useful to note that the methodology based on 2020 census data applied only to Veneto farms would lead to these percentages: 50.2% (low sustainability), 41.6% (medium) and 8.2% (high), data that is not very different, given that the methodology based on census data also includes very small farms (not included in the FADN observation field). Based on the 2010 Census of agriculture census results, Arzeni and Sotte (2014) showed that in 2010, 80.1% of agricultural units were "non-businesses". It is plausible to assume that, based on the methodology proposed in this context, these "non-businesses" would have been classified as "not sustainable" or with "low sustainability", classes that, with reference to 2020, included 77.2% of farms (Table 2); this percentage is slightly lower than the percentage of "non-businesses" estimated in 2010.

6. MAIN CONCLUSIONS AND FUTURE WORK

Increasing sustainability and modernizing the national agricultural system are two parallel, unavoidable processes that can also be speeded up by the National Recovery and Resilience Plan, defined in 2021. In this framework, the periodic measurement of the degree of agricultural sustainability becomes an essential objective.

The methodology proposed in this work aims to provide an overall evaluation of the sustainability of Italian farms. This approach requires the availability of indicators at farm level, typically sourced from agricultural censuses, which are conducted every ten years. Based on 2020 data, the methodology utilises five indicators reflecting specific farm dimensions related to sustainability. These dimensions include crop or livestock diversification, organic farming, additional gainful activities beyond basic agricultural production, innovation and economic size. The number of sustainability indicators possessed by each farm (ranging from 0 to 5) forms the basis of the classification. A farm is considered sustainable if it meets at least one sustainability dimension: in 2020, more than 508,000 farms (45% of active farms) met this criterion. Comparisons with 2010 are challenging due to the absence of innovation data in the Sixth Agricultural Census. Nevertheless, we estimate that the degree of sustainability increased by 9.6% over this decade.

The proposed system of indicators does not claim to be definitive or to establish a sustainability model that should remain unchanged. The five indicators only partially cover the three main dimensions of sustainability (economic, environmental and social) because the agricultural census was not designed with sustainability in mind. For instance, aspects such as the use of precision agriculture, the training levels of the workforce beyond the farm manager, additional environmental protection measures beyond organic farming, and most notably, the quantities of plant protection products and nutrients used in crop cultivation are not fully captured. Therefore, it is crucial to enhance collaboration between institutions that manage information databases, including administrative ones, related to agricultural holdings. This would enable the cross-referencing of indicators with high informational value at the individual farm level.

It is important to replicate these calculations at intervals of less than ten years. While the convergence process aimed at reducing the historical north-south divide is undoubtedly in progress, it is essential to monitor its pace and territorial reach. Agricultural systems, which remain divided into two major groups – predominantly modern market-oriented holdings and smaller, self-subsistence farms – are no longer sustainable.

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Research article

Economic analysis of irrigation services. An application of the hedonic price method on the FADN data

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Abstract. The economic valuation of water uses, as the Water Framework Directive (EC/60/2000) suggests, should support policymakers in water management. Aiming to assess the economic value of irrigation water services, a hedonic price analysis was conducted on the value of farmland. Specifically, we examined the differences between collective and self-supply irrigation services, with the hypothesis that each reflects different water supply qualities that are capitalized into land value. A homogeneous sample of olive farms in the Apulia region was analysed using data from the Farm Accountancy Data Network. The results confirm the hypothesis that different economic values are assigned to water services. A higher value of self-supply service with respect to collective ones might be associated with the greater security and reliability of the service provided. Finally, our analysis points out that the Farm Accountancy Data Network database can provide policymakers with a harmonized dataset for the economic evaluation of irrigation water. This can help them to develop evidence-based policies, as required in the Water Framework Directive.

Keywords: water economics, irrigation, water service valuation, Farm Accountancy Data Network, olive grove.
JEL codes: Q15, Q25.

HIGHLIGHTS

- Collective and self-supply water services have a different impact on the value of farmland.
- Hedonic analysis on the value of irrigated land reveals the higher value of self-supply service compared to collective service.
- FADN database provides the basis of a common dataset for the economic evaluation of irrigation water.

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1. INTRODUCTION

In recent years, the focus on the sustainable management of water resources has increased as a result of the pressure exerted by increased withdrawals. Moreover, the reduced availability of water resources is countered by the variability of the quantity of water due to climate change (Raggi *et al.*, 2008). From a regulatory standpoint, the Water Framework Directive (WFD) (EC/60/2000) drew the attention of the European community to the need to strengthen economic valuation tools, acknowledging their importance for efficient management and allocation in a situation of scarcity and uncertainty. The economic analysis of water uses lays the foundations to achieve a twofold objective: on the one hand, it is configured as a cognitive element to support policymakers, representing both a regulatory obligation for the drafting of a Water Master Plan at the basin scale and an indication of the condition of scarcity of the resource. Therefore, it should be at the basis of choices regarding the allocation rules among competitive uses. On the other hand, the economic analysis should steer Water Authorities to define tariffs capable of recovering the "full cost" associated with the use of the resource.

However, it is important to specify that water as a good in agriculture, and likewise in the civil and industrial setting, does not exist as such but is always associated with the concept of water services. In agriculture, the general distribution of irrigation resources is divided into two service categories: i) collective water service and ii) self-supply water service. In the first case, the irrigation provider organizations, which in Italy are mostly represented by the Land Reclamation and Irrigation Consortia (*Consorzi di Bonifica e Irrigazione*), deal with distribution and allocation (i.e., who has access, for what use, and in what volume). The service offered by the consortia has characteristics linked to the delivery mode: i) rotating delivery, ii) on demand, iii) continuous operation, iv) with reservation, v) under pressure. In the second case, the self-supply service ensures the demand for water through a different modality, according to which farmers can draw the resource on their farm or close by and, mostly relevant, when needed (i.e., on-demand). However, all the costs (both for the initial investment and operational) for the sourcing, catchment and distribution of the resource are borne by the farmer. In addition, access to water sources is issued by licensing that can be charged with fees as documented in some European Member States (Berbel *et al.*, 2019).

Some scientific papers available in the literature argue that the self-supply service from groundwater is associated with a rather low pumping cost, making it a valid alternative or supplementary source to the collective service that generally uses surface water (Giordano *et al.*, 2007; Ross, Martinez-Santos 2010; Sardaro *et al.*, 2020). In addition, the feeling of forced control over withdrawals generally exercised in cases of collective service appears to fade (Kahil *et al.*, 2016). There is a growing theory however that the advantage associated with a self-supply irrigation service, rather than being related to a lower cost (which varies depending on factors such as technology, depth of the aquifer, as well as regional specifications regarding concession fees), is related to the security and guarantee of supply that could make it qualitatively better and more highly appreciated than the collective service (Mesa-Jurado *et al.*, 2012; Giannoccaro *et al.*, 2019; Mirra *et al.*, 2021). In a context of climate change that produces strongly altered hydrological and rainfall regimes, the quality of the irrigation water service becomes more important, translating into an adequate guarantee of resource provision (Rigby *et al.*, 2010; Giannoccaro *et al.*, 2019; Fernández García *et al.*, 2020). Furthermore, at a time when smart irrigation, digital irrigation and precision farming represent the most advanced solutions to achieve the objectives of sustainability in agriculture, a timely, reliable and secure water service becomes a worthy requisite to save irrigation water. Although irrigation advisory services can release valuable irrigation-related information to farmers (Altobelli *et al.*, 2021; Galioto *et al.*, 2017), the potential for water saving will vanish with poor quality-of-service delivery (e.g., if delivery scheduling is longer than advised watering time).

Given the premise, the objective of this study is the economic evaluation of irrigation water services, the characteristics of which constitute a major factor in determining the success of the practice. Specifically, the study aims to estimate the economic value of the two types of water services commonly adopted in the Italian irrigation sector: collective vs. self-supply. The hypothesis underlying this research question is that each type of service expresses different qualitative characteristics of water supply and that these are valued by the operators.

While the economic benefits of irrigation water have been largely investigated (see Young, Loomis (2014) for a review), few scientific works have so far recognised the importance of the type of service adopted in determining the economic value of the irrigation water (Joshi *et al.*, 2017; Mirra *et al.*, 2021). In the absence of a competitive market, such as in the case of irrigation water, the economic valuation of irrigation services can be indirectly estimated. Previous literature showed that the value of irrigation intrinsically influences the value of land, which is an asset in a well-defined market (Young, Loomis, 2014). It may be linked to the fact that irrigation increases the productivity of land (Ruberto *et al.*, 2021) and the range of possible land uses (Gioia *et al.*, 2012) and allows the stabilization of quality productions, reducing the fluctuations in yields and consequently of agricultural incomes (Giannoccaro *et al.*, 2016).

Therefore, to answer the research question, a hedonistic evaluation was conducted (Taylor, 2003; Freeman III, 2021) on the value of agricultural land. The hedonic price method (HPM) suggests that variations in the economic value of agricultural land are influenced by each attribute or characteristic of the land, such as access to irrigation water or volume of water (Young, Loomis, 2014). With reference to the Italian context, examples of the valuation of irrigation resources can be found in Mirra *et al.* (2021), Rosato *et al.* (2021), and Tempesta *et al.* (2021), among others. Although in these studies the HPM is commonly applied to the land value, the source of the dataset used is different. In Mirra *et al.* (2021), monetary value for land was gathered by surveying landholders. They collected self-reported values of the likely market price for land owned by interviewees, also called "asking price", which is the price suggested by a seller but usually considered to be subject to bargaining. The main shortcoming of direct interviews with landholders is the high cost associated with gathering land value, which refers to a value at a point in time. Average Agricultural Value[1] has been used by Rosato *et al.* (2021). Despite being easily accessible, the validity of the criterion adopted to determine the Average Agricultural Value and its appropriateness to estimate the value of an asset remains controversial (Marone, 2008; Gioia *et al.*, 2012). Most importantly, for an accurate economic analysis of water use in agriculture, some relevant variables, such as type of service and irrigated volume, are not available when using the Average Agricultural Value. In the absence of the water quantity for the individual land observations, the approach is termed "quasi-hedonic" (Berbel *et al.*, 2007). In Tempesta *et al.* (2021), real transactions on the farmland market are scrutinised to gather land values. The major limitation of an HPM application on farmland refers to a lack of a competitive land market on which land prices are generated (Schimmenti *et al.*, 2013), as well as the lack of a sufficient number of transactions.

In order to test the research hypothesis, an econometric analysis was conducted on the value of agricultural land in a pilot area appropriately chosen for crop homogeneity, farm characteristics, and presence of multiple irrigation services, i.e., collective vs. self-supply from underground aquifer. The survey area falls within the Apulia region and corresponds to an area of greatest specialisation in irrigated olive trees. Agricultural land values were obtained from the database of the Farm Accountancy Data Network (FADN). In this context, a further innovative element of this research was to explore the potential of the FADN dataset as a valid support in the economic analysis of water use in agriculture. To do so, we also checked for the robustness of the land value reported in the accounting sheet of FADN's dataset and whether it can reveal the value of services for irrigation. To the best knowledge of the authors, this study is the first attempt to conduct an economic analysis of irrigation water using the FADN land values.

The research presents a description of the regional context on which the analysis is focused, a description of the observations of the analysed sample, and a section dedicated to the methodology used for the economic evaluation. Then, in the results section, the main descriptive analyses conducted will be discussed and the findings of econometric models shown. Finally, the last two paragraphs are dedicated to a discussion of the results obtained and the conclusions of the study, including future implications.

2. MATERIALS AND METHODS

2.1. The regional context of study area

The Apulia region is characterised by a strong agricultural vocation, with a total of 191,430 farms throughout the region, based on ISTAT agricultural census data (ISTAT, 2020). The production orientation characterising the territory sees olive cultivation as most prevalent, involving 160,080 farms. According to the census data, among the agrarian permanent crops, the olive tree is the most widespread and influences the distribution of agrarian permanent crops in Southern Italy, representing 71% of the surface area cultivated with agrarian permanent crops in Apulia. In this region, the water resource plays an important role in determining the technical-economic specialisation: indeed, the olive tree is the most widespread irrigated crop, followed by the wine grape, together accounting for 61% of the irrigated area in Apulia (Giannoccaro *et al.*, 2020).

Apulia is a region with poor surface water streams (with the exception of the Ofanto and Fortore), so it depends on other neighbouring regions to meet its irrigation water needs, which are met through interregional schemes. The organisation of the water service is of two types: collective distribution, under the respon-

[1] Average Agricultural Value (Valore Agricolo Medio) of the farmland carried out by the provincial commissions, established pursuant to Article 41 of the Presidential Decree of 08/06/2001 No. 327, to determine the compensation for expropriation for public utility.

sibility of the various Land Reclamation and Irrigation Consortia in the territory, and self-supply service, i.e., mainly individual users with an authorisation to use water for irrigation purposes. Collective distribution is managed by six consortia operating in the territory. The consortium structures are supplemented by the collective networks managed by the Regional Agency for Irrigation and Forests (ARIF). As far as individual users are concerned, this phenomenon has a significant size and constitutes 65% of regional irrigation (Giannoccaro *et al*., 2020). However, the region is characterised by striking differences across the provinces. Foggia, for example, achieves the highest share of irrigated land serviced by collectively delivered surface water (50%), while for Lecce almost 80% of the total is served by on-farm abstraction of groundwater. The average irrigation volume for Apulia is estimated at 655 million m^3 (Lupia *et al*., 2013), however, groundwater abstraction increases considerably in periods of severe drought (Portoghese *et al*., 2021).

In order to obtain a sample of farm observations that would be homogeneous in terms of structural characteristics, cultivation system and location, the study area of interest was identified as the area of greatest irrigated olive-growing specialisation in the Apulia region (Figure 1). Olive groves also show a uniform adoption of on-farm drip irrigation systems. With respect to structural and cultivation homogeneity, the study area reflects the infrastructural heterogeneity of Apulia's irrigation service. Indeed, there is a coexistence between the collective service offered by the Capitanata and Terre d'Apulia Land Reclamation and Irrigation Consortia and the self-supply service from the groundwater.

2.2. FADN dataset and description of the sample

The total of olive groves located in the area of interest was extracted from the FADN database, considering farms with at least 0.5 ha of olive grove area to avoid the presence of outliers. As a whole, a sample of 63 farms was

Figure 1. Map of the rivers, streams, public waters and the equipped area of collective irrigation network across the survey area.

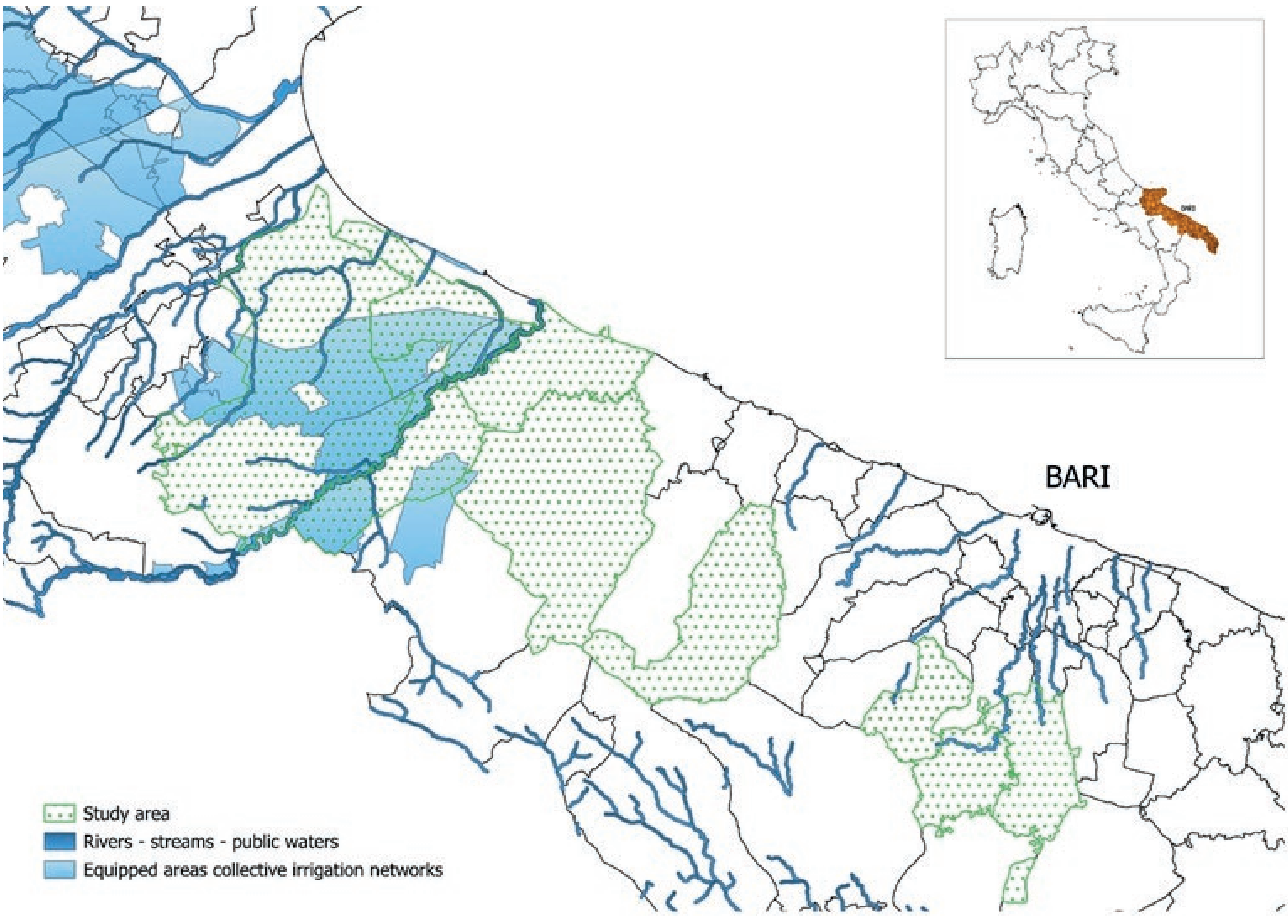

Table 1. Description of variables and relative descriptive statistics.

Variable	Description	Mean	Std. Dev.
Land value	Bare land value expressed in thousands of euros per hectare	28,282	11,406
Collective service	Availability of consortium service (1= if yes; 0= otherwise)	0.48	0.50
Self-supply service	Adoption of self-supply service (1= if yes; 0= otherwise)	0.36	0.48
Irrigated surface	Irrigated hectares	2.91	3.86
Volumes*	Volumes irrigated in cubic metres per hectare	1,420	655.83
Plant density	Number of plants per hectare (0= less than 100; 1= greater than 100)	0.60	0.49
Slope	Type of slope (0= flat; 1= steep)	0.09	0.28
Altitude	Altitude in metres above sea level	112.34	106.70

*Note: The information on irrigation volumes is recorded in the FADN dataset at crop level; for this study they have been derived at the specific plot level by average calculation in relation to plot area.
Source: own elaboration of FADN data.

retrieved, while the dataset gathered consists of 169 observations of land plots[2], recorded from 2016 to 2019. Following the removal of duplicate observations made for the same land plot over time, the observations create a pooled dataset that measures a distinct land value for each plot.

Broadly speaking, the FADN database provides information on various aspects of agricultural production, collected at different farm levels such as whole farm, specific crop and land plot. Hence, in accordance with the aim of the research, we included in the sample the variables that are strictly collected at the plot level. Table 1 shows the descriptive statistics of the variables included in the sample. The variable "land value" is contained in the land section of the FADN database and shows the value of the bare land estimated according to the criterion of most probable market value (Povellato, 1997; Gioia *et al.*, 2012). The estimation is performed by taking the portions of farmland on which condition of homogeneity occurs with respect to the main variables affecting the value of the land itself (Gioia *et al.*, 2012). Namely, the land value is linked to altitude, land features (e.g., slope), and land improvements (buildings and stable plants, agricultural hydraulic equipment, etc.) (Povellato, 1997). The FADN data is based on the separate estimation of the value of bare land and the value of plantations such as olive groves or other permanent crops. An inflationary update to 2019 was carried out on these monetary values by using the agricultural land prices index published by Eurostat[3].

[2] The plot is defined as a portion of land, even if not continuous, with uniform potential and physical-productive characteristics and mainly intended for homogeneous use (same type of cultivation), with the same title of ownership, with the same pedological characteristics (altitude, position and texture), the surface area of which is located in the same municipality.

[3] The index was calculated using the agricultural land prices index calculated at the regional level, which is available on the Eurostat website at https://ec.europa.eu/eurostat/data/database.

The variables relating to the type of irrigation service, planting density and location have been coded as binary variables. Specifically, the variable "collective service" refers to the availability and, consequently, access to the irrigation service managed by the Land Reclamation and Irrigation Consortia. That is, 48% of the sample observations are provided by collective service. The "self-supply" variable, instead, includes observations relating to farms that have access to the resource through private self-supply infrastructures (36%), while the remaining 16% do not have access to any irrigation service. Regarding the variables relating to the use of water resources, the average irrigated area is 2.91 hectares, and the annual irrigation volumes average 1,420 m^3 per hectare. As far as plant density is concerned, we can state that 60% of the olive groves on the farms in the sample analysed have a plant density with a number of trees per hectare of more than 100. This threshold can be considered the value below which one is in the presence of extensive and traditional types of cultivation systems. The variable "altitude" indicates that the land owned by the farms is located in a predominantly lowland area, with an average altitude value of approximately 112 metres above sea level. In addition, the variable "slope" describes the slope of the land with respect to the horizontal plane and indicates that only 9% of the examined observations have a land inclination between 5 and 20%.

2.3. Methodology

To conduct this study we used the HPM, which is based on the feature value theory originally proposed by Lancaster (1966). The HPM states that any good can be described as a set of characteristics and the levels these take on and that the price of the good depends on these characteristics and their respective levels (Birol *et al.*, 2006). According to the theory that proposes this methodology of analysis, the value of an asset (in this case agricultural land) can be attributed to a vector of *n* characteristics through a direct and functional relation (Lancaster, 1966; Rosen, 1974; Hanley, MacMillan, 2008). The chosen methodology proposes a hedonic analysis aimed at evaluating the water resource for irrigation purposes, under the assumption that a higher economic value can be associated with land with irrigation service access. Since irrigation is a practice that increases the productivity of agriculture (Ruberto *et al.*, 2021), the increase in revenue from this practice can be capitalised in the land value (Giannoccaro *et al.*, 2016). Furthermore, a higher economic value can be associated with self-supply service with the capacity to act as a reliable water service for irrigation, providing water on demand.

In mathematical terms, we can express the relation between the value of the land and its *n* characteristics through an econometric regression such as:

$$p_l = f(x_{l1} + x_{l2} \dots + x_{ln}) \quad (1)$$

where p_l denotes the value of land, and x_{ln} is the vector of each characteristic associated with the land value. Economic theory imposes no constraints on the form of the hedonic price function (Palmquist, 1989) as a consequence the choice of this form must be determined empirically and correctly interpreted as an approximation of the true hedonic price function (Garrod, 1999). Indeed, among the most widely-used regression models (i.e., linear, log-log, log-linear and linear-logarithmic), the one that best fits the available data is the log-linear one, which is also confirmed performing the Box-Cox test:

$$ln(Y_i) = \beta_0 + \beta_n X_n + \varepsilon, \quad (2)$$

where Y_i, the dependent variable, is the value of land per hectare expressed in Euro, X_n is the vector of explanatory variables, β_n forms the set of respective parameters to be estimated, ε is the residual obtained from the estimation of the regression model, while β_0 is the estimated parameter referring to the constant (intercept). The econometric model was estimated using the ordinary least squares (OLS) method.

Based on the data available at plot level (Table 1), equation 2 was estimated. In addition, with the aim of investigating the potential endogeneity bias (Moore *et al.*, 2020) in the hedonic estimates, two different model specifications were implemented. The decision to implement two different econometric models was driven by the strong influence that the altitude variable may have on the other explanatory variables (i.e., water services, slope and irrigated surface). Therefore, the first model differs from the second only in the presence of the altitude variable.

The estimated hedonic equation for the first model was specified as:

$$\ln(\textit{land value}) = \beta_0 + \beta_1(\textit{collective service}) + \beta_2(\textit{self-supply service}) + \beta_3(\textit{irrigated surface}) + \beta_4(\textit{volumes}) + \beta_5(\textit{plant density}) + \beta_6(\textit{slope}) + \beta_7(\textit{altitude}) + \varepsilon \quad (3)$$

where the value of the land is expressed as a function of its characteristics, such as irrigation service (collective or self-supply), irrigated area, irrigated volumes, plant density, slope and altitude.

The estimated hedonic equation for the second model was specified as:

$$\ln(\textit{land value}) = \beta_0 + \beta_1(\textit{collective service}) + \beta_2(\textit{self-supply service}) + \beta_3(\textit{irrigated surface}) + \beta_4(\textit{volumes}) + \beta_5(\textit{plant density}) + \beta_6(\textit{slope}) + \varepsilon \quad (4)$$

3. RESULTS

3.1. Analysis of water-related descriptive statistics

A preliminary analysis was conducted to verify the characteristics of the entire sample. Firstly, we examined the variation in the averages of the value of the land in relation to the type of service adopted with the aim of verifying the presence of a difference in monetary terms of the land between the two irrigation services. This difference is attributable to intrinsic characteristics of the service. The results (Table 2) report an average value per hectare of approximately 29 thousand euro for land accessed to the collective service (therefore served by consortia), while the observations concerning land on which there is a groundwater self-supply infrastructure report a slightly higher average value of approximately 34 thousand euro per hectare. As expected, the lowest average is reported for land that does not have access to irrigation water (approximately 12 thousand euro per hectare).

The Kruskal-Wallis test was used to determine the existence of a statistically significant difference between the medians of three or more independent groups. This test is the non-parametric equivalent of one-way ANOVA and is typically used when the assumption of normality is violated, i.e., it does not assume the normality of the data and is less sensitive to outliers than the one-way ANOVA. The p-value resulting from the test confirms a statistical difference between the groups considered, stating that at least one group differs. Generally, if the results of the Kruskal-Wallis test are statistically

Table 2. Land plot value based on irrigation service accessed.

Irrigation service	No. obs.	Mean value (euro/ha)	Std. Dev.
absent	26	12,327 [a]	2,490
collective	82	29,269 [b]	7,640
self-supply	61	33,756 [c]	11,866
Kruskal-Wallis test			*p-value* = 0.001

Note*:* numbers followed by different letters are statistically different at p > 0.1%
Source: own elaboration of FADN data.

Table 3. Volumes (m³/ha) used based on irrigation service accessed.

Irrigation service	No. obs.	Mean volume (m³/ha)	Std. Dev.
collective	82	1,479 [a]	614
self-supply	61	1,342 [a]	706
Two-sample *t-test*		*t* = -1.24	*p-value* = 0.217

Note: numbers followed by different letters are statistically different at p > 0.1%.
Source: own elaboration of FADN data.

significant, it is appropriate to determine via Dunn's test exactly which groups differ. In this case, the statistically significant values indicate that all groups differ from each other, so it can be asserted that the land value appears to be different for all three groups. In particular, the results of the test show a substantial difference in the land value of rainfed land compared to irrigated land but a higher value for land served by self-supply than for land served by collective networks.

With the aim of investigating the causes that would potentially influence this statistical difference, two hypotheses were formulated accordingly: in the first case, the adoption of one type of service with respect to another may depend on the volume of water used; in the second case, investigating the presence or absence of economies of scale, we verified whether the average irrigated surface area differs based on the irrigation service adopted.

Regarding the first hypothesis, as can be seen from the data shown in Table 3, the average volumes (m^3/ha per year) used are almost similar between the two types of service. Based on the t-test results, there is no statistical evidence to reject the null hypothesis, indicating that the average volumes of water used do not significantly differ based on the type of irrigation accessed.

Finally, from the data in Table 4, we highlight that the difference in the average irrigated area between the consortium service and self-supply service, as suggested by the Wilcoxon test, is not significant according to which the mean of cultivated land does not statistically differ according to the water service accessed.

Data reveal differences in the land plot value based on irrigation service accessed while the usage volume and extent of irrigated land is randomly distributed among the two services.

3.2. Econometric model

Following the methodology described above, the results of the hedonic model are shown in Table 5.

Table 4. Irrigated surfaces (ha) compared to irrigation service accessed.

Irrigation service	No. obs.	Mean surfaces (ha)	Std. Dev.
collective	82	3.4 [a]	4.6
self-supply	61	2.2 [a]	2.4
Two-sample *Wilcoxon test*			*z* = -1.52 *p-value* = 0.128

Note: numbers followed by different letters are statistically different at p > 0.1%.
Source: own elaboration of FADN data.

Model 1 includes all independent variables, while Model 2 does not include the altitude variable to account for potential endogeneity bias caused by the correlation between altitude and other variables.

In both models, all beta coefficients of the variables have the expected sign while their statistical significance changes significantly. Overall, the first model has a much higher degree of fit to the data, R^2 equal to 0.78, indicating that 78% of the variations in land values are explained by the model. In the second model, however, the degree of fit R^2 to the data is 0.53, indicating that the estimated model fits the data quite well and is therefore considered useful in explaining the relationship between the variables.

In general, as regards the goodness of fit of the different model specifications, the F-statistic and Root Mean Square Error (RMSE) assess that Model 1 fits the estimated relationship well. In Model 1, the F-statistic is higher (81.05 > 30.32), and the RMSE is lower (0.22 < 0.32) compared to Model 2. Moreover, regression diagnostics were carried out on multicollinearity (variance inflation factor – VIF). The VIF values exclude predictor collinearity problems because they are lower than the thresholds frequently utilized by analysts (Snee, 1973; Marquandt, 1980). In model 1, the VIF values referring to the water services are comprised of between 5 and 10, indicating a moderate correlation between these vari-

Table 5. Regression models

	Model 1		Model 2	
	Coeff.	*St. Err.*	*Coeff.*	*St. Err.*
Collective service	0.1499*	0.8607	0.7779***	0.1054
Self-supply service	0.1798**	0.0871	0.8807***	0.1018
Irrigated surface	-0.0039	0.0057	0.0054	0.0082
Volumes	-0.0001***	0.0001	-0.0001	0.0001
Plant density	0.1021**	0.0421	0.1630***	0.0609
Slope	-0.1283**	0.0623	-0.0755	0.0904
Altitude	-0.0035***	0.0003	--	--
Cons	10.4647***	0.0939	9.3687***	0.0687
No. Obs.	169		169	
F-statistic	F (7, 161) = 81.05		F (6,162) = 30.32	
Prob > F	0.0000		0.0000	
R-squared	0.7790		0.5290	
Adj R-squared	0.7694		0.5115	
Root MSE	0.2204		0.3207	
Mean VIF water services	6.26		4.24	

Note: Asterisks (***), (**) and (*) indicate significance at 1%, 5%, and 10% respectively.
Source: own elaboration of FADN data.

Table 6. Exponential transformation of coefficients.

	Model 1		Model 2	
	Coeff.	e^{β} - 1	Coeff.	e^{β} - 1
Collective service	0.1499*	0.1617	0.7779***	1.1769
Self-supply	0.1798**	0.1970	0.8807***	1.4125
Plant density	0.1021**	0.1074	0.1630***	0.1770
Slope	-0.1283**	-0.1204	-0.0755	-0.7268

Source: own elaboration of FADN data.

ables and other predictors. In model 2, instead, the VIF that refers to the variables included in the model is less than 5, indicating a lower correlation among regressors.

Regarding the statistical significance of the estimated coefficients, in the first model the explanatory variables are all statistically significant, except for the irrigated area. In this case we noted that the altitude variable (continuous, expressed in metres above sea level) strongly influences the relationship between the explanatory variables and dependent variable, with negative changes in the value of land as it increases. In the second model, the significant variables are the dummies relating to the type of service adopted and the plant density. Moreover, in both models, it is worth noting that the intercept value is highly significant and of a large magnitude, a sign that there is, in general, a base value for agricultural land in the area.

Since a semi-logarithmic form of regression was used, the estimated β would represent the impact on the logarithm of the dependent variable. In order to obtain the effect that a percentage change in the independent variable has on land value, a further transformation of the dummy variables was required, which included the calculation of e^{β}-1. The results are shown in Table 6.

The coefficient of an explanatory variable of a dichotomous type expresses the percentage change attributable to the presence of a certain quality attribute, all other conditions being equal. Therefore, in the first model, our estimates reveal that the case of land provided by water services reports a higher land value compared to rainfed land (16% for land with collective service and 20% for land with private self-supply infrastructure). However, the beta comparison test of the two different services conducted on this model does not show a difference in the land value of the two services in statistical terms, given a p-value equal to 0.44. Moving from a lower density of one hundred plants per hectare to a higher one, the land value undergoes a positive change of 11%, while moving from flat land to land with a steeper slope, the value undergoes a change of -12%.

From the second model, it can be inferred that the variables influencing the value of land are those related to the type of service and plant density. Thus, all other things being equal, the value of land under a collective supply system differs by 117% compared to rainfed land. Furthermore, the value differs by 141% in the presence of private self-supply systems. The beta comparison test of the two different services has confirmed for this model, given a p-value of 0.07, a difference in the land value of the two services in statistical terms. The plant density variable explains how the land value changes by +17% when the number of plants per hectare is greater than 100. The other variables are not significant.

4. DISCUSSIONS

The results confirmed the hypothesis that the value of land provided with a self-supply water service is statistically different from and higher than the value of land provided with a collective water service. The application of the HPM made it possible to disaggregate the value of land for each attribute, recognising that a self-supply service has a greater capacity to contribute to the value of land in monetary terms. The result is in line with other works in the literature that have seen the need to adapt the strand of analysis on the economic value of irrigation to climate change. As demonstrated by Joshi *et al.* (2017), the value of land is influenced not only by the presence or absence of irrigation water but also by the type of infrastructure and service that facilitates its utilization. Also Mirra *et al*. (2021), through self-reported land values by farmers show that in the long run, a higher value associated with self-supply irrigation service is capitalised in the buy-sell price of the land. The hypothesis common to these works is that the increased security and reliability associated with the farmer-managed service is reflected in its unit value, acknowledging these attributes as having a positive economic value.

The use of a sample as homogeneous as possible by limiting the analysis to a specialised olive grove area partly justifies the modest difference, in terms of economic value, between the two services. In fact, the olive tree is a crop that can also be grown in conditions of limited availability of water resources (controlled water deficit), an aspect that mitigates the difference in absolute value compared to what would happen if one were to consider a particularly water-demanding crop (e.g., processing tomatoes and fresh-cut vegetables) for which timeliness and security in the distribution of the resource are essential characteristics (Giannoccaro *et al*., 2019).

Another fundamental aspect to be considered in the interpretation of the results concerns the altitude variable, which is such a determinant factor in defining the land value that it is included as an explanatory variable in the majority of hedonic regression models conducted to date (Giannoccaro *et al*., 2016; Sardaro *et al*., 2020; Rosato *et al*., 2021; Tempesta *et al*., 2021). The altitude of a land plot significantly influences numerous factors such as soil productivity, distance from a built-up area, the possibility of mechanisation of agricultural processes as well as access to water resources (e.g., depth of well). However, from a methodological point of view, this influence is reflected in the presence of endogeneity, a well-known factor distorting the estimates made using OLS regression models (Moore *et al*., 2020). This aspect emerges clearly when we compare the results of the two models shown in Table 5. Indeed, the estimated coefficients related to water services differed greatly. This is related to the high correlation of altitude with other independent variables (e.g., water services adoption and altitude are highly correlated), even though the inclusion of altitude in Model 1 improves the estimates as a whole. In a recent work, multiple correspondence models have been identified as a way to overcome this limitation (Tavares *et al*., 2022). Despite the highlighted limitations, the model can be considered to be good compared to models conducted to date in the Italian scientific literature (Mazzocchi *et al*., 2019; Rosato *et al*., 2021), as it achieves an R^2 value well above the minimum acceptable threshold defined by Hair *et al*. (2019).

Finally, the aspect that most emphasises the potential of our experiment in comparison to the pre-existing literature concerns the nature of the data used. In fact, the authors that have so far attempted to assess the water resource by means of hedonic estimates have mostly employed data collected through direct surveys (Latinopoulos *et al*., 2004; Schlenker *et al*., 2007; Giannoccaro *et al*., 2016; Mirra *et al*., 2021) with the self-reporting technique, for which the large margin of approximation often observed with respect to land values is well known. In contrast, other authors have employed land registry data, and regional and/or provincial databases (Pirani *et al*., 2016; Mazzocchi *et al*., 2019). Rosato *et al*. (2021), in an attempt to use a uniform dataset on a provincial scale, used the database of Average Agricultural Values made available by the dispossessions office. However, Average Agricultural Values struggle to take into account on-farm water volume and, most relevantly, irrigation services.

Compared to the previously-mentioned literature, we opted to use the FADN database, which has the benefit of accurately approximating the real values of land plots with a set of specific characteristics (e.g., altitude, slope, etc.), in addition to the type of service and irrigation volume. Additionally, the availability of FADN data, for the whole country and in homogeneous form, highlights its potential in representing the reference as a database for the economic evaluation of irrigation water. However, some relevant variables that affect land value, such as plot access to the main road or distance from the city centre (see Sardaro *et al*., 2020) are not available in the FADN dataset.

5. CONCLUSIONS

This work aligns with the ongoing debate regarding the economic evaluation of water resources in agriculture. The article analysed how water services affect the land value of olive farmland in the Apulia region through the estimation of an HPM. More specifically, we investigated whether the collective and self-supply services might have a different impact on the value of farmland. Similar to previous research, our findings show that irrigation increases the value of land. Additionally, we found that self-supply service has a higher impact compared to collective ones. While there is no difference in the applied volume, the higher value of self-supply service may be related to the aspect of promptness, security, and guarantee of supply of the resource.

Our findings have several policy implications. One of the main ones is that consortia should improve the quality of service in terms of timeliness. Even though an advisory irrigation service can enhance water saving, uneven patterns of scheduling or unreliable water supply of a collective service can frustrate farmers' decisions. Otherwise, a collective service should try to introduce a price-differentiation mechanism according to the reliability of water delivery as recently proposed by Mirra *et al.* (2023).

Despite the limitations of the data collected, the research highlights the potential of the FADN dataset in supporting the possibility of making systematic use of a uniform dataset on a regional and national scale, which would allow progress in the previously undertaken path of data harmonisation on agricultural irrigation. It is definitely a priority at the national level, where the economic evaluation of the resource for irrigation use appears to be not homogeneous.

Nevertheless, the study is not free of limitations. Firstly, we confined our analysis to a small sample of farms located in a homogeneous area and growing the same crop. Therefore, the analysis should be conducted at least at a regional level, considering all crops, to better support the economic analysis of water uses in the Water Master Plan. Another important limitation, from a methodological point of view, is related to the need to identify an econometric model that would allow for the inclusion of a relevant variable in the determination of the value of land, such as altitude. At the same time consideration should be given to the endogeneity issues that arise, given the relationship that altitude has with other variables. Lastly, as regards the FADN data, the possibility should be considered of collecting other relevant information at plot level (i.e., water quality and cost for irrigation) to go in-depth into the economic evaluation of irrigation water. However, the results of the estimated model can still be considered robust due to the detailed information collected at plot level by the Italian data collection system.

In light of the findings of this research it is worth noting that, during a period where the uncertainty caused by climate change prominently threatens agricultural production in both quantitative and qualitative terms, the aspect of security and guarantee of supply of the resource cannot be neglected when identifying the economic value of the distribution service of the resource. Therefore, future research should take heterogeneity into account due to the different water services in the evaluation of water resources.

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AUTHOR CONTRIBUTIONS

Conceptualization, E.T. and G.G.; Methodology, E.T., L.M., S.R. and G.G.; Data gathering: G.V. and D.C; Software: E.T. and S.R.; Validation: E.T., L.M., S.R. and G.G.; Formal analysis: E.T., L.M. and S.R.; Data curation: E.T.; L.M. and S.R.; Writing – Original Draft, E.T. and L.M.; Writing –Review & Editing, L.M., S.R., G.V., D.C. and G.G.; Visualization: E.T.; Supervision, G.G. and G.V; Funding Acquisition, G.G.

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Research article

Challenges and opportunities of genome edited crops: An analysis of experts' views in Italy through a Delphi survey

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Abstract. New Breeding Techniques (NBTs) in agriculture have generated significant interest due to their potential to address many sustainability challenges related to food production. However, this potential is hindered by existing regulations and negative societal attitudes. The debate is wide open internationally. In this study, a Delphi technique was applied to assess the potential challenges and opportunities associated with genome editing applied to Italian agriculture. To this extent, a panel ranging from 22 to 27 experts from different professions, including academics, staff scientists, policymakers and farmer associations has been interviewed. The Delphi process included two rounds of expert inputs to reach a reasonable consensus and, in some cases, a potential dissensus. Results revealed that experts reached a strong consensus on the potential benefits of NBTs in agriculture, such as greater agronomic performance and enhanced quality for consumers. Nevertheless, experts did not reach a consensus on excluding some potential risks, like possible toxicity or allergy generation. They also shared concerns about some socio-economic risks like limited seed access, traceability, or negative consumers' attitudes.

Keywords: New Breeding Techniques, innovation, risk, regulation, Delphi technique.
JEL codes: Q16, O13, O33.

HIGHLIGHTS

- Experts (in Italy) agree on the potential benefits of NBTs as greater agronomic performance and enhanced quality for consumers.
- Experts do not reach a consensus on excluding some potential risks, like possible toxicity or allergy generation.
- Experts have shown concerns about some socio-economic risks like limited seed access, traceability or negative consumers' attitudes.
- Experts are still divided on regulatory aspects such as risk assessment procedures and labelling.

1. INTRODUCTION

New Breeding Techniques (NBTs) based on genome editing (GE) have progressed rapidly in recent years, leading to the creation of plants with novel traits. NBTs, like CRISPR/Cas or cisgenesis, are instrumental to the selective modification of DNA at specific genomic loci. These techniques encompass several methodologies, such as point mutations, excision, or the incorporation of new sequences. They differ from the "first generation" of genetically modified organisms (GMOs) which include foreign genetic material from different organisms (Wolt *et al*., 2016; Lowder *et al*., 2015; Fiaz *et al*., 2022).

This section provides a short literature review on NBTs and the current debate around them. NBTs development in agriculture is applied to a wide variety of crops and possible results include the development of new varieties resistant to abiotic or biotic stressors (Mishra, Zhao, 2018; Jaganathan *et al*., 2018; Gao, 2021). These encompass challenges related to climate change, such as rising temperatures and increasing drought exposure (Shinwari *et al*., 2020). Furthermore, NBTs could facilitate sustainable intensification i.e. reducing the use of chemical pesticides by developing resistance to pests and other diseases (Bisht *et al*., 2019). CRISPR/Cas9 genome editing has been successfully demonstrated in a large number of plants, including maize (Svitashev *et al*., 2016), wheat (Liang *et al*., 2017), rice (Toda *et al*., 2019), tomato and wheat (Aliaga-Franco *et al*., 2019; Okada *et al*., 2019). Currently, many disease-resistant crops against non-viral pathogens have even been developed for rice, wheat, tomato and citrus (Yin, Qiu, 2018). NBTs have also been developed to create new products as functional food or food with other desired attributes such as seedless vegetables (Lusser *et al*., 2012; Sedeeck *et al*., 2019).

The European Academies Science Advisory Council (EASAC) – based on scientific results published in the previous 20 years on the risks and benefits of crop NBTs – highlighted that "policy-makers must ensure that the regulation of applications is evidence-based, takes into account likely benefits as well as hypothetical risks, and is proportionate and sufficiently flexible to cope with future advances in the science" (EASAC, 2017). However, the regulatory landscape governing NBTs remains highly heterogeneous across different countries. Some nations, like the US, Japan, Argentina and recently India have adopted a liberalizing approach (Sprink *et al*., 2022) where NBTs do not need to adopt the same risk assessment procedures as those used for GMOs. Other countries, most notably the European Union (EU), have upheld strict regulations (Sprink *et al*., 2016) that do not authorize any GMOs.

Nowadays, many scientists and other stakeholders are calling for the liberalization of NBTs claiming that it is not possible to distinguish new varieties from those obtained through other more consolidated genetic methods like mutagenesis or from mutations that occurred in nature (Broll *et al*., 2019; Callaway, 2018; Dederer *et al*., 2019; Zimny *et al*., 2019). There is a call for the European Union to shift its position on plant biotechnology if agriculture has to meet the challenges of the coming decades (Halford, 2019). In 2018 the EU Court of Justice concluded that, according to the EU's regulatory framework for GMOs, targeted, genome-editing mutagenic technologies are GMOs, regardless of whether any foreign DNA is present in the final variety (Purnhagen, Wesseler, 2020). In 2021, the European Commission published a new study, at the request of the Council of the EU, according to which NBTs could contribute to a more sustainable food system, but the EU GMOs regulatory framework is currently challenging the development of innovative genetic technologies[1]. A legislative process has since then started and on July 5, 2023, the European Commission (EC) adopted a new proposal[2] to regulate plants obtained by certain new genomic techniques (NGTs) and their use for food and feed. The genome editing proposal was presented as part of the adopted package of measures for the sustainable use of key natural resources, and it will now be evaluated by the European Parliament and Council of the EU.

In the context of Italy, studies have been conducted to assess the feasibility and potential benefits of NBTs applications in Italian agriculture, particularly addressing the challenges related to climate change and crop sustainability (Nerva *et al*., 2023). Many authors have investigated public perception regarding NBTs and how the information may provide a substantial impact on public acceptance (Marangon *et al*., 2021; DeMaria, Zezza, 2022).

The aim of this study is to contribute to the existing literature to shed some light on the following two issues: 1) the opportunities and challenges of agricultural products obtained through genome editing techniques; 2) the governance questions including risk assessment, varietal approval procedures and labelling.

To achieve these objectives, a Delphi survey has been conducted (Avella, 2016; Okoli, Pawlowski, 2004) to anonymously analyse the level of consensus among a panel of Italian experts coming from different backgrounds.

[1] https://food.ec.europa.eu/system/files/2021-04/gmo_mod-bio_ngt_eu-study.pdf

[2] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13119-Legislation-for-plants-produced-by-certain-new-genomic-techniques_en

2. MATERIALS AND METHODS

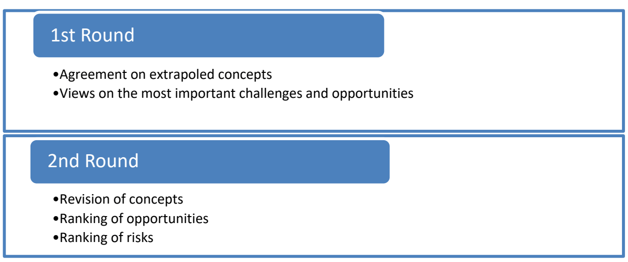
The Delphi approach, first described by Dalkey and Helmer (1963), is a well-established and widely used forecasting process based on the results of multiple rounds of *ad hoc* questionnaires sent to a panel of experts. The Delphi consensus technique has been employed by the research community for a broad range of problems, utilizing experts' viewpoints and knowledge, although it has not frequently been applied in the context of agriculture (Frewer *et al*., 2011; Rikkonen *et al*., 2019) even to transgenic agricultural products (Badghan *et al*., 2020).

In this paper, the experts' judgment concerning concepts, risks and opportunities in new breeding techniques has been analysed. According to the report of Okoli and Pawlowski (2004) among others, the Delphi methodology presents several advantages such as:

- no need for a physical meeting of experts;
- no requirement for a large number of experts, as long as participating ones are specialized in the subject;
- an appropriate method to rank opinions;
- it's a flexible method for follow-up interviews;
- it's a suitable method for complex questions that require deep knowledge;
- it's a compatible method with regard to specific issues that need experts' deep understanding of several dimensions (economic, environmental, agronomical, social and political).

The methodology adopted in the present study involves two distinct stages (Figure 1). In the first stage, the questionnaire was divided into three sections. The first section introduced the subject and the research purposes along with a description of the Delphi methodology. The second section directly inquired about participants' level of agreement/ disagreement with the issues that are more frequently reported in the debate on NBTs, such as the role of public vs private research, labelling and risk analysis. The third section investigated participants' general views on the most important

Figure 1. Delphi strategy.



allowed participants to compare their responses with the others, and eventually to change, or revise, their views.

Next, the questions where consensus had not been reached were reformulated by considering the inputs provided by the panellists in the first round. For this part, a four-point Likert-type unipolar scale omitting the "neutral" option to encourage experts to express straighter opinions was used. Finally, the survey on the challenges and opportunities proposed in the first round was proposed again in a modified "ranking-type" version to assess the level of consensus.

Due to the results of the two Delphi rounds along with the complexity and sensitivity of the topic it was decided not to continue with a potential third round, essentially because it was evaluated that the panellists had had enough opportunity to explain their viewpoints and thus preserve some dissensus. For this reason, forcing a third round would have caused a potential risk of increasing both the time required to provide further answers and the drop-out rate. This situation is not new in Delphi literature (Rowe, Wright, 2001; Toma, Picioreanu, 2016) and it is especially true in the so-called "policy Delphis" where views on policy alternatives (Cuhls, 2015; De Loë *et al*., 2016; Franklin, Hart, 2007) are required.

The classical Delphi method aims to reach expert consensus, assuming that experts behave rationally and that, after sharing and discussing arguments, will tend to converge on a reasonable agreement. However, in the context of policy questions, this approach is no longer considered realistic or desirable: experts often disagree, and decision-making may require considering pluralistic alternatives. Indeed, when concerning policy decisions, a combination of the "consensus and dissensus" Delphi is needed (Rikkonen *et al*., 2019). In this context, the data analysis of consensus was based on the measures of central tendency (modes, medians, percentages of agreements that take into account variations in responses and thus potential dissensus). The main limitations of a Delphi survey consist of selecting different experts who can provide different views (Marbach, 1991: 97). Furthermore, generalizing Delphi survey results is always very critical when the selection of the participants is not randomly based (Belton *et al*., 2019). On the other hand, authors (Anney, 2014; Kuper *et al*., 2008) underline the importance of transferability of the Delphi results rather than their generalizability. In other words, what really matters is whether, or not, the results have described the phenomenon under analysis in a sufficient manner to transfer the conclusions to the current times, contexts and people (Polit, Beck, 2010).

The study starts with the definition of the research problem and the characteristics of participants for the

Table 1. Characteristics of the expert panellists for the Delphi survey.

Row Labels	1st round	2nd round
Consumers Association	1	1
Farmers association	3	2
Green Chemistry Association	1	1
Ministry	1	1
Organic Association	2	2
Producers Association	1	1
Public Research	5	4
Region	2	2
University	11	8
Total	27	22

Delphi process based on the nature of the specific issues under investigation. Then, the panel was identified and invited to complete the questionnaire. According to the recent Belton *et al.* (2019) review a Delphi panel should consist of a range from 5 to 60 experts, depending on the issue. Furthermore, a heterogeneous sample of panellists seems to be always preferable to better represent the variety of perspectives on a particular topic and to obtain more accurate and reasonable judgments (Bolger, Wright, 2011; Spickermann *et al.*, 2014).

The panel used in this research included heterogeneous experts engaged in agriculture policy and research (academics, staff scientists, policymakers and farmer associations) as reported in Table 1. The first-round questionnaire was distributed to 50 experts, with 27 responses received. The second-round questionnaire was distributed to all 27 respondents of the first round and responses from 22 experts out of 27 were received. Each round was open for a month and several reminders were sent to ensure timely participation[3].

3. RESULTS

3.1. First Round

The Delphi exercise started by consulting the experts on some concepts extracted from the literature review in the form of a close-ended questionnaire. The intention was to examine the extent to which experts agreed with each concept, by converting them into questions with a five-point Likert-type scale (1: totally agree to 5: totally disagree).

Upon receiving responses, the percentage of agreement (by summing up the 1 and 2 scores – totally agree and agree) and the statistics of centrality median and mode to evaluate a consensus among Delphi experts were calculated. According to Hsu and Sandford (2007), a range between 70-80% of the percentage of agreement allows a reasonable consensus to be achieved with the possible support of median and mode (Table 2).

1 – Increased communication between researchers and society can enhance social acceptance of NBTs. This was one of the two concepts where the agreement was reached in the first round, with an 88% percentage of agreement and no neutral (score=3) position. Two experts expressed their views, one stating that: *"Researchers have a favourable bias and therefore act in terms of reassurance rather than objective framing"* and the other affirming that: *"Favourable researchers have never told the truth on GMOs and NBTs"*.

2 – Assessing the risks deriving from the introduction into the environment of organisms engineered with NBTs should be based on the nature of the organism and of the environment in which it will be introduced rather than the modification method. This statement, although similar to the previous one, achieved a partial consensus (74%). Two experts expressed their views on what should be considered in the risk assessment process: *"The risks assessment must cover all relevant aspects, including the genetic modification technique"* and *"Risks are not limited to the effects on the environment and health but also extend to food quality"*.

3 – The label should clearly indicate that the product was obtained by NTBs. Consensus on this statement reached 62%. Respondents motivated their disagreement by pointing out that: *"The indication on the label is not justified given the absence of risks"* and that, in the same vein, *"Labelling would suggest that there may be risks associated with consumption of such products"*. Others suggested that there should be no distinction i.e. with products obtained by mutagenesis stating that *"It is not indicated on the flour that the grain used was obtained thanks to a mutation"*.

4 – The fact that genetic technologies are covered by patents held by the private sector poses a challenge to social acceptance. Based on the responses to this statement, a consensus was not reached as the percentage of agreement was 60%. There were some opinions to support this statement such as: *"If it were true, the same should also apply to medicals"* or *"In the absence of patents, research in the private sector is discouraged"*. In the same vein, others affirmed that: *"There are also public sector patents"*, *"Few know what a patent is"* and finally *"Most new technologies are protected by patents"*. Interestingly, one expert underscored that: *"Only a specific segment of society, primarily concerned about the capi-*

[3] The survey was conducted between September and November 2022.

Table 2. Percentage of agreement, median and mode of the concept items in the first round (ordered by the highest percentage of agreement).

Items	Percentage of agreement	Median	Mode
1. Increased communication between researchers and society can enhance social acceptance of NBTS.	*88%*	1	1
2. Assessing the risks deriving from the introduction into the environment of organisms engineered with NBTs should be based on the nature of the organism and of the environment in which it will be introduced, rather than the modification method.	*74%*	2	1
3. The label should clearly indicate that the product was obtained by NTBs.	*62%*	2	1
4. The fact that genetic technologies are covered by patents held by the private sector poses a challenge to social acceptance.	*60%*	2	2 – 1
5. A gap exists between risks as perceived by the public and those considered by the experts.	*59%*	2	2
6. There is no evidence of specific dangers arising from the use of new genome editing biotechnologies.	*59%*	2	1
7. Consumers might have a more favourable view of foods obtained through new genetic technologies if they were developed by public research centres rather than by private industry.	*59%*	2	1
8. Consumer acceptance of foods produced through NBTs could increase if the products contain traits directly beneficial to consumers rather than just agronomic traits such as pest resistance, herbicide tolerance and yield increase.	*52%*	2	3
9. The risks associated with organisms engineered with NBTs are comparable to those associated with the introduction into the environment of unmodified organisms and organisms modified by other genetic techniques.	*48%*	3	3

talization of GMOs, is concerned about this aspect while others prioritize environmental and health risks".

5 – A gap exists between risks as perceived by the public and those considered by the experts. Although the median and mode were indicative of agreement, the percentage of agreement of 59% showed that consensus was not satisfactorily reached. Some experts expressed their views in this regard. One expert pointed out that: "*Very often the attention is placed on the short-term effects, neglecting or attributing less weight to the long-term ones*". On the contrary, another expert affirmed that: "*The experts are aware of the existence or the absence of objective risks*".

6 – There is no concrete evidence of specific dangers arising from the use of new genome editing biotechnologies. On this issue, a partial consensus with 59% percentage of agreement was reached. Seven out of 27 experts remained neutral. Among the experts who expressed their views, there were different opinions such as: "*There is scientific literature that highlights unexpected effects of genome editing*" and "*There is no evidence that there are any dangers arising specifically from the use of new genome editing biotechnologies*" on the one side and "*There is no third-party research on the matter and risks are not only about health*" on the other. One expert affirmed that "*These assessments should be carried out on a case-by-case basis*".

7 – Consumers might have a more favourable view of foods obtained through new genetic technologies if they were developed by public research centres rather than by private industry. This statement showed a percentage of agreement of 59% indicating a lack of consensus among experts. They also shared some interesting contrasting opinions such as: "*Consumers have no interest in knowing where the research is done*", and "*The private sector provides many goods that the consumers accept*" on the one side, and "*Consumer information is dominated by commercial and non-informative interests*" or "*This statement applies to everything related to health and the environment*" on the other.

8 – Consumer acceptance of foods made with NBTs could increase if the products contain traits directly beneficial to consumers rather than just agronomic traits such as pest resistance, herbicide tolerance and yield increase. This concept did not achieve consensus as the percentage of agreement was only 52%. The number of people with no opinion on this matter was quite high (9 out of 27). Some interesting opinions on how communication should be addressed were expressed such as: "*The principle of food and environmental safety should be central to the marketing of such foods*" or "*Effective communication to the public should emphasize that even agronomic traits (less perceived by the consumer) are actually "direct" benefits for the consumer/citizen*". However, there were also critical viewpoints, such as: "*Even if they contain "wonders", the fundamental issue still remains: they are GMOs*".

9 – The risks associated with organisms engineered with NBTs are comparable to those associated with the introduction into the environment of unmodified organisms or organisms modified using other genetic techniques. This statement showed the lowest level of agreement with only 48% of consensus. Many experts (11) were on the neutral side, showing a lack of opinion in this regard. Two opinions showed interesting different perspectives: *"I don't think there is evidence in this sense and therefore the precautionary principle always applies"* on the one side, and "*The organisms obtained with NGT are indistinguishable from those obtained with classical mutagenesis, indeed the process is much more precise"* on the other.

The second part of the questionnaire consisted of items related to opportunities and challenges assessed by using a four-point Likert unipolar scale of importance (1=not all important; 4=very important). Responses were processed reporting the percentage of consensus (adding very and moderately important) and the usual statistics of centrality, median and mode (see Tables 3 and 4).

Among the opportunities, "Drought resistance", "Reduction of water consumption" and "Reduction of use of chemical products" ranked the highest and obtained complete consensus. On the other hand, the potential opportunity of "Export growth" ranked the lowest, showing no agreement among experts. Interestingly, the results concerning the challenges were highly heterogeneous. "Possible toxicity" and "Negative consumer attitude" reached a good level of agreement in the importance, followed by "Possibility of causing allergic disease" and "Limited access to seeds". Additionally, "Religious issues" and "Adherence to commercial and specific agreements" obtained high and good levels of low importance and thus a substantial disagreement.

Table 3. Opportunities extracted for gene-edited products: first round statistics (ordered by the highest percentage of agreement).

Opportunities – Items	Percentage of agreement	Median	Mode
1. Drought resistance	*100%*	4	4
2. Reduction of water consumption	*100%*	4	4
3. Reduction of use of chemical products	*100%*	4	4
4. Weed control	*96%*	4	4
5. Reduction of chemical residues	*96%*	4	4
6. Contribution to the Sustainable Development Goals	*93%*	4	4
7. Reduction of production costs	*89%*	4	4
8. Increased productivity	*85%*	3	3
9. Defence of biodiversity	*85%*	3	4
10. Technological innovation of agriculture	*85%*	3	4
11. Higher nutritional value	*81%*	4	4
12. Product shelf-life improvement	*81%*	4	4
13. Food safety	*81%*	4	4
14. Development of innovative products	*78%*	3	4
15. Improved competitiveness	*74%*	3	4
16. Export growth	*67%*	3	4

3.2. Second Round

In the second round, the first round of questions on which consensus had not been reached were reformulated. Since consensus was reached on 2 out of 9 concepts, 7 concepts were redeveloped. This process had considered also the opinions expressed by the panellists in the first round. The new concepts are reported in Table 5. At the end of the second round, 22 experts out of 27 replied to this new concepts' evaluation.

Table 4. Challenges extracted for gene-edited products: first round statistics (ordered by the highest percentage of agreement).

Challenges – Items	Percentage of agreement	Median	Mode
17. Possible toxicity	*78%*	3	4
18. Negative consumer attitude	*78%*	3	4
19. Possibility of causing allergic diseases	*74%*	3	4
20. Limited access to seeds	*74%*	3	3
21. Traceability issues	*70%*	3	4
22. Resistance to antibiotics	*67%*	3	4
23. Involuntary transfer of genes	*67%*	3	3
24. New viruses and toxins	*67%*	3	4
25. Direct or indirect effects on the ecosystem	*67%*	3	3
26. Threat to biodiversity	*63%*	3	4
27. Absence of labelling systems	*63%*	3	4
28. Pesticides resistance	*59%*	3	4
29. Fear of unknown effects	*56%*	3	4
30. Low product quality	*52%*	3	3
31. Lack of expert consensus on impact	*52%*	3	4
32. Risks of loss of traditional production systems	*52%*	3	1
33. Incompatibility of organic farming	*44%*	2	1
34. Negative impact on imports	*33%*	2	1
35. Absence of commercial and specific agreements	*30%*	2	2
36. Religious issues	*19%*	1	1

Table 5. Concepts extracted for gene-edited products: second round statistics (ordered by the highest percentage of agreement).

New Concepts	Percentage of agreement	Median	Mode
1. Consumers are more interested in product innovations rather than process innovations (e.g., seedless varieties, higher content of microelements, etc.).	*73%*	2	2 – 1
2. Scientists can comprehensively evaluate all the potential risks associated with the introduction of edited varieties.	*68%*	2	2
3. Enhanced social acceptance of foods obtained through new genetic technologies would result if they were developed by public research centres rather than by private industry.	*59%*	2	3
4. Specific labelling is necessary for products obtained through NBTs.	*55%*	1,5	1
5. The fact that genetic technologies are protected by patents owned by the private sector hinders social acceptance.	*55%*	2	1
6. Risk assessment of the introduction of new modified varieties should follow the protocols used for non-genetically modified varieties rather than those required for transgenic organisms.	*45%*	3	5 – 2 – 3
7. There is no evidence supporting the existence of specific dangers arising from the use of new genome editing biotechnologies.	*41%*	3	3

Reformulating the questions produced different results in 6 out of 7 cases. For two questions the level of agreement increased with concept n. 1, reaching a good level of consensus (above 70%); whereas the experts agreed that consumers would be more interested in product innovations rather than process innovations. Partial consensus (68%) was reached on concept n. 2: "Scientists are able to consider all the potential risks deriving from the introduction of edited varieties". All other issues remained highly controversial, even showing a lower percentage of consensus. Particularly opinions on the evidence of the existence of specific dangers arising from the use of new genome editing biotechnologies and labelling were revisited with fewer experts agreeing on the absence of risk and at the same time, fewer advocating for specific labelling.

Respondent behaviour becomes clearer when opinions on perceived benefits and risks are analysed. In this regard, the survey on the challenges and opportunities proposed in the first stage was reformulated in a modified "ranking-type" version to assess the level of consensus. Concerning the benefits, the experts were asked to confirm, or not, the ranking gained in the first round. The majority of experts confirmed the ranking, whereas just 3 out of 22 expressed their doubts on the general presence of such benefits, claiming that the same was announced but not realized in the case of first-generation GMOs.

The ranking regarding the risks or challenges, gained in the first round, with regard to the cases where consensus had not been reached (i.e., from item number 5 to number 18; see Table 4) was presented to the experts. They were then invited to indicate which of these were effectively risks to be considered as such.

Figure 2. First-round percentages of agreement (very + moderately) related to the challenges and percentages of experts who confirmed those challenges in the second round.

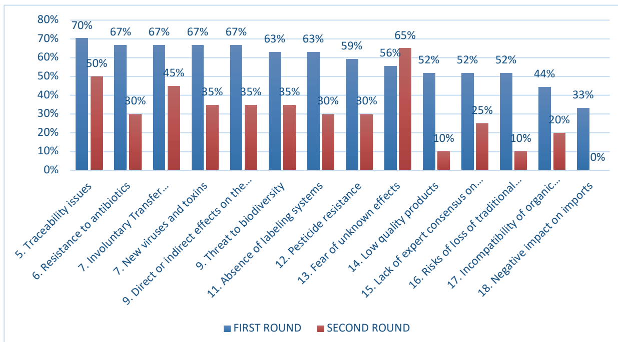


Figure 4 reports a comparison of the two rounds. The "traceability issues" that reached a 70% consensus in the first round were not confirmed in the second since only 50% of the experts declared that it was an effective challenge. All the other issues were confirmed not to be alarming except for "fear of unknown effects" where consensus grew with respect to the first round.

4. DISCUSSION

To analyse the results, given the high number of insights from the two Delphi rounds, it is useful to organize the discussion under four main questions:

4.1. What are the potential NBTs benefits?

4.2. What are the foremost concerns in terms of NBTs safety?

4.3. Which factors influence public opinion about NBTs?
4.4. How should NBTs be regulated?

4.1. What are the potential NBTs benefits?

This area is notably the least controversial both among the panel and within the existing literature.

Abiotic stress factors, such as drought, heat and salinity currently stand as major causes of yield losses in crops, posing a significant threat to food security. Adapting to climate change requires the development of improved crops with higher tolerance against abiotic stress factors. Conventional and transgenic breeding approaches have primarily focused on developing drought-tolerant crop varieties. Nevertheless, these methods are – for different reasons – both very time-consuming. In addition, GMOs face significant regulatory hurdles. Considering that drought and salinity stress tolerance are polygenic traits influenced by genome-environment interactions, CRISPR/Cas9-based transgene-free genome editing is considered a very promising approach, enabling many genes to be manipulated concurrently, thus working on very complex metabolic pathways (Raza *et al*., 2023; Joshi *et al*., 2020; Shelake *et al*., 2021).

Biotic stresses, caused by pathogens, represent another significant factor contributing to reduced crop yields, thereby compromising food security and farmers' income. At the same time, addressing crop diseases often relies on chemical pesticides, which can be harmful both to humans, to water quality and, more generally, to the natural environment. Reducing the dependence of food production on chemical pesticides is a key objective reflected in many Sustainable Development Goals (SDGs). Conventional breeding techniques and GMOs have proved to be successful in creating resistant crop varieties but with several limitations that can hinder their ability to address the challenges posed by increasing food demand in the context of global climate change. As remarked on in the introductory literature review, genome editing holds great potential for overcoming these limitations.

The panel reached a unanimous consensus on three issues: drought resistance, reduction of water consumption and decrease in the use of chemical products. Almost total consensus was also observed for potential benefits related to weed control and the reduction of chemical residuals. This consensus is in line with Lassoued *et al.* (2019a), whose study reveals that experts largely agree on the potential benefits of genome-edited crops in terms of agronomic performance (disease resistance, drought tolerance, and climate change resilience). Similar results were reported by Ruder and Kanlikar (2023) for Canada.

4.2. What are the foremost concerns in terms of NBTs safety?

Qaim (2020) distinguishes two different types of risk that need to be considered: risks associated with the breeding process and those related to the developed traits. As a matter of fact, while off-target effects can occur, they are generally detectable and can be eliminated or mitigated during the testing phase. Research evidence suggests that GMOs do not pose more risks than conventionally bred crops (EASAC, 2013; NAS, 2016; German National Academy of Sciences Leopoldina, 2019), although there are diffused concerns about possible negative health and environmental consequences. The second type of risk, associated with the new trait itself, cannot be generally assessed, as each new trait can have different effects. Therefore, trait-specific risks need to be assessed case by case, calling for a product-based regulatory approach akin to the regulatory framework applied for the new varieties obtained through conventional breeding methods.

Concerning this domain, achieving a consensus proved to be challenging. Broadly, the lack of agreement is clearly reflected in the different approaches to risk assessment at world level, with safety regulations being much stricter for GMOs than for any other agricultural technology (Qaim, 2016). This absence of consensus is not only evident in the existing literature (Lassoued *et al*., 2019b) but also in this study panel.

The concept of risk was analysed from various points of view. Initially, the questions aimed to understand if panellists perceived a risk perception gap between the general public and experts. There was no consensus in this regard, with someone asserting that scientists paid more attention to short-term time effects than to the long-term consequences. It was also mentioned that third-party research in this domain is lacking. No agreement was found on the concept that: the risks associated with NBTs do not differ significantly from those related to conventional breeding methods. This view is in line with the current EU legislation based on the application of the precautionary principle.

While investigating specific risks associated with NBTs, a partial consensus was reached on the fact that an obstacle is raised by the fear of unknown effects On the other hand, there was also agreement on other potential obstacles, such as resistance to antibiotics, release of new viruses and toxins and direct and indirect effects on the ecosystem.

4.3. What factors influence public opinion about NBTs?

In their extensive survey of existing studies on consumers' attitudes about NBTs-based food, Beghin and Gustafson (2022) highlighted the limited familiarity of the general public with these issues but also existing consumers' concerns about food's naturalness. They also found that higher levels of trust can be achieved when consumers perceive tangible benefits, such as increased nutritional value or more sustainable production processes, including reduced pesticides usage (Lusk *et al*., 2015; Gaskell *et al*., 2003) as well as other environmental benefits (Delwaide *et al*., 2015; Lusk *et al*., 2004; Gaskell *et al*., 2003). Additionally, consumers' acceptance is influenced by several factors such as trust in technology developers (Lucht, 2015; Siegrist *et al*., 2012, Vindigni *et al*., 2022), ethical and cultural values, and health concerns (Lusk, Coble, 2005; Costa-Font *et al*., 2008).

Within the panel, consensus was reached on the notion that improved communication between researchers and society could have a positive impact on the acceptance of NBTs. However, there was no agreement regarding whether distrust in the private sector plays a role in limiting social acceptance. Furthermore, the panel did not agree on the concept that traits directly linked to food quality, rather than to the production process would be accepted more readily by consumers. This result was confirmed when panellists were asked to rank opportunities related to NBTs. In this case, 100% consensus was reached for traits such as drought resistance, reduction in water consumption and the use of chemicals.

4.4. How should NBTs be regulated?

The debate surrounding the regulation of NBTs has gained further attention contextually to the development of such techniques, leading many countries worldwide to reconsider their legislative frameworks, distinguishing between NBTs from traditional GMOs regulations. In the EU, this issue has been central in the political agenda ever since the Court of Justice of the European Union determined in 2018 that genome-editing mutagenic technologies are considered GMOs, under the EU's regulatory framework for genetically modified organisms (GMOs), regardless of the presence of any foreign DNA in the final variety. Many scholars including Halford (2019) and Dederer *et al*. (2019) have highlighted the urgent need for a shift in the European Union's position on plant biotechnology in agriculture to address the challenges of coming decades.

Throughout the literature, some authors distinguish between process-triggered, where the regulatory framework and risk assessment solely depend on the product characteristics, and process-triggered regulation, where the regulation framework depends on the method used for creating the innovation (Hartung, Schiemann, 2014; Hamburger, 2019; Ishii, Araki, 2017; Medvedieva, Blume, 2018; Qaim, 2020; Smyth, 2020; Tagliabue, Ammann, 2018). Lemarie and Marette (2022) note that the Canadian regulation represents one extreme of product-based while the EU stands at the opposite extreme of process-triggered regulation. Other countries such as the US, Argentina and Australia, adopt a mixed approach, where legislation is process-triggered on some aspects and product-based on others. According to Lusk *et al*. (2018), consumers support the idea that genetically modified (GM) food products should be regulated based on a risk analysis of their impact on health and the environment rather than on the specific process used to create new varieties. In the panel, the assumption that "*The assessment of the risks deriving from the introduction into the environment of organisms engineered with NBTs should be based on the nature of the organism and of the environment in which it will be introduced rather than on the method by which it was modified*" reached a partial consensus in the first round (74%), but only 45% in the second round when the question was reformulated.

Another aspect of concern pertains to the labelling of products derived from NBTs. In the EU, GM products approved for import must comply with EU regulations that require labelling and traceability of food and feed containing GMOs. However, the panel did not achieve any agreement consensus on the need to specify labelling either in the first or second round.

Both of these results underline the very controversial issue of how to regulate NBTs also in Italy.

5. CONCLUDING REMARKS

The development of NBTs in agriculture is considered a potential answer to the many challenges associated with the growth of food demand: food security, climate change mitigation and adaptation, and environmental sustainability. NBTs innovative varieties have not yet been widely diffused and, in many countries, experimentation remains confined to laboratories. In Italy, the law that allows field trials of NBTs is also very recent. Therefore, it is very difficult to objectively assess the potential benefits for farmers, the agricultural industry and consumers. The same is true for the assessment of the risks, whether related to the environment or food safety.

Regulations governing NBTs are currently subject to a protracted and articulate debate worldwide, primarily due to the uncertainty surrounding market approval procedures for new varieties and the approach to GMOs risk assessment. Ethical and socio-economic considerations are also intensively debated in this context. Moreover, beyond market approval, another contentious argument under discussion is whether and how the products obtained through NBTs have to be labelled.

In this work, given the absence of objective data to analyse opportunities and risks associated with NBTs innovation, experts' opinions was examined through a Delphi study to identify where a consensus can be reached among experts and which concepts remain the object of dissensus. In the light of these findings, this research may contribute to the ongoing debate, in Italy and the EU, on the urgent need to revise the present legislation on NBTs, also to avoid the shift of R&D investment to countries that have already adopted a product-based approach.

Results have indeed shown that, among experts, there is a very high consensus on the potential benefits of NBTs in agriculture. They agree on many aspects such as improved agronomic performance (e.g., drought resistance, pest resistance, increased productivity) and better-quality products for consumers (e.g., improved nutritional value, shelf life). Nevertheless, experts do not reach a consensus on excluding some potential risks, like possible toxicity or generation of allergies. They also express certain concerns about some socio-economic risks like limited seed access, traceability or negative consumers' attitudes. In discussing regulatory issues, the experts have not reached an agreement on the approach to be adopted (process or product-based) in risk assessment and about labelling.

Understanding the future of new breeding technologies and their ability to contribute to solving the many challenges of food systems worldwide still requires a lot of research. In this context, regulatory issues are central in shaping how the benefits will be distributed across the whole supply chain. Controversies upon regulatory issues may be strongly related to the perception of the different impacts of the innovation on the various actors involved. For these reasons, an open-minded and informed dialogue between all the stakeholders is very much required and demanded.

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AUTHOR CONTRIBUTIONS

A.Z.: Conceptualization, Writing – Original draft preparation, Methodology, Data Curation, Supervision, Writing – Reviewing and Editing. M.V.: Methodology, Writing Methodology, Data Analysis, Validation, Writing – Reviewing and Editing.

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Research article

Agricultural work in European prisons. An exploratory analysis

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Abstract. Work in prisons has taken on various meanings over time. In European contexts, it serves as a valuable tool for enhancing inmates' quality of life. Specifically, agricultural work is recognised for its benefits, such as physical and psychological rehabilitation, vocational training, job placement, education, and recreational activities. Some of these aspects align with Social Farming (SF), which attributes a socio-welfare role to agricultural practices. To identify any SF elements within European prisons, an exploratory analysis was carried out, examining experiences in four countries (Denmark, Greece, Italy, and Sweden) using a qualitative approach. The findings reveal that many aspects of these experiences align with the SF framework and contribute to the rehabilitation of prisoners engaged in agricultural work.

Keywords: social farming, prison farms, agricultural work in prisons, European prisons.
JEL codes: H53, I39, K14.

HIGHLIGHTS

- Social Farming elements can be found in the agricultural activities carried out in the experiences analysed.
- In European prisons the direct involvement of inmates in agricultural activities is a key element in their rehabilitative path.
- The economic value associated with inmates' work contributes to giving them a sense of usefulness.

1. INTRODUCTION AND OBJECTIVES

At international level, work in prisons has been regulated since the 1950s by the United Nations Organisation. During the First United Nations Congress on the Prevention of Crime and the Treatment of Prisoners, held in Geneva in 1955, "Standard Minimum Rules for the Treatment of Prisoners" were adopted[1].

In drafting them, the wide variety of legal, social, economic and geographical conditions in the world was accounted for, and their adoption was unanimously accepted as minimum conditions by all members of the Organisation. With regard to work, the rules prohibit its afflictive nature, requiring – rather – that the occupation represents an opportunity for the maintenance or enhancement of the skills of inmates. In addition, the Organization requires that working conditions (in terms of time and remuneration, as well as security) should be comparable to those generally practised in society outside prison, "so as to prepare prisoners for the conditions of normal working life" (Standard 72-1).

Later, in 1990, basic universal principles in the treatment of prisoners were established. Drafted by the UN OHCHR (Office of the High Commissioner for Human Rights), these include the resolution according to which "conditions must be created to enable prisoners to engage in meaningful paid employment, that facilitates their reintegration into the country's labour market and enables them to contribute to their own economic livelihood and that of their families" (principle number 8)[2].

At European level, the prison system has been regulated since 1950 with the enactment of the European Convention on Human Rights[3]. The document represented a milestone in the path undertaken by the Allied Powers to prevent the most serious human rights violations that occurred during the Second World War. With regard to work (Art. 4), the document reads that no one shall be held in slavery or required to perform forced or compulsory labour.

In 1973, the Council of Europe developed its own Standard Minimum Rules for the Treatment of Prisoners (European Prison Rules), not binding on the Member States, which were adopted by the Committee of Ministers (Resolutions 73.5) and reformulated in 1987.

European Prison Rules (Art. 26) also state standards regulating work, defining the positive and non-punitive nature of work in prisons, specifying that the work provided by prison authorities must enable them to maintain or improve the prisoners' skills, with a view to a successful social and labour reintegration upon release. Moreover, the document mentions the need to equate as far as possible the organization and working methods used in detention facilities with the ordinary one used in working life (Art. 26.7). According to this statement, the work must be remunerated fairly and regulated, in terms of daily and monthly working hours, according to national rules or those protecting workers internationally, and the pursuit of profit in the production activities carried out within correctional institutions cannot prevail over interest in the personal growth of inmates.

According to the international and European rules, agricultural work is broadly used to implement training and working programmes inside penal facilities. Agriculture in penal institutions has a great rehabilitation power: firstly, it allows prisoners to work in the open air, restoring a sense of freedom and proximity to civil society (Moran, Turner, 2019; Piccioni *et al.*, 2022); secondly, it allows them to take care of other living beings (plants and animals), activating processes of accountability towards themselves and third parties (Payne *et al.*, 2023), as well as processes of gradual assumption of autonomy; thirdly, since the outcome of their efforts has an economic value, they recover a sense of usefulness and self-realization (Borsotto *et al.*, 2022); finally, it is an opportunity to learn a job and increase inmates' employability (Ascencio, 2018; Bhuller *et al.*, 2020; Borsotto *et al.*, 2022). The agricultural work carried out inside prisons can be powerful because working on the land can provide inmates with a meaningful and purposeful endeavour (Ciaperoni, 2009a; 2009b). It needs to be underlined that in some cases the inmates work in farms inside the prisons, in other cases they can work in farms located outside, depending on the legal framework and local opportunity. Considering these elements, agriculture in detention centres can be traced back to Social Farming, which links agricultural practices to socio-welfare purposes (Ricciardi, Dara Guccione, 2018; Borsotto *et al.*, 2022).

The aim of this study is to identify the characteristics of agricultural work in European prisons and to highlight elements common to Social Farming that

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[1] Approved by the Economic and Social Council in resolutions 663 C (XXIV) of 31 July 1957 and 2076 (LXII) of 13 May 1977. These standards were revised by the General Assembly in 2011. The revision process lasted until 2014. After that, the revisions were approved in Cape Town in 2015 and were named the Nelson Mandela Rules.

[2] "Basic Principles for the Treatment of Prisoners" – Resolution 45/111 by General Assembly of 14 December 1990. https://www.ohchr.org/sites/default/files/basicprinciples.pdf.

[3] Quote from the original 1950 text: https://www.echr.coe.int/Documents/Archives_1950_Convention_ENG.pdf. The most recent version of the Convention follows the provisions of Protocol No. 15 (CETS No.213) as of its entry into force, i.e. as of 1 August 2021, and Protocol No. 14 (CETS No. 194) as of its entry into force, i.e. as of 1 June 2010. Article 4 remained, however, unchanged.

can contribute to the social and occupational inclusion of inmates. To this end, an exploratory analysis was conducted by gathering information from existing literature and various European experiences. Labour and prison regulations were examined to develop a comprehensive framework and to gain a deeper understanding of legislative choices regarding rehabilitation through work. In the second section, we explore the interpretation and definition of Social Farming in the European literature and the value of agricultural work in prison settings. The third section outlines the method used to investigate the phenomenon and select relevant case studies. Finally, the results, discussion, and concluding reflections are presented.

2. THEORETICAL APPROACH

In the last decades, many scholars used the concept of Social Farming (SF) in order to analyse a set of heterogeneous practices taking place in farms having social and ethical purposes in common, generally aimed to offer 1) pathways for the social and/or labour inclusion of people with disabilities, social disadvantage, addiction problems, mental or psychiatric problems, who experience or have experienced periods of imprisonment; 2) care and/or health services addressed to support the public system in their intervention at local level (Di Iacovo, 2009; Di Iacovo, O'Connor, 2009; Guirado *et al.*, 2017; Hassink, Van Dijk, 2006; Hine *et al.*, 2008; Jarábková *et al.*, 2022; Moruzzo *et al.*, 2019; Sempik, 2010).

The European Economic and Social Committee defines SF as follows: "a cluster of activities that use agricultural resources – both animal and plant – to generate social services in rural or semi-rural areas, such as rehabilitation, therapy, sheltered jobs, lifelong learning and other activities contributing to social integration (according to the definition used in COST (European Cooperation in Science and Technology) Action 866 – Green Care). In this sense, it is about – among other things – making farms places where people with particular needs can take part in daily farming routines as a way of furthering their development, making progress and improving their well-being" (Willems, 2013).

On the other hand, the European Economic and Social Committee suggests that it is not useful to include Social Farming in a rigid definition, because of the many forms it can take (Willems, 2013). In fact, according to van Elsen (2016), it would be more correct to think of SF as a broad "concept", i.e. something in the making that can take on new forms and evolve. As suggested by Di Iacovo (2020), in Europe these practices are identified with different locutions: "Farming for health", "Green Care", "Social Farming", "Health Farming", depending on the area in which it is practised, the different welfare models, historical evolution and meaning attributed to these practices. In the European context, two different models of Social Farming can be distinguished (Di Iacovo, O'Connor, 2009): the Northern European one, where agricultural activities are promoted and mainly financed by institutions for therapeutic and rehabilitative purposes (Green Care or Green Care in Agriculture or Care Farming); and the Mediterranean one, where Social Farming initiatives are aimed at population groups with low levels of contracting, i.e. who are unlikely to be employed for work tasks (Borsotto *et al.*, 2022).

Agricultural work in prison was introduced in the 18th century, when in several Western countries prisoners were forced to work, following the Protestant model of "communal living" and the idea of controlling them and imposing better behaviour on them. At first, it took on a punitive value and was implemented as a form of sentence reduction by the prisoner. Only during the second half of the 20th century, agricultural work became a means of re-educating prisoners (Foucault, 2005).

The literature highlights the contribution of agricultural activity to reducing the risk of recidivism through increased employability skills and the positive impact of working outdoors (Welch, Eldridge, 2020). Studies on the use of plants and animals, focusing on farm animal care and husbandry, are particularly lacking, as Payne *et al.* (2023) show. However, other authors (Artz, Davis, 2017; Fitzgerald *et al.*, 2021) state that, while animals used in therapeutic interventions bring benefits, the interactions with commodified and objectified animals are likely not facilitating empathy and rehabilitation, due to the violence animals have to suffer.

There is also evidence that horticultural therapy (HT), which is considered a declination of SF (Makau *et al.*, 2024), brings benefits to physical, social and mental health, and has a positive effect on inmate rehabilitation and recidivism (Ascencio, 2018). Also, Lee *et al.* (2021) observed positive changes in the health conditions of prisoners participating in the HT programme, i.e. decreased depression and increased self-esteem and life satisfaction. This kind of activity also allows offenders to learn specific skills (growing process, management, etc.) that will increase their employability in fields (Jiler, 2006; Borsotto *et al.*, 2022; Ricciardi, Dara Giccione, 2018). Furthermore, a qualitative study of a horticulture programme in Canadian prisons shows both the positive impacts associated with planting, tending and harvesting, and those associated with donating food to local communities (Timler *et al.*, 2019).

Another important aspect relates to the additional benefits linked to the adoption of organic farming, the benefits of which in prisoning contexts were broadly analysed by Italian researchers in the early 2000s (AIAB, 2007; Ciaperoni, Ferrante, 2008). These authors pointed out that the lower use of synthesis inputs for addressing plant pathologies provides operators with a far greater degree of safety for their health with respect to conventional farming techniques. Moreover, organic farming holds considerable value in terms of re-education, consenting the cultivation of a positive disposition and connection with the natural environment and encouraging a consciousness regarding sustainable practices. Consequently, it improves the sense of responsibility towards other human beings and all living creatures. (Giarè *et al*., 2017; Guirado *et al*., 2017; Nicli *et al*., 2020).

Nevertheless, some authors (Chennault, Sbicca, 2023) provide a critical perspective, as prison agriculture can embody explicit forms of exploitation, highlighting how, in some contexts, the prison population is exploited to produce an economic profit that goes to "repay" the damage that the crime committed by the prisoner has caused to the public community. In the literature, this approach is associated with the concept of racial capitalism (Chennault, Sbicca, 2023; Hazelett, 2023). However, penal systems around the world are quite different, as is the historical and cultural evolution of prison work (Council of Europe Development Bank, 2021).

3. METHOD AND DATA

Due to the lack of comprehensive data and information on agricultural activities within European penal institutions, an exploratory analysis was conducted, following a bottom-up qualitative research approach. Exploratory research is a methodology approach aimed at investigating research questions that have not previously been studied in depth.

Data were collected by a literature review on agricultural practices in prisons and using questionnaires and interviews. Four phases were planned, each with an increasing depth of inquiry and information sought: (1) scouting phase, (2) a preliminary qualitative questionnaire, (3) a second qualitative questionnaire, and (4) interviews. The information has been collected in order to have a framework of agricultural activities in prisons and compare them with the main characteristics of SF, as defined in the literature.

3.1. Scouting phase

The research started with a preliminary scouting phase through an online survey, using the same keywords for each European country in the main online search engine (Google): "prison farm", "open prison", "agriculture in prison", "agriculture and detention". This approach enabled the identification of 32 penal institutions engaging in agricultural activities across Europe (Figure 1). Italian experiences, on the other hand, were identified based on the literature (Borsotto *et al*., 2022) and direct knowledge. The entire exploratory phase was conducted between February and April 2022.

3.2. Preliminary questionnaire

The second phase involved the development of a structured, standardized and self-administered questionnaire (available in the supplementary material) based on the literature (AIAB, 2009: 45), aimed at gathering information about the activities carried out in prison farms. The questionnaire was delivered to the identified institutions via email, using "Google Forms", between May and June 2022. A total of 15 responses were collected (Table 1, Q1).

3.3. Second questionnaire

The development of the second questionnaire (available in the supplementary material), which was also

Figure 1. Analysed prison farms per country.

Table 1. Contribution of the identified European prison farms to the study.

Prison (Country)	Q1	Q2	Interview	Role of the interviewee
Strafvollzugsanstalt Graz – Außenstelle Lankowitz Gutshof (AT)	X			
Justizanstalt Sonnberg (AT)	X			
Justizanstalt Schwarzau (AT)	X			
Penitentiair Landbouwcentrum van Ruiselede (BE)	X			
Søbysøgård Fængsel (DK)	X	X	X	Danish penal and prison service administrative staff
Sønder Omme Fængsel (DK)	X	X	X	Danish penal and prison service administrative staff
Kragskovhede Fængsel (DK)	X	X	X	Danish penal and prison service administrative staff
Renbæk Fængsel (DK)	X	X	X	Danish penal and prison service administrative staff
Agrotiko Katastima Kratisis Agias – Grammateia (EL)	X	X	X	Agronomist
Casa di Reclusione Ancona Barcaglione (IT)	X	X	X	Agricultural technician
Casa Circondariale Viterbo Mammagialla (IT)	X	X	X	Legal representative of the cooperative ORTO
Casa di Reclusione Sant'Angelo dei Lombardi (IT)	X	X	X	Penitentiary Police in charge of agricultural activities
Anstalten Rödjan (SE)	X	X	X	Prison staff who manages the agricultural activities
Anstalten Svartsjö (SE)	X	X	X	Farm manager
Sörbyns fängelse (SE)	X			

Please, note that the names of the prisons are reported in the original language.

structured, standardized and self-administered, was aimed at obtaining in-depth, detailed and specific information: the characteristics of the agricultural enterprises in terms of cultivated area; the activities carried out and use of the products; the organization of work activities; the methods for selecting and training inmates for work; inmates' earnings; networking activities conducted by the prison; as well as social aspects, such as the criteria for selecting and hiring inmates. This phase of the research was conducted between July and September 2022, and 10 responses were collected (Table 1, Q2).

3.4. Interviews

The respondents to the second questionnaire were invited to participate in a semi-structured focused interview (available in the supplementary material) to gain a deeper understanding of the specific experiences conducted within their respective institutions. The interview guide has been defined as a list of questions (Whiting, 2008; Krauss *et al*., 2009), in order to direct the conversation towards the research topic (Krauss *et al*., 2009). The flexible form of the semi-structured interview allowed dialogue during the interview (Whiting, 2008) and the possibility to deepen based on the specific context.

All interviews were conducted online via the "Microsoft Teams" platform, digitally recorded, and transcribed with the participants' consent. Each interview lasted around 60 minutes. This phase of the research took place between September and December 2022; a total of 7 interviews for 10 institutions were conducted as some interviewees were representatives of multiple penal institutions[4].

The analysis presented in the results therefore considers prison farms in Denmark, Greece, Italy and Sweden, which are the experiences from which we were able to get all the necessary information for the goal of our study. Prison farms in Austria and Belgium have not been included in the study because they replied only to the first questionnaire. Specifically, In Denmark, the interviewee works in the headquarter within the Danish penal and prison service at a political-administrative level and is responsible for the activities that prisoners have to attend while they are incarcerated (DK1). She replied collectively for all prison farms in Denmark (Søbysøgård**,** Sdr. Omme Fængsel**,** Kragskovhede Fængsel and Renbæk prisons). The respondent from Greece is an agronomist (EL1), who leads the agricultural department of Agia prison**.** In Italy, we interviewed people with different roles, due the variety of situations: the legal representative of the cooperative ORTO, who in 2017 started the social agriculture project "Semi Liberi" in Viterbo prison (IT1), the agricultural technician of th**e** Penitentiary Institution of Ancona (IT2) and a member of the penitentiary police in charge of agricultural activities in Sant'Angelo dei Lombardi prison (IT3). In Sweden, we interviewed the farm manager responsible for all kinds of work for the prisoners in Svartsjö prison (SE1);

[4] Further information on the prison farms analysed can be found in the supplementary material.

and the manager of agricultural activities from the Rödjan prison (SE2).

For a conscious and clear reading of this analysis, it is important to emphasise that the opinions and points of view expressed in the work are not those of the inmates because it was not possible to obtain the required permissions to speak with them. From now on, we will only use the name of the place where prisons are located to illustrate results.

4. RESULTS

As already mentioned, the analysis considers prison farms in four countries: Denmark (4), Greece (1), Italy (3) and Sweden (2). Results are presented by topic in order to directly compare experiences in relation to: general information (4.1), agricultural activities (4.2), use of products (4.3), economic revenues (4.4), organization of work (4.5), inmates' selection and job preference (4.6), training of prisoners (4.7), working conditions (4.8), role of work and agriculture in the legislative system and advantages of agricultural work (4.9), and networking (4.10). Given the exploratory nature of our research, we will be reporting in the results all the aspects that have emerged from the questionnaires and interviews, even when they are not strictly related to our research goal. Later on, in the discussion session, we will highlight the aspects emerging from our exploration that can be linked to SF.

4.1. General information

The agricultural activities conducted within prisons vary in terms of the number of prisoners involved, which can range from 2 to 150, due to differences in the organization, size of the farm, and available working opportunities. The study considered only male prisoners. The exploratory analysis of the participating prisons highlighted that the farms associated with these institutions are of different sizes: the total agricultural area (TAA) varies between 0.4 and 1,100 hectares, while the utilized agricultural area (UAA) can take on a value ranging from less than 1 hectare up to 600. Table 2 summarises information about prisoners and agricultural area per prison analysed.

4.2. Agricultural activities

The production orientation (Tables 3a and 3b) is in line with the agriculture of the examined countries. Northern European prison farms are characterized by large extensions and focus their activities mostly on cereals, forage, forestry and livestock. Instead, among the Southern European prisons, Italian farms have a rather small TAA and UAA, which they valorise with niche productions with high added value, such as small fruits in Ancona Barcaglione (IT), aloe vera and aromatic herbs in Viterbo (IT) and sericulture in Sant'Angelo dei Lombardi (IT). Differently, the Greek prison is characterised by productions typical of both small and large farms. The number of inmates employed in agricultural activities is generally higher in the north proportionate to the higher UAA.

The prison farms are involved in diversification in non-agricultural activities (Table 4), such as direct sale, food and wood processing. Direct sale is typical of the Italian prisons, and is also done in Rodjan (SE). Product processing is rather widespread everywhere, while wood processing is more common in Northern Europe-

Table 2. Number of prisoners and agricultural area (hectares).

Prison (Country)	Total prisoners	Prisoners working in agriculture	TAA (ha)	UAA (ha)
Søbysøgård Fængsel (DK)	3,600*	150*	230	200
Sønder Omme Fængsel (DK)			1,100	950
Kragskovhede Fængsel (DK)			1,000	600
Renbæk Fængsel (DK)			200	160
Agrotiko Katastima Kratisis Agias – Grammateia (EL)	85	2	138	101
Casa di Reclusione Ancona Barcaglione (IT)	80	5-10	2	2
Casa Circondariale Viterbo Mammagialla (IT)	503**	5	0.4	0.3
Casa di Reclusione Sant'Angelo dei Lombardi (IT)	180	10	1.2	1.15
Anstalten Rödjan (SE)	107	35	387	387
Anstalten Svartsjö (SE)	120	35-40	400	400

* Total for all Danish prisons.
** Data taken from the Italian Ministry of Justice website (09/09/2022), because the answer to the questionnaire was 5.

Table 3a. Agricultural productions by prison.

Prison (Country)	Cereal	Forage	Fruit	Horticulture	Olive	Aromatic herbs	Forestry	Livestock	Gardening
Søbysøgård Fængsel (DK)	X	X				X	X	X	
Sønder Omme Fængsel (DK)	X	X				X	X	X	
Kragskovhede Fængsel (DK)	X	X				X	X	X	
Renbæk Fængsel (DK)	X	X				X	X	X	
Agrotiko Katastima Kratisis Agias – Grammateia (EL)		X	X	X	X	X		X	
Casa di Reclusione Ancona Barcaglione (IT)				X	X			X	
Casa Circondariale Viterbo Mammagialla (IT)			X	X	X	X			
Casa di Reclusione Sant'Angelo dei Lombardi (IT)			X	X	X	X			
Anstalten Rödjan (SE)	X	X		X			X	X	
Anstalten Svartsjö (SE)	X	X						X	X

Table 3b. Agricultural productions by prison.

Prison (Country)	Firewood	Beekeeping	Floriculture	Edible sprouts	Aromatic herbs	Aloe farming	Viticulture	Sericulture
Søbysøgård Fængsel (DK)		X						
Sønder Omme Fængsel (DK)		X						
Kragskovhede Fængsel (DK)		X						
Renbæk Fængsel (DK)		X						
Agrotiko Katastima Kratisis Agias – Grammateia (EL)			X					
Casa di Reclusione Ancona Barcaglione (IT)		X				X		
Casa Circondariale Viterbo Mammagialla (IT)			X	X	X			
Casa di Reclusione Sant'Angelo dei Lombardi (IT)		X					X	X
Anstalten Rödjan (SE)								
Anstalten Svartsjö (SE)	X							

an countries. The prison of Rodjan (SE) is the only one producing energy. Table 5 summarizes the agricultural method used in the prison analysed.

In Denmark, the move towards organic farming in prisons started in the 1990s. The EU organic certification was obtained with the support of a consultancy agency, which provided information on EU rules, regulations and financial aspects (i.e., access to fundings). The interviewee underlined the importance of this support as she claimed that bureaucracy in organic farming can sometimes constitute a limitation. The Danish administration pays great attention to sustainability and in the past promoted the analysis of the sustainability potentials of prison farms in Denmark, with the support of external consultants. Different aspects of sustainability are included, such as saving water, energy, biodiversity, life quality, economics management, soil management and animals.

In Agias (EL), efforts are generally made to minimise fertilisers and other inputs to be as environmentally friendly as possible, but organic certification is only obtained for vegetables and herbs because it is considered too expensive (i.e., excluding forage production, fruit farming, olive growing, livestock and floriculture).

None of the analysed Italian prisons complies with the EU organic standards, mainly due to the low production quantity and the difficulty in managing the administrative procedure on behalf of the prisons. Nevertheless, all the interviewees report a minimal use of chemical inputs, which can result in lower production. The interviewee from Sant'Angelo dei Lombardi claims that this low-input choice is both for environmental protection and because the final aim of the agricultural work that they do *"is not to produce and make money but to re-educate and train prisoners"* (IT3).

The two Swedish prison farms produce under the Swedish organic certification KRAV; the Rodjan (SE) detention centre is one of the oldest farms that acquired the certification in the late 1980s. KRAV is a certifica-

Table 4. Activities related to agriculture by prison.

Prison (Country)	Direct sale	Product processing	Energy production
Søbysøgård Fængsel (DK)		X	
Sønder Omme Fængsel (DK)		X	
Kragskovhede Fængsel (DK)		X	
Renbæk Fængsel (DK)		X	
Agrotiko Katastima Kratisis Agias – Grammateia (EL)			
Casa di Reclusione Ancona Barcaglione (IT)	X	X	
Casa Circondariale Viterbo (IT)	X	X	
Casa di Reclusione Sant'Angelo dei Lombardi (IT)	X	X	
Anstalten Rödjan (SE)	X	X	X
Anstalten Svartsjö (SE)		X	

Table 5. Agricultural method by prison.

Prison (Country)	Organic	Conventional
Søbysøgård Fængsel (DK)	X	
Sønder Omme Fængsel (DK)	X	
Kragskovhede Fængsel (DK)	X	
Renbæk Fængsel (DK)	X	
Agrotiko Katastima Kratisis Agias – Grammateia (EL)		X
Casa di Reclusione Ancona Barcaglione (IT)		X
Casa Circondariale Viterbo (IT)		X
Casa di Reclusione Sant'Angelo dei Lombardi (IT)		X
Anstalten Rödjan (SE)	X	
Anstalten Svartsjö (SE)	X	

tion more restrictive than the EU organic one, since there are more rules and controls[5]. Consequently, it is a strong brand, and its products are sold at higher prices with respect to EU organic certification.

4.3. Use of products

The interviews highlight that products obtained in prisons are both self-consumed (except for Viterbo prison) and sold, as shown in Table 6.

In Denmark, the meat is sold to "Danish Crown" and the dairy products to ARLA, which is a large dairy production company, through periodic and structured contracts. They also sell to large scale distribution and specialized shops. The interviewee specified that they sell to big companies because they can manage the strict regulations of organic farming.

Also, in Agia prison part of the production is sold and part of it is self-consumed. Prisoners and employees can buy the products made in prison. The rules establish that first of all these products should be used to supply the prison, then the employees and finally the free market. Prisoners have the possibility to cook the food that they buy (and produce) in the central kitchen. Organic products are sold to specialized shops while not certified products are sold to any buyer in the free market. They only sell raw products and not in large quantities. They don't have a registered brand.

In Italy products are generally sold to companies or cooperatives that participate in tenders organised by the Ministry of Justice but they can also be used for self-consumption in accordance with the provisions of the national Law[6]. In Viterbo, products are sold to farmers' markets, specialized shops, online, and in the shop located outside the prison. In Ancona prison, part of the production is for sale, which takes place through a registered trademark "Fattoria Barcaglione", partly at the farm shop and partly at farmers' markets and Christmas markets. The production from the prison voluntary social garden (about 0.3 ha) is given free of charge to the inmates; the excess of the social garden is distributed to needy families in the area indicated by the Social Services of the Municipality of Ancona. This activity is supported with the contribution of the Marche Region Department of Agriculture, the Regional Guarantor

[5] For more information, see the following links: https://wwwkravse.cdn.triggerfish.cloud/uploads/sites/2/2022/12/krav-standards-2023-1670933646.pdf (KRAV standards); https://agriculture.ec.europa.eu/farming/organic-farming/legislation_en (European ones).

[6] Law no. 354/1975, art. 20, paragraph 12: "Prisoners may be allowed to engage in the activity of producing goods for self-consumption. A decree of the Minister of Justice, in consultation with the Minister of Economy and Finance, establishes the procedures for carrying out the activity for self-consumption, including through the use of prison administration goods and services". For more information see: Troncone, P. 2014. Manuale di Diritto Penitenziario. Torino. Giappichelli Editore.

Table 6. Use of products.

Prison (Country)	Use of products				Brand
	Self-consumption	Direct sale	Large-scale distribution	Local retailer	
Søbysøgård Fængsel (DK)	X		X	X	
Sønder Omme Fængsel (DK)	X		X	X	
Kragskovhede Fængsel (DK)	X		X	X	
Renbæk Fængsel (DK)	X		X	X	
Agrotiko Katastima Kratisis Agias – Grammateia (EL)	X		X	X	
Casa di Reclusione Ancona Barcaglione (IT)	X	X		X	X
Casa Circondariale Viterbo (IT)		X		X	
Casa di Reclusione Sant'Angelo dei Lombardi (IT)	X	X			X
Anstalten Rödjan (SE)	X	X	X	X	
Anstalten Svartsjö (SE)	X		X	X	X

of the prisoners and local nurseries. In Sant'Angelo dei Lombardi, the horticultural products are partly used in the prison canteen, where about seven inmates work, and a part is sold at the farm shop. As for processed products such as wine, honey, jams, they are sold under the brand "Fresco di galera" at the farm shop and in specialised shops, such as the e-commerce "Economia Carceraria" and the related shop Vale la Pena.

In Svartsjö prison (SE), a very small part of the greens is used for self-consumption. Products are sold in the open market to the company "Lantmännen", which is a cooperation between farmers, while cows are sold to a slaughterhouse (SCAN). The production is also sold to the food industry and large-scale distribution under the trademark of the company and under the KRAV brand. In Anstalten Rödjan (SE), sales are made to a farm shop (store located in prison), the food industry (crops to big warehouses, milk to large industries, animals to external slaughterhouses), and local supermarkets (wheat flour).

Regarding promotional activities, the examined experiences generally don't carry out marketing and products promotion activities, except for Svartsjö, Agia and all Italian case studies where some marketing activities are organised by the prison staff. In particular, in Italy, inmates who are under a specific regime (Article 21 Law no. 354/1975) that allows them to go outside, can participate in some promotion activities and local events where their work is valued and publicised.

4.4. Economic revenues

The management of the farm budget is different in each case study analysed. Particularly interesting is the experience of Denmark, where the prisons have a single farm budget, thus realizing economies of scale in the purchasing department, as well as in production and distribution. The interviewee for the Danish prisons reported that every year there is a deficit in the farm balance but this does not constitute a concern as *"earning money is not the point. It is important that the farm works commercially so that it resembles a real job and it is more meaningful for inmates, with the goal of creating a meaningful environment where people work for something that they actually sell"* (DK1).

In Greece, economic revenues are allocated to the central state, in particular to the Ministry of Protection of Civilians, which in turn funds the prison.

In Italy, the income is paid to the central prison administration, which also manages investments, because of specific norms about production and commercialization. In the case of Viterbo prison, activity, income and expenditure are managed by a cooperative (which, by definition, cannot make profits). Revenues are used to give a supplementary treatment of wages to inmates and to give inmates tutors a refund of expenses.

In Svartsjö prison, the farm budget is directly managed by the prison, reinvesting the income deriving from the sale of products. Instead, in the other Swedish prison farm (Rödjan), the income earned from the sale of products is managed by the head office of the Swedish Prison and Probation Service.

4.5. Organisation of work

The organisation and management of agricultural work activities are heterogeneous (Table 7), due to the

Table 7. Organization of work.

Prison (Country)	Prison staff	External actors	Inmates
Søbysøgård Fængsel (DK)	X		
Sønder Omme Fængsel (DK)	X		
Kragskovhede Fængsel (DK)	X		
Renbæk Fængsel (DK)	X		
Agrotiko Katastima Kratisis Agias – Grammateia (EL)		X	
Casa di Reclusione Ancona Barcaglione (IT)	X	X	
Casa Circondariale Viterbo (IT)		X	
Sant'Angelo dei Lombardi (IT)	X	X	
Anstalten Rödjan (SE)	X	X	X
Anstalten Svartsjö (SE)	X		X

diversity of the personnel in charge and actors involved. In general, the administrations of the single penal institute are responsible for the organisation and management of work and choose the figure (prison staff, external contractor, inmate) who leads the activities. In Italy, for instance, in the case of external contractors there are stringent regulations in this area, the working relationship is between the inmates and external companies, e.g. social cooperatives, which manage the work activity. While the relationship of the latter with penal institutions is defined by specific conventions (Art. 15 Law no. 354/1975.)

Some interviewees (Rödjan and Svartsjö (SE)) highlight the importance of the active involvement of prisoners in the management and organization of agricultural work. In Svartsjö, the staff involves inmates by displaying the planning of activities and the timing, so that inmates have a long-term vision of what they have to do. Moreover, the interviewee from Svartsjö reported that *"we use the skills that prisoners have, for example mechanics, and they can plan their own work for themselves, order the materials, organize themselves under the supervision of their experts"* (SE1). This is an extremely important aspect, not only because it makes the work of the inmates more interesting and gratifying, but above all because it activates a process of responsibility and helps to develop and increase organisational and management skills. In addition, the engagement is fundamental to the re-educational process and for future reintegration into work once the sentence has been served.

4.6. Inmates' selection and job preference

As for the inmates' selection, each penal institution refers to its own national legislation in force on the matter. Although these regulations are very different from one another and give rise to different strategies for the rehabilitation of inmates, they all have a common denominator. Indeed, for access to work they generally consider the low level of dangerousness of the inmates, which implies a low level of security. In addition, the inmates have the possibility of expressing a preference regarding the type of job to be employed in.

In Denmark, social workers evaluate inmates against psychological criteria. According to this evaluation, inmates are assigned to the activities available in the prison they are in. Members of organised crime gangs or terrorists are the only ones not allowed to work with other inmates. Groups consist of inmates both with high competency level and with lower ones, in order to favour the resocialization and integration (Statutory Declaration n. 1333/2019, Chapter 8, Section 29).

The legislation in Greece provides that all prisoners are assigned specific tasks according to the type of offence committed, work experience, skills, preferences and health status. Prisoners with a high level of security are not allowed to work outside prison. In Greece, each day of work is associated with three days of sentence reduction (Greek Penal Code, Art. 42).

In Italy, prisoners' wishes and attitudes must be considered for the job assignment (Art. 20 Law no. 354/1975 modified by Law no. 663/1986 & Art. 21 Law no. 354/1975); other priority criteria for work assignment are: length of time unemployed during detention, family burdens, professionalism, previous and documented activities carried out and those to which the prisoner will be able to devote himself after release.

In Sweden, as one interviewee reported, *"the main criterion for being selected to work on prison farms is to require the lowest level of security. However, short sentences are not desirable for agricultural work because there is often not enough time to teach prisoners the work, but above all a prisoner is obliged to carry out or take part in the occupation assigned to him"* (SE2).

Moreover, according to the Rödjan interviewee, prisoners can express a preference for the specific activity they want to do and they are assigned to that activity *"if they show to be responsible"* (SE2). In Sweden, the job is compulsory and there are no specific written criteria for accessing it.

4.7. Training of prisoners

Training is an essential element in the inmates' empowerment path as it allows them to acquire skills and knowledge that they could potentially be able to exploit after the detention period (Bhuller *et al.*, 2020; Council of Europe Development Bank, 2021).

In Sweden and Greece, the training of prisoners follows a practical approach; dedicated staff working in agriculture teach them and show them how the tasks need to be done and prisoners learn by doing. Moreover, prisoners are trained also according to their specific inclinations towards specific tasks.

In the case of Denmark and Italy, the approach is both theoretical through courses after which inmates get a participation certificate, and practical in the fields. In the case of Ancona and Sant'Angelo dei Lombardi, courses are carried out in collaboration with the regions where the prisons are located (Marche and Campania, respectively). Giving inmates a participation certificate is a tool to formalise the skills acquired and increase the chances of finding a job after the detention, and therefore have an easier reintegration into civil society.

From the interviews, it emerged that agricultural work has the peculiarity of having a wide range of tasks that require different skill levels, allowing the prison staff and administration to find specific tasks for everyone. However, the possibility of using skills acquired in the agricultural sector can depend on the context inmates go to afterwards; interviewees in Sweden, indeed, claimed that a very small number of inmates have found work on a farm after detention, as most came from an urban area where there are not many farms and other sectors are more attractive.

4.8. Working conditions

In Northern European prisons, inmates work for longer hours, with work taking most of their day, while in Italy and Greece daily hours range from 2 to 5 (Table 8). However, these data do not correspond to the situation in all prisons in the countries examined, since there are different organisations, opportunities and actors involved in the realization of work inclusion pathways.

As for the reward, in Denmark the hourly wage for incarcerated individuals is € 1.49, but it can increase over time, based on the skills acquired and consistency in work. Denmark is the only country in which the legislator has established the hourly rate for revenues; in the other case studies this choice is left to the competence of the prison administrations. In fact, the legislation only established that prisoners are entitled to compensation for the work performed. Therefore, the values indicated in table 8 for Sweden, Italy and Greece were reported directly by the interviewees. In more detail, in Sweden, prisoners get a monetary reward for their work of 13.00 SEK per hour (€ 1.15/h). In Viterbo prison (IT), in the case of the "Semi Liberi" project, inmates receive a minimum salary from the administration (€ 4.00 per hour, net of contribution to expenses) and a flat-rate remuneration from the cooperative. In Ancona (IT) prison, inmates are rewarded for their work with a minimum of € 4.30 and a maximum of € 6.32 per hour. In Sant'Angelo dei Lombardi prison (IT), inmates are paid €10 gross. In Greece, work is rewarded with a symbolic amount of € 1.76 per working day (4 hours).

Table 8. Working conditions.

Prison (Country)	Daily hours of work	Revenues/ hour (€)
Søbysøgård Fængsel (DK)	~8	1,49
Sønder Omme Fængsel (DK)	~8	1,49
Kragskovhede Fængsel (DK)	~8	1,49
Renbæk Fængsel (DK)	~8	1,49
Agrotiko Katastima Kratisis Agias – Grammateia (EL)	4	1.76
Casa di Reclusione Ancona Barcaglione (IT)	5	4.30-6.32
Casa Circondariale Viterbo Mammagialla (IT)	2	4.00
Casa di reclusione Sant'Angelo dei Lombardi (IT)	4	10.00
Anstalten Rödjan (SE)	7+	1.15
Anstalten Svartsjö (SE)	7+	1.15

4.9. Role of work and agriculture in the legislative system and advantages of agricultural work

According to our findings, work and training activities acquire different meanings. Primarily, work is seen as a means of providing prisoners with skills and abilities useful after the period of imprisonment, so that they can lead a life free of crime. Moreover, it is a way to train prisoners' ability to handle difficulties and problems which they might meet in civil society. The goal is to train them to be responsible, getting up, going to work on time, getting an instruction or taking feedbacks on their social skills. The Swedish legislative system summarizes this concept with the expression "bättre ut", which translates to "better out". The respondent for Swedish prisons said that: "*The meaning is that an inmate, during the detention period, should be more motivated to live a life that does not include criminal behaviour and have more tools to handle difficulties. They should be prepared to handle life and problems out in the real world and life outside prison. For prisoners, the feeling of being proud, accomplished and do difficult things is what makes them grow*" (SE2).

One of the main pieces of evidence gathered from our interviews concerns the empathetic attitude that agricultural tasks require from prisoners, as stated by another interviewee: *"These guys [administrative staff responsible for the agricultural activities] are very, very professional and I believe that actually, they also have a very positive impact on the inmates because they just care about their craft very, very much. And it's not building a shed or building something. It's handling an animal, handling nature, we have fields, we have everything. And the way that you had to attend these things and it's something that happens outside of your control. You have to work with these things with nature. With the animals, you have to do this in a very attentive manner"* (DK1).

Moreover, in accordance to previous studies (Auty, Liebling, 2020; Hill, 2020; Lee *et al.*, 2021), work is considered a resocialization factor and a way to maintain a relaxed and safe environment. According to the point of view of prison staff, engaging in a structured daily regimen, characterized by the temporal patterns of employment, facilitates the reconstruction of an environment akin to that experienced in the external societal context: *"When you have a big prison and then people just sit doing nothing, then this creates quite a violent environment because grown men mostly […]; the fact that the prisoners have somewhere to go, every day and something to do helps to create what we call "dynamic security". It's not so much something you can call the security of prison guard, but it's a security of keeping the inmates sort of busy, part of a structured and respectful environment, meeting them respectfully etc."* (DK1).

This approach is in line with the European Prison Rules and with the Recommendation of the Council of Europe Committee of Ministers Rec (2003)23, 18.a: in particular, so-called "dynamic security" is defined as "the development by staff of positive relationships with prisoners based on firmness and fairness, in combination with an understanding of their personal situation and any risk posed by individual prisoners". The phenomenon has also been analysed by the United Nations Office on Drugs and Crime in the Handbook on Dynamic Security and Prison Intelligence (Bryans, 2015). It is a broad concept, but we would like to report some institutionally recognised key elements. The UN considers that dynamic security is based on:

- Positive relationships, communication and interaction between the staff and prisoners
- Professionalism
- Collecting relevant information
- Insight into and improving social climate of the penal institution
- Firmness and fairness
- Understanding personal situation of the prisoner
- Communication, positive relations and exchange of information among all employees[7].

The participants in our exploratory study confirmed the positive value of the dynamic security approach, as suggested by the above-mentioned guidelines.

Regarding the value of work, a respondent stated that the main reason why prison farms are still in service is that they can always offer a job to everyone and train prisoners' social skills: *"The goal is to train them [inmates] to be in a work place: get up, go to work, get an instruction, take feedbacks so that you train their [of inmates] social skills. It is important for them to feel needed and that they do meaningful work because what they do is for their customers. It is important that they feel what we feel outside, to be needed and useful and meaningful, not that they produce things that go to the garbage"* (SE1).

Again, the Danish interviewee claimed that: *"Work is resocialization. It is so because we also incorporate work and skill training in the work, but it is also just being a part of a workplace, having this structured routine to have a resocializing effect"* (DK1).

Lastly, interviewees reported that work is a means of empowerment because prisoners are entrusted with important work execution and planning tasks and in particular, agricultural work, that involves caring for plants and animals in a professional manner, which contains this empowering value and activates processes of gradual assumption of autonomy and responsibility. An intriguing moment emerged during the interview, when one participant articulated: *"Sometimes it's hard for us to understand as well, and people don't always agree, but with the example of farming, you would say our farms are commercial. I mean, they are there for a reason, they have to have a high quality, they have to sell the milk to ARLA…[big buyer], so it has to have a certain level of quality. And the belief is that if you do this commercially it resembles more a real job and it's more meaningful for inmates to work in this environment than if they were just to do something that wasn't meaningful or create something that you can just throw away [...]. So, they are actually able to use this economic flow and use it to organize their work"* (DK1).

4.10. Networking

SF initiatives that adopt an inclusive paradigm also leverage networks to provide beneficiaries with the

[7] Prison Administration, Ministry of Justice, Republic of Croatia, Dynamic Security in Penal Institutions, Presentation at 7th conference of European Penitentiary Training Academies, 25-27 June 2014, Barcelona, Spain.

chance to engage in and cultivate positive interactions with entities external to the organisation (such as farms and various stakeholders within the food supply chain, social cooperatives, consumers, etc.). This choice has two main effects: the recipients can expand their network of relationships; social stigma around diversity can be reduced. However, our experience suggests that in the case of prisons, networking can be particularly difficult due to the specific context. In the examined experiences, the prisoners are only involved in the marketing of products, as in the case of Viterbo prison (IT), where the collaboration with the cooperative O.R.T.O. includes the involvement of experts and agronomists from the University of Tuscia, particularly about the processing of raw materials.

Another interesting experience is the social garden initiative in Ancona (IT), that receives support from the regional administration and a professional agricultural organisation. The respondent testifies that during some events, such as the Christmas holidays, inmates with a low level of security can participate in village markets, having a chance to have direct contact with society outside the prison. According to the Ancona interviewee, the search for work outside prison should be increased, favouring companies that hire prison labour.

The Sant'Angelo dei Lombardi prison has developed several collaborations with local public bodies, such as the Federico II University in Naples for some courses, and with two institutes: the Vanvitelli in Lioni (hotel management) and the De Santis in Sant'Angelo (accountancy) that give lessons to inmates who are unable to leave, while the art. 21 inmates can go to the institutes themselves.

5. DISCUSSION

The results showed two different approaches to agricultural activity in prisons, both also characterized by a strategy of economic and value return: the first, specific to North-European prisons analysed, is characterized by large-scale productions; the second, present in the Mediterranean experiences, regards niche productions. Although the specificity of production is not mentioned as a crucial element of SF, our study reveals and confirms that it can take on specific value and thus have a special effect on inmates.

When it comes to sales channels, Northern European prisons target the large scale, favouring supermarkets, the agri-food industry and wholesalers. In the Mediterranean countries, on the other hand, prisons sell their products mainly through farm shops, specialized shops, farmers' markets and prison economy e-commerce. The market they rely on is certainly niche, compared to Northern European institutions that are more open to the competitive market. The two sales models are adapted to the quantity of products and possible commercial outlets in that given area. Only three of the prisons analysed are selling their products under a trademark that allows them to make their products recognizable in the market. Among the sale channels, local retailers are those preferred by all prisons analysed except for Sant'Angelo dei Lombardi (IT). As demonstrated in the existing literature (Giarè *et al.*, 2018), this suggests the great importance of creating links with the local context for the inclusion of prisoners in the local community where the prison is located, reducing the isolation that often characterises prison settings. Similarly, the representative for Ancona Barcaglione (IT) prison testifies that promotion activities and events where inmates meet the local community are *"occasions of work and have a high emotional impact"* (IT2).

From the interviews, it emerged that the awareness that they receive economic income from their work – even if it is managed by the prison administration – gives inmates a sense of usefulness and responsibility for their occupation. It can also show them that they are contributing to and committed to a real business. Thus, also economic revenues can represent an important element referable to SF.

With regard to the work organization and selection process of inmates, in some experiences, such as for Rödjan and Svartsjö prisons, inmates' engagement in the management of agricultural activities promotes feelings of responsibility and self-esteem in them. At the same time, when selection criteria also include personal skills and attitudes, the likelihood of inmates' improvement and active involvement in work activities is greater. Both factors contribute to a higher quality of life for prison inmates.

Similarly, working conditions are mainly set by national standards and are not specific to agricultural activities. Nevertheless, it is possible to highlight how the interviewees have placed emphasis on the rehabilitative purpose of prison work (in compliance with international and European guidelines) and the re-socialization power of working conditions, such as daily working hours and inmate pay (even when merely symbolic).

Training and the role of agricultural work activities for prisoners verified that in the experiences considered these represent two important factors useful for prisoners' rehabilitation and are also included in the concept of SF. Training programmes – which can be theoretical and/or practical – are viewed with high regard, as is work engagement: all representatives involved confirmed that these elements can contribute to inmates' feelings of meaningful efforts.

On the other hand, agricultural work in the prison context differs from SF in others because it is less able to engage recipients (inmates) in relationship-intensive activities, such as direct sales, events with local communities, participation in fairs or exchange with other farmers, etc. In fact, with the exception of the Italian experiences examined, characterised by collaboration with social cooperatives and a few sporadic opportunities for inmates to meet with external actors (local markets during the Christmas holidays, in the case of the Ancora prison under Article 21 Law no. 354/1975.), the prisons in this study only involve inmates in cultivation and/or breeding practices, and in product processing, when present. Thus, with regard to this aspect, it would be useful for current penal systems to increase opportunities for inmates to have relations with other actors and meet customers.

The life of prisoners inside prison is a rather controversial topic in the scientific literature, as well as in public opinion. The prison system – in Europe and abroad – differs between countries, for historical and cultural reasons and social structure. It remains undoubted, however, that imprisonment is a trying experience for the individual, for various reasons. First of all, isolation. Work in this context has represented (and we do not exclude that in some cases it may still represent) a means of exploitation and punishment in order to compensate for the damage caused by the guilty party towards the community as a whole. However, a different value has been attributed to it over time: work can be a tool for the recognition of one's own abilities and therefore for obtaining a "clean" autonomy, far from irregularity and illegality. Conversely, the rehabilitative potential of agricultural work in prisons is not just a matter of acquiring manual skills or executive abilities, but of knowing and understanding the importance of work as a difficult affirmation of self.

The explorative analysis allows us to say that the agricultural activities conducted in these prisons can be considered at least partly as SF, given their characteristics. It is also important to note that our study collected testimonies from practitioners, administrative staff and external operators (a representative of a cooperative and agronomists), who present a "different" point of view from the inmates, who are directly affected. However, the interviews confirm some of the existing literature on the issue. In general, the interviewees regard agricultural work in the prison context favourably, even if there are some regulatory limitations. The analysis allows us to infer that agricultural activities in prison mainly contribute to improving the condition of prisoners.

6. CONCLUSIONS AND IMPLICATIONS

The explorative analysis aimed to catch some characteristics of agricultural work in European prisons and compare them with Social Farming ones. The study provides an initial overview of the agricultural activities conducted within European prisons. Specifically, it identifies the unique characteristics of each programme, both in terms of the social and agricultural aspects, to highlight similarities and differences with SF initiatives. Examples include the direct involvement of prisoners in work organisation and certified training programmes, as well as the possibility of selling the products they cultivate. This enables inmates to attribute meaning to their efforts, thereby rediscovering the intrinsic value of work – namely, contributing to collective welfare and justice. Among the challenges mentioned by the interviewees, it is important to emphasise that the specific administrative structures can significantly hinder the creation of an effective workplace. The execution of work activities is often constrained by the availability of staff and the necessary security measures, which also limit potential interactions with external actors.

Furthermore, the analysis highlights that prison-based agricultural activities are not particularly open to the outside world, which contrasts with the inclusivity often found in Social Farming practices. This is partly due to the security systems and controlled procedures required within the prison context, although some institutions do allow inmates to maintain relationships with external actors. Our analysis of agricultural activities, according with previous studies, shows that penal institutions able to build networks with local communities, works in prison benefits both the inmates, who are exposed to a broader range of human interactions, and members of civil society, who can gain a better understanding of the prison environment.

The study offers the possibility of grasping some elements presented both in SF practices and prison work, such as purposes (inclusion, re-education, empowerment, etc.), type of activities (training, agricultural and related activities, engagement in the work organization), organization of activities, networking with external actors to a straight re-educational process (relational aspects and re-socialization). Further in-depth studies could provide the opportunity to understand if and how the elements differ and how SF practices could contribute to the development of effective agricultural activities in prisons.

Policies can play a significant role in developing new approaches to address both agricultural and social issues. However, at EU country level there are no specific laws on SF, except in Italy, while local health and social systems offer different opportunities and economic support for the implementation of SF initiatives. Due to the importance and complexity of the issues, further studies could be focused on the topic, in order to compare the situation at European and international level.

The analysis had an exploratory approach using online surveys and interviews with prison staff, given the evident difficulty in contacting and involving prisoners. Consequently, the results come from the unique perspectives of the management and staff responsible for agricultural activities and may be very different from – or opposing – those of prisoners. In order to capture interpretations and experiences of these agricultural programmes or initiatives by prisoners, a specific study should be conducted. A more specific analysis could also allow us to fill the gap related to technical information (e.g. percentage distribution among end users or food consumed in prisons) or methodological or ethical issues (e.g. level of involvement of prisoners). In particular, addressing the issue of income generation in different countries, also considering the literature on prison labour exploitation, could offer the opportunity to understand whether prison workers' rights have the same level of satisfaction compared to the outside and how social agriculture could contribute to create a more inclusive and fairer context.

In conclusion, our work contributes to the improvement of existing scientific research on the topic, because – despite the limitations – to our knowledge, no previous study has linked the experience of agricultural work in prison to the characteristics of Social Farming. This element is important to understand the different declinations of SF in European contexts.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at doi: https://doi.org/10.36253/rea-15329. This includes the appendices that are referred to in the main text of the article.

AUTHOR CONTRIBUTIONS

M.A.: Investigation, Conceptualization, Methodology, Data curation, Writing-Original draft preparation. F.F.: Investigation, Conceptualization, Methodology, Data curation, Writing-Original draft preparation. F.G.: Conceptualization, Methodology, Visualization, Supervision. G.G.: Investigation, Conceptualization, Methodology, Data curation, Writing-Original draft preparation.

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Short communication

'No farmers, no food': a sentiment analysis of the 2024 farmers' protests in Italy

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Abstract. Starting in January 2024, street protests by farmers' groups spread in several European countries. The demands, which started from rather specific aspects, have broadened to involve economic, environmental and geo-political considerations, calling the already weakened European Green Deal even more into question. Starting from an analysis of the motivations for the protests and the responses provided by national governments and European institutions, the article tracks the main arguments that characterized the motivations of the so-called 'tractor protests', through the methodology of Sentiment Analysis applied to the social network of accounts (specifically, X) relating to different categories of subjects interested in the debate. The results indicate a generally positive sentiment, characterised by trust and anticipation, suggesting potential for improving the relationship between society, institutions, and the conditions of farmers. Farmers remain at the centre of the debate, which focused on two key areas: the economic and competitive conditions of agricultural businesses, and the compatibility and economic sustainability of the environmental regulations embedded in European policies. The research revealed that the demands were somewhat fragmented and inconsistent. Nevertheless, the protests, although short-lived, had a significant impact by prompting European institutions to steer environmental and agricultural policies in new directions. Additionally, the research highlights that innovative investigative methods can be effectively applied to examine the interplay between the technicalities of public policies and collective perceptions.

Keywords: farmers' protests, agriculture, social media, European Union, Italy, sentiment analysis.
JEL codes: Q18, Q17, O13.

HIGHLIGHTS

- The 'tractor protests', which have taken place in several European countries since January 2024, have been characterised by an important role of the social media.
- Sentiment Analysis applied on X posts by relevant stakeholders has been used to understand the common reactions to the farmers' protests.
- The results highlighted that most sentiments were positive, especially for specialized media and Members of European Parliament.

- The Sentiment Analysis highlights that the economic and social condition of farmers, and their place in the overall economy, were the prevailing aspects.

1. INTRODUCTION

The recommendation by the European Commission (EC) to exclude agricultural emissions from the reduction of greenhouse gases by 90% by 2040 and the withdrawal of the halving of pesticide use are rather clear evidence of the apparent success of the protests of farmers affecting several important European Union (EU) Member States (MS), including Germany, France, Belgium, Italy, Spain, Poland and Portugal, since January 2024. Beyond such apparent success, it is worth investigating what the main arguments have been, the most active actors and the reactions of different categories of stakeholders to the farmers' protests. The protests have radically questioned the latest EU decisions and policies on environment and agriculture, such as the Green Deal, Farm to Fork and Common Agricultural Policy (CAP), and especially on their lack of answers to the long-standing issue of agricultural incomes instability. This theme has been in opposition to the issue of sustainability in agriculture and ecological transition. Such opposition requires proper thinking, also considering the flexibility the new CAP intends to offer to the MS and their farmers (De Castro, 2020; Cagliero *et al.*, 2023). In Italy, given the relevance of small farms in terms of number of units and their contribution to production and land stewardship (Henke, Sardone, 2022), a crucial aspect of the protest has addressed the future role of small-scale farming activity. In this context, the social media and informal organizations have assumed a particular importance in orienting and manoeuvring the public debate. As Matthews states (2024a: 83), 'this leaves the door open to the potential for disinformation by outside actors (via social media) as well as attempts to influence the protests by non-farm groups'.

Provided that the impact of narratives on food systems is powerful (Mazzocchi *et al.*, 2023), we aimed at reconstructing the main arguments during the protests through a textual-analysis methodology, to catch and interpret the general attitude towards the protests emerging in social networks. In this context, it is important to report that the protests have left their mark not only in their influence on the recent European elections, but also in several high-level documents, including the CE President von der Leyen's political guidelines, and the report 'A shared prospect for farming and food in Europe' published in September 2024 in the framework of the Strategic Dialogue on the Future of EU Agriculture (Strohschneider, 2024). However, the protests have faded from the headlines and reconducted within the traditional frames of technical and specialised organs.

During the protests, tractors blocked roads and supermarkets, protests received massive media attention, and slogans such as 'no farmers, no food' resonated widely in the public debate (Finger *et al.*, 2024). This article tracks the main arguments that characterized the motivations of the so-called 'tractor protests', through the methodology of the Sentiment Analysis (SA) applied to posts on social network accounts (specifically, X) relating to different categories of subjects interested in the debate. The study is motivated by the perception that the debate was influenced by the public media debate during the central months of the protests. It is precisely this element of novelty that is the core of our analysis and opens the doors to innovative methods of investigation applied to the relationship between the technicalities of public policies and collective perception. Although referred to the Indian context (Neogi *et al.*, 2021; Singh, 2022; Sresta *et al.*, 2024), the Sentiment Analysis has already been tested as a valid methodology to analyse massive amounts of unstructured reviews and convert them into meaningful opinions (Tiwari, Nagpal, 2022). Nevertheless, the research does not intend to explore the policy implications of the protest, nor the outcomes it has produced within the European Parliament (EP) or, more generally, in European policies.

2. FROM PROTESTS TO RESPONSES

2.1. The origins and dimensions of protests

Although seemingly initiated by a rather jagged series of specific issues in some MS, the protest has converged on some demands, yet patchy, calling for a change in the directions assigned to European agricultural policies by the recent CAP reform and the agricultural elements of the Green Deal (Matthews, 2024a; Finger *et al.*, 2024). The protest has been recognized by the EC as 'a crisis situation in EU agriculture', paving the way for two prevailing lines of considerations: one includes a wide series of economic issues, from farmers' income to increased production costs, passing through competition with non-EU countries; the second involves the more general social pact between farmers and society based on the supply of and demand for social, environmental and economic complementary services provided by farmers.

On the first point, there is much discussion about the importance of the economic sustainability of agricultural activity so that all related services of an environmental and social nature can be ensured (Finger, El Benni, 2021). Matthews (2024b) sought to shed light on the state of agricultural incomes in Europe, challenging the prevailing narrative of small and medium-sized agricultural enterprises being under immense pressure due to a multitude of crisis factors, including the pandemic and ongoing wars, compounded by the structural crises of European family farming (Antošová *et al.*, 2021). Matthews' perspective stands in contrast to the mainstream view. Contrary to large part of protests' narratives, agricultural incomes in Europe, and in most MS, have remained stable or even grown since 2005, despite the rising costs of intermediate inputs. This analysis fails to account for non-agricultural income, which significantly impacts the household income of farm families, potentially confirming or offsetting the positive trend observed in strictly agricultural income. Indeed, Eurostat income indicators reveal a surprising positive trend, moving in unison. The two numerators of these indicators, agricultural income and entrepreneur's income, show little difference in growth rates; when reported per work unit, the percentage growth is even more evident (Matthews, 2024b). Agricultural income and entrepreneur's income grew by 84% and 119%, respectively, between 2005 and 2023, with the surge in income occurring precisely from 2020 onwards, contrary to what happened in sectors such as construction. These dynamics, however, are due to the sharp decline in total and family labour force in Europe over the years considered. Among the economic elements, there is the failure to recognize a fair price for farmers within the agri-food chains. According to a prevailing narrative during the farmers' protests, this is attributed to financial speculation on raw materials, the failure to recognize the principle of equivalence of environmental and trade union standards in international trade, and, to a lesser extent, the value-added distribution mechanisms dominated by large-scale retail chains (Ferroni, 2024).

The second issue is the rapidly changing relationship between agriculture and civil society (Strohschneider, 2024), to the extent that the protests have surfed the general discontent on the perceived burden of environmental regulations and restrictions. Agriculture is ideally entrusted with a more complex and composite role than simply producing food, textile fibres, and raw materials for supply chains (Van Huylenbroeck *et al.*, 2007), providing social and environmental services that often take on the features of public goods (Sotte, 1997; Henke, 2004). The social recognition of such a role corresponds to a broadening of the justifications for public spending, which therefore shifts from supporting the status of farmers as 'objectively' disadvantaged to remunerating the production of services demanded by citizens and for which taxpayers are willing to pay (Sotte, 2023). This new concept of agricultural support, which has increasingly favoured measures for environmental and rural land interventions, relies on a complex system of regulations and incentives that, according to farmers, drops its administrative burden precisely on the actors of the production phases. It is worthwhile recalling that the ecological transition pledged by the EC is a long and complex path and concerns an articulated balance between economic, social and environmental objectives that often show apparently irreconcilable trade-offs (Kanter *et al.*, 2018). Nevertheless, a large part of the protests has focused on the effects of environmental regulations in terms of increased administrative burden and lower revenues due to smaller cultivable areas to leave room for natural elements in favour of biodiversity (consider, in this regard, the revision of the Good Agricultural and Environmental Condition – GAEC – standards of the CAP). This has happened despite the fact that it is now recognised that the ecological transition can no longer be postponed for long, and that European agriculture must continue on its path of strengthening the elements of sustainability in a clearer and more systemic way. Furthermore, concerns about prioritizing food production after the Ukraine war, coupled with the perceived burden of environmental regulations, fuelled opposition to the EC's legislative proposals for achieving goals outlined in the Farm to Fork and Biodiversity Strategies. The apparent success of the protests and the almost immediate abandonment of some of the positions most favourable to a sustainable transition – with a speedier pace than the traditional path dependency of the CAP (Henke *et al.*, 2018) – should be carefully analysed, with a focus on what the future consequences could be.

2.2. The responses

Overall, farmers' protests have caused a shift in the EU's political landscape. This is evident in the slowdown of the Green Deal legislation, the watering down of certain environmental measures within the recent CAP reform, and the implementation of stricter limitations on agricultural imports from Ukraine. However, some analysts (Matthews, 2024a) point out that the responses implemented by the EC and national governments, while consistent with the political shift that led to the sacrifice of several Green Deal elements, were hasty, limited in scope, and aimed primarily at quelling the protests.

In response to the economic motivations behind the protests, in March 2024 the EC presented proposals to improve farmers' remuneration and their position in food supply chains. These included the establishment of an Agriculture and Food Chain Observatory to examine production costs, margins and trading practices in the agri-food sector, potential modifications to the Common Market Organizations regulation, and a possible revision of the Unfair Commercial Practices Directive. Furthermore, in the wake of the protests, some MS took action, capitalizing on the momentum of the demonstrations, to call for the relaxation of certain unfavourable conditions, such as Italy's request to the European Council for a moratorium on agricultural business debts.

As for the second group of motivations, the proposal for a Sustainable Use of Pesticides Directive, which aimed to establish reduction targets for MS, was rejected by the EP and subsequently withdrawn by the Commission. The Nature Restoration Law Directive faced a more complex fate. While it ultimately passed the Parliament due to divisions within the EPP group, key targets related to agricultural ecosystems were significantly weakened or eliminated through political compromise with the Council. Despite an initial agreement, several MS later withdrew their support, casting doubt on the Council's final approval. The Industrial and Livestock Rearing Emissions Directive, despite approved in its watered-down version, gained some traction, securing approval by the Parliament and anticipated endorsement by the Council. However, the Commission's proposed expansion of the Directive's scope to encompass larger livestock units and additional industrial pig and poultry facilities was largely rejected. Finally, the EC opted to postpone the introduction of a Framework Law on Sustainable Food Systems, initially intended to integrate sustainability principles across all food-related policies, until its next mandate. These setbacks highlight the ongoing challenges within the EU in achieving a comprehensive and ambitious approach to sustainable food systems (Matthews, 2024a).

In this framework, in response to the February 1st 2024 European Council meeting, which urged the Council and Commission to address challenges in the agricultural sector, the EC proposed a series of amendments to the CAP regulation agreed upon in 2021 and implemented since 2023. These amendments include simplification measures to reduce the administrative burden of inspections and controls for both farmers and national administrations, and relaxation of the GAEC standards that farmers must meet to be eligible for direct payments. In parallel with these regulatory changes, the Commission has launched a survey to gather farmers' perspectives on the administrative burden imposed by regulations. Additionally, the EC is actively developing measures to improve farmers' position within the food chain and protect them from unfair trading practices. Proposals addressing these concerns are expected to be presented shortly and will cover areas such as market transparency, trading practices throughout the value chain, and production costs. Additionally, on 25 January 2024, a Strategic Dialogue on the Future of Agriculture was launched at the initiative of the Commission President von der Leyen, managed by a forum tasked with defining a shared vision for the future of the EU agricultural and food system and to overcome the polarization that currently characterizes agricultural policies.

3. METHODOLOGY AND RESULTS

A collection of 4,260 Italian posts was carried out from X by means of X-APIv2 Basic (X Developer Platform, 2024) from January the 1st to March the 17th 2024. These posts were initially selected by following 56 X accounts composed of Members of European Parliament (MEPs) (for the 2019-2024 mandate), journalists, opinion people, social partners, specialized media and successively reduced to 477 posts by using keywords[1] more focalized to the protest.

The strategy of analysing the posts consisted in a mixed approach of Sentiment Analysis Classification (SAC) and Text Mining-Clustering (TM-C; Gupta, Lehal, 2009; Mandják *et al.*, 2019; Younis, 2015). SA has emerged as a new tool for analysing Web 2.0 information (Cambria *et al.*, 2017) and it has the main objective of classifying opinions, social media posts or simply sentences as positive, neutral, negative (Liu, 2015). Specifically for SAC the affective lexicon NRC Emotion Lexicon[2] (Mohammad, Turney, 2013) was applied. SA and TM-C are additional methods for textual data processing to reveal unknown patterns within the elicited texts by means of the words' co-occurrences (Illia *et al.*, 2014). The automatic textual analyses were performed by the

[1] Two levels of keywords were used to select the post. The first level is comprised of terms like: "trattori, protesta, proteste e agricoltori". The second level includes terms like: "agricoltura, ambiente, ambientale, ambientali, cibo, agroindustria, aziende agricole, Bruxelles, contadino, contadini, eco-schemi, eco-schemi, esenzione, esenzioni, estero, Europa, europeo, europea, Farm to Fork, green deal, Irpef, normativa, normative, manifestazione, manifestazioni, marcia, mercato, mercati, milleproroghe, presidio, sostenibile, sostenibilità, prezzo, prezzi, reddito, redditi, transizione ecologica, politica agricola comune, sussidi e gasolio". The posts were selected when: a) at least a term of the first level was present; b) at least a term of the first and the second level was present; c) at least two terms of the second level were present.

[2] This lexicon was recently updated in August 2022 with automatic translations from English to 108 languages and it embodied eight basic emotions other than the polarities positive and negative. The NRC lexicon is available here: http://saifmohammad.com/WebPages/NRC-Emotion-Lexicon.htm

Table 1. Accounts and posts.

	Accounts				Posts on X			
	n	(%)	Topic 'Protest	(%)	n	(%)	Topic 'Protest'	(%)
Journalists	3	*5.4*	2	*4.6*	390	*9.2*	6	*1.3*
Specialized media	14	*25.0*	11	*25.0*	600	*14.1*	55	*11.5*
Opinion people	12	*21.4*	11	*25.0*	1,035	*24.4*	179	*37.5*
MEPs	19	*33.9*	12	*27.3*	1,895	*44.6*	140	*29.4*
Social partners	8	*14.3*	8	*18.2*	330	*7.8*	97	*20.3*
TOTAL N	56	*100*	44	*100*	4,250	*100*	477	*100*

Figure 1. Sentiment Analysis Classification – Polarities (%).

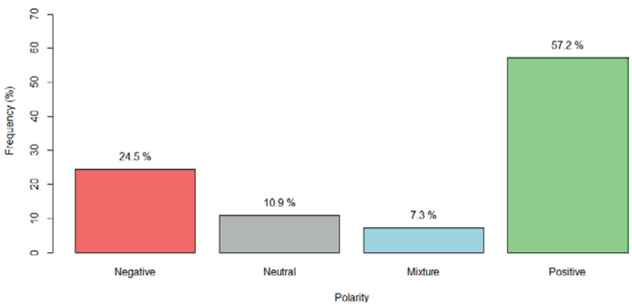
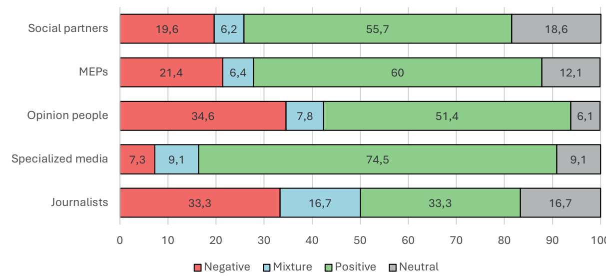


Figure 2. Sentiment Analysis Classification by account categories.



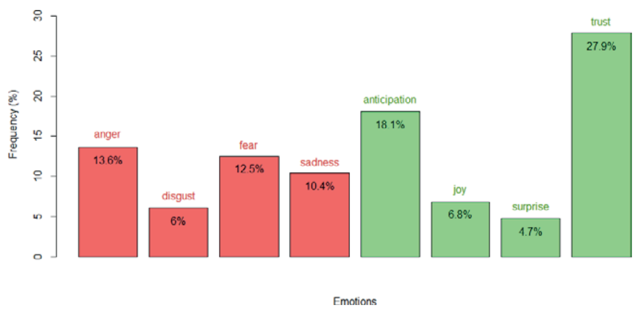
software R (R Core Team, 2021) and IRaMuTeQ version 0.7 alpha 2 (Ratinaud, 2014).

Table 1 reports the posts and accounts distributions. The number of accounts is reduced to 44 out of 56. Figure 1 depicts the SAC polarities with 57.2% positive views, 24.5% negative, 10.9% neutral and 7.3% a mixture between positive and negative.

Looking at Figure 2, the distribution of accounts by polarities highlighted that despite the positive feeling generally found across all categories, the specialized media showed the highest percentage (74.5%) whereas opinion people and journalists the highest negative ones (34.6% and 33.3%). Journalists also showed the same percentage of positive polarity (33.3%) while social partners the highest level of neutral posts (18.6%) very close to the percentage of negative polarity (19.6%).

The NRC lexicon furnishes also eight basic emotions within each polarity depicted in Figure 3. Although the protest released more or less uniform negative emotions like anger, fear and sadness, it has also generated a high level of trust and anticipation of possible positive outcome, often in terms of policies[3].

Figure 3. Sentiment Analysis Classification – Emotions by polarities (%).

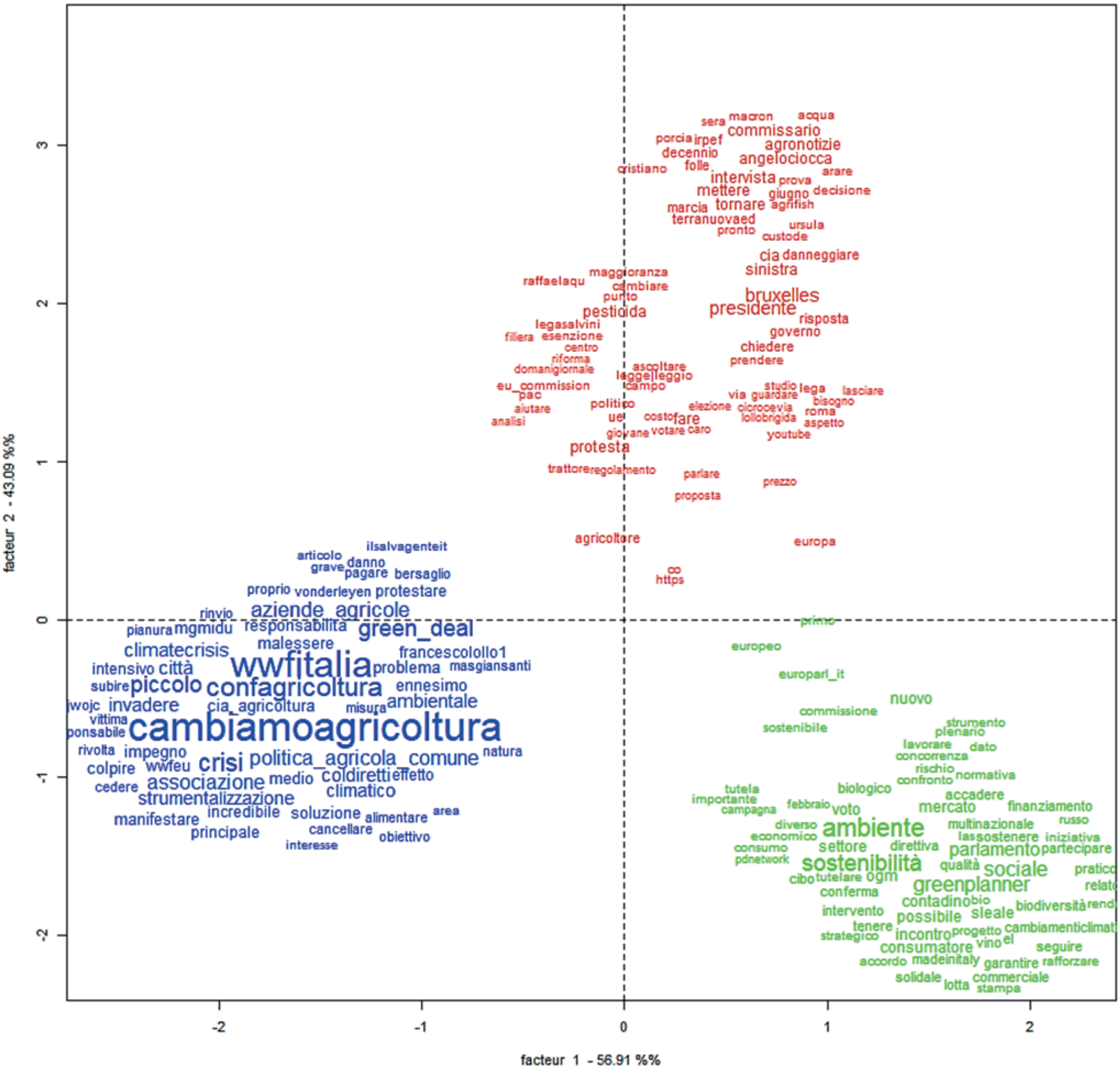


Figures 4-5 depict TM-C solutions on the entire collection of 477 posts.

The TM-C yielded a robust statistical result based on the hierarchical descending classification (HDC) algorithm throughout the Chi-squared distances to group the posts into common and independent clusters. Each cluster represents a homogeneous view of the protest because the internal vocabulary of the posts is similar.

[3] Example of anticipation post: "I agree with the president's words on the importance of strategic dialogue with farmers. I support the need for environmental sustainability that includes social, productive and economic aspects. Farmers and the environment are allies, not adversaries". Example of trust post: "Brussels for a fairer common agricultural policy for workers, farmers need the European Union and its common agricultural policy as long as the latter places as a priority respect for the rights and protections of anyone who works in the fields"

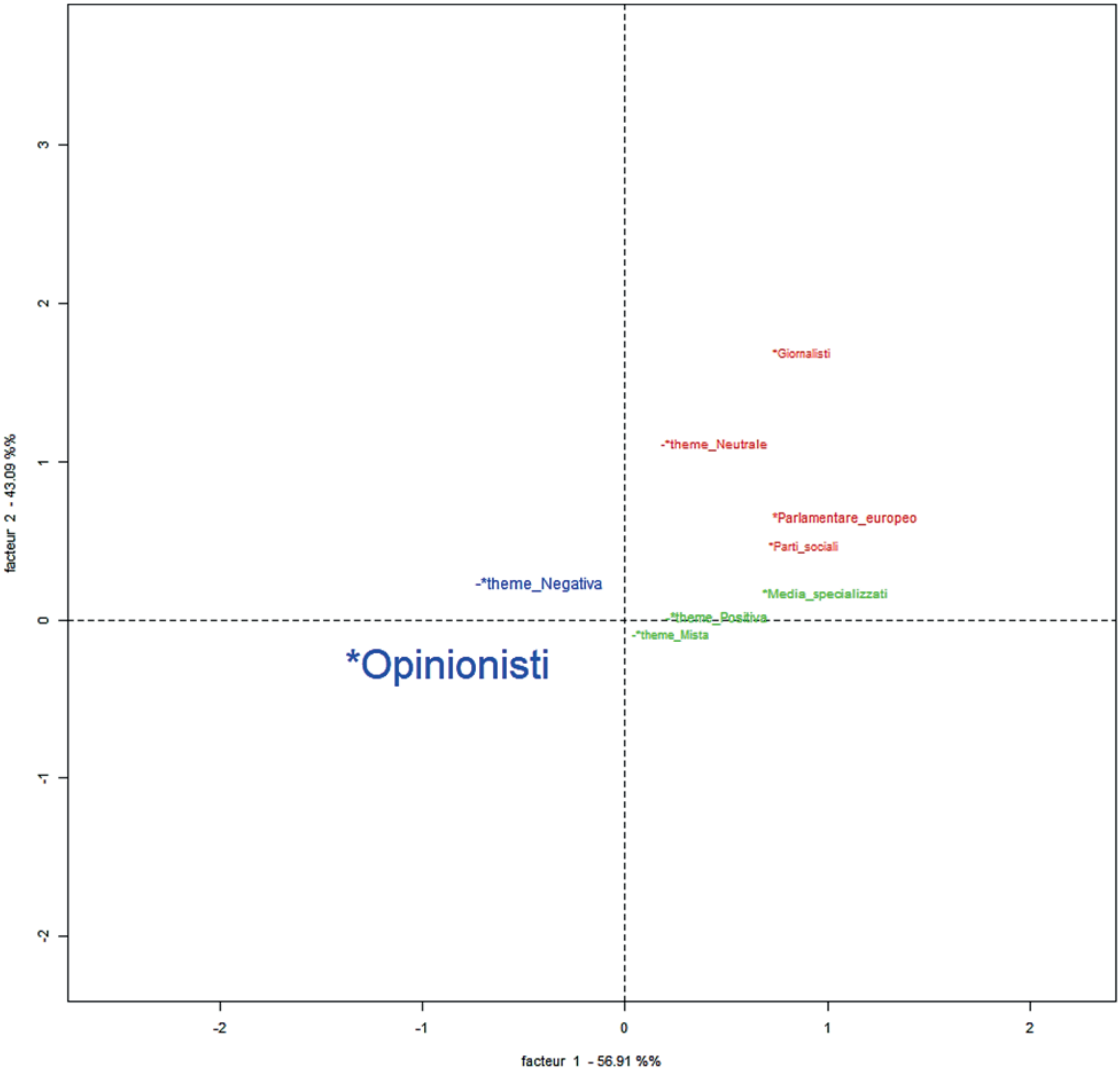
Figure 4. Correspondences Factor Analysis diagram between clusters identified in the polarized posts. English language equivalents are reproduced in Table A.1.



Figures 4 and 5 respectively depict the correspondence factorial analysis diagrams of the clusters wording and the variables that characterize them (i.e., the accounts categories and polarities of the posts are the two variables that initially grouped the posts). The classification stability provided a solution with 75.13% of the words segments correctly classified. Hence, the three clusters were very homogeneous and distant from each other.

The green cluster is the one with more terms (35.4%), is defined by positive and mixture polarity and is mainly composed of specialized media (see Figure 4) who draw attention on the multiple domains of sustainability, ranging from environmental sustainability to market and consumers. As a matter of fact, the most important words, i.e. the biggest in Figure 4, the most important and concatenated words with the others within each cluster are: *ambiente* (environment), *sostenibilità* (sustainability), *parlamento* (parliament), *mercato* (market), *consumatore* (consumer), *sociale* (social), OGM, (GMO) and *multinazionale*

Figure 5. Correspondences Factor Analysis diagram between clusters identified in the polarized posts and account categories. English language equivalents are reproduced in Table A1.



(multinationals), with hashtags like '#ogm, #cambiamenticlimatici and #madeinitaly'. The red cluster is the second with more terms (33.5%), is identified by neutral posts and is mainly composed of MEPs, social partners and journalists. The most important words and hashtags are: *presidente* (president), *fine* (end), *protesta* (protest), *intervista* (interview), *pesticida* (pesticide), *sinistra* (left), *commissario* (commissioner), *chiedere* (ask), #Bruxelles, #cia, #agronotizie, #angelociocca (MEP), #UE'.

The blue cluster is the least numerous with 33.1% of the terms, is distinguished by a negative polarity and predominantly composed of opinion people who place their attention on: a) problematic issues regarding the inequality of the CAP; b) the bad role of the agricultural associations that take advantage of this situation to use the farmers' disappointment for holding back the ecological transition; c) and even responsibility is given to farms with intensive livestock that work against the environment that: 'non possiede trattori per invadere le città' (i.e., quoting a post that says 'it – the environment – has not tractors for occupying cities').

3. DISCUSSIONS AND CONCLUSIONS

Back in 1999, Tim Lang stated that food policy "cannot be understood as an issue of consensus. It is, and almost always has been, a battleground of competing interests" (Lang, 1999: 217). These conflicting interests were starkly highlighted during the tractor protests. Far from promoting a 'win-win' logic, which invokes the concept of supposed food sovereignty – much like the Smithian invisible hand, assumed to systematise and effectively develop the agri-food system for all – one of the most significant outcomes of the protests was to bring into public debate the inherent lock-ins and trade-offs between different sustainability objectives within the food system (Herring, 2015). The European Parliament, recently elected for the 2024-2029 legislature, faces critical challenges regarding the future of the European food system. As the Strategic Dialogue on the Future of EU Agriculture acknowledges, the transition of agri-food systems inevitably involves conflicting interests and complex trade-offs, which can only be addressed through compromise (Strohschneider, 2024).

On the one hand, the results of the research show rather jagged and scattered demands and requests, in which economic grievances are juxtaposed with an unstable and rapidly changing geo-political context. On the other hand, while historically agricultural policies, especially at the national level, have been characterised by a rather close relationship between farmer unions and Ministries of Agriculture (Matthews, 2024b), today's negotiations and demands involve a series of new actors with different priorities, including environmental agencies and interest groups but also public health advocates and climate activists. At the same time, even at the European level relationships have become more complex, with the augmented role of the Parliament which gave rise to the so-called trilogue between Parliament, Commission and Council.

The results highlighted that most sentiments related to the 'tractor protests' were of positive polarity (57.2%), especially for the specialized media and MEPs. The prevailing positive sentiment is trust, followed by anticipation, two sentiments that suggest positive expectations for the improvement of the relationship between policies and farmers' conditions. Despite lower than positive sentiments, the prevalent negative feelings are anger and fear. These are expressed to a greater extent by commentators and journalists, confirming the coverage of the climate of protest given by the media, characterized both by symbolic acts, slogans, demonstrations in the streets, tractor parades, and by more aggressive gestures, especially in France and in front of the headquarters of the European institutions.

Three different representations and nuances that the media have given to the protest have been provided by the clusters. The green cluster, mainly characterized by the specialized media, which expressed the highest percentage of positive sentiment, focuses on the aspects of environmental sustainability and the relative role of consumers and economic conditions. The word GMO also appears in this cluster, a sign of how the protest has also called for issues that have mature and shared legislation and debate, putting even opposing positions on the same scale. In fact, in Italy no GMO can be cultivated for commercial purposes as foreseen by the regulation of GMOs in the EU. The red cluster is predominantly neutral and the categories that most characterize it are journalists, social partners and MEPs. The lemmas appear less compact and therefore the discussion seems to have been more scattered and fragmented, focusing from time to time on specific points. However, it should be noted that the crucial words 'protest' and 'tractor' are found in this cluster, demonstrating how the discussion was rather broad and chaotic. The blue cluster, dominated by opinion leaders with negative sentiment polarity, is characterized by a strong relevance of sector organizations and the main social partners involved in the themes of agricultural and environmental policies. It is a very compact cluster, where a rather accentuated narrative is found on climate-environmental issues and the relative different positions expressed by subjects pursuing different purposes and interests.

Overall, it appears that the recent protest served as a means to refocus attention on a longstanding, unresolved issue in European agriculture and the CAP: the income level and income disparity compared to the rest of the economy. Economic sustainability is often seen as a prerequisite for a sector that can provide environmental and social public goods, but only when economic stability is ensured. Despite many years of CAP support, this income gap has not been closed or even reduced for small multifunctional farms, while larger industrial businesses, fully integrated into the global food supply chain, have often been overcompensated (Pierangeli *et al.*, 2024).

Another significant aspect emerging from the discussion is the evolving relationship between science and policy, as well as between science, knowledge, and information. One key issue relates to the role of the press and social media, which have played a notable role in the brief history of the protests. It is crucial to question and explore, at various levels, the sensitive relationship between science, policy, and information. This is particularly important, as social media content does not adhere to traditional, more formal review processes and is driven solely by the opinions of individual users. However, during a particularly heated period, such as the protests, social media decisively influenced the debate, complementing or even replacing professional or institutional information sources. The second issue, closely connected to the first, concerns the 'sustainable-washing' trend, which seems to dominate discussions around new policies and consumer choices. It is difficult to reduce multidimensional sustainability to merely a marketing attribute to 'better sell' European products, only to abandon it when it becomes a real, tangible approach towards transitioning European agri-food systems and territories. For these reasons, the short-term 'easy wins' and the seemingly 'forgotten' tractor protests could ultimately result in a long-term lost battle for everyone.

AUTHOR CONTRIBUTIONS

Conceptualization, G.M. and R.H.; Methodology, M.V and G.G; Investigation, G.M, R.H, M.V and G.G; Writing – Original Draft, G.M, R.H., M.V.

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APPENDIX

Table A.1. Syllabus of the TM-C for cluster blue.

Italian	*English*
agricolo	agricultural
agricoltore	farmer
agroecologia	agroecology
aleequilibrium	Alessandro Leonardi (X account)
alimentare	food
ambientale	environmental
ansaambiente	information website (X account)
area	area
articolo	article
associazione	association
attuale	current
attuazione	implementation
azienda	company
aziende agricole	farms
bene come	well as
bersaglio	target
cambiamento	change
cambiamoagricoltura	Associations Coalition (literally: Let's Change Agriculture) (X account)
camillalaureti	Camilla Laureti (MEP) (X account)
cancellare	cancel
causa	cause
cedere	to give in
cia agricoltura	CIA agriculture (Farmers' Union) (X account)
città	city
cittadino	citizen
climatecrisis	climate crisis
climatico	climate
coldiretti	Coldiretti (Farmers' Union)
colpire	hit
confagricoltura	Confagricoltura (Farmers' Union) (X account)
copacogeca	COPA COGECA (trade association) (X account)
crisi	crisis
danno	harm
dedicare	to dedicate
deroga	derogation
eco schema/eco schemi	ecoscheme/ecoschemes
ecologico	ecological
effetto	effect
emissione	emission
ennesimo	umpteenth
essere	to be
essere | suonare	to be | to play
europainitalia	EU in Italy (X account)
fimianif	Fabio Fimiani (X account)
fonte	source
fossile	fossil
francescolollo1	Francesco Lollobrigida (Ministry of Agriculture)
grande	big
grave	serious
green deal	Green Deal
ignorare	to ignore
ilsalvagenteit	information website (X account)
impegno	commitment
impollinatori	pollinators
incredibile	incredible
iniquo	unfair
inquinante	polluting
intensivo	intensive
interesse	interest
interno	internal
invadere	invade
irresponsabile	irresponsible
italia	Italy
maggiore	greater
malessere	malaise
manifestare	to demonstrate
masgiansanti	Massimiliano Giansanti, President of Confagricoltura (one of the Farmers' Union) (X account)
medio	medium
mgmidu	Maria Grazia Midulla (Head of Climate and Energy, WWF Italy)
miliardo	billion
misura	measure
morire	to die
natura	nature
naturale	natural
obiettivo	objective
Opinionisti	Opinionists
ottenere	to obtain

Italian	*English*
padano	padanian
pagare	To pay
paolodecastro	Paolo De Castro (politician) (X account)
peggiorare	to get worse
penalizzare	to penalize
pianura	plain
piccolo	small
politica agricola comune	Common Agricultural Policy
pressione	pressure
principale	principal
problema	problem
produzione	production
proprio	own
protestare	protest
ragione	reason
reddito	income
responsabilità	responsibility
rinviare	to postpone
rinvio	postponement
risolvere	solve
rivolta	revolt
sapere	know
sbagliare	to be wrong
siccità	drought
sintesi	synthesis
soluzione	solution
strumentalizzare	to instrumentalize
strumentalizzazione	instrumentalization
subire	to suffer/to undergo
suolo	soil
sussidio	subsidy
taglio	cut
transizione	transition
ultimo	last
utilizzare	use
vittima	victim
volere	to want
vonderleyen	Ursula von der Leyen (Head of EU Commission) (X account)
wwfeu	WWF EU (X account)
wwfitalia	WWF Italy (X account)

Table A.2. Syllabus of the TM-C for cluster red.

Italian	*English*
acqua	water
agricoltore	farmer
agrifish	Agriculture and Fishing Council
agronotizie	AgroNotizie (magazine) (X account)
angelociocca	Angelo Ciocca (X account)
arare	to plow
ascoltare	to listen
cambiare	to change
campo	field
chiedere	to ask
cia	CIA (Farmers'Union) (X account)
commissario	commissioner
cosa	time
cristiano	christian
custode	guardian
danneggiare	to damage
decennio	decade
decisione	decision
esenzione	exemption
europa	Europe
fare	to do
fine	price
folle	crazy
giornalisti	journalists
giugno	June
governo	government
intervista	interview
irpef	income tax (IRPEF)
lega	Lega (political party)
legasalvini	Lega (political party) (X account)
legge	law
macron	Emmanuel Macron
maggioranza	majority
marcia	gear
mettere	to put
pac	CAP (Common Agricultural Policy)
parlamentare europeo	member of European Parliament
parlare	to talk
parti sociali	social partes
pesticida	pesticide
politico	politic/politician

Italian	English
porcia	Porcia (Italian small city)
prendere	to take
presidente	president
prezzo	price
pronto	ready
protesta	protest
prova	proof/attempt
punto	point
raffaelaqu	Raffaella Quadretti (journalist) (X account)
risposta	answer
roma	Rome
sera	evening
sinistra	left
tempo	time
terranuovaed	Terra Nuova edizioni (magazine) (X account)
tornare	to return
trattore	tractor
ue	EU
via	away

Table A.3. Syllabus of the TM-C for cluster green.

Italian	English
accadere	to happen
accordo	agreement
agroalimentare	agri-food
ambiente	environment
ansaterragusto	Ansa Terra e Gusto (magazine) (X account)
basare	to base
bio	biological
biodiversità	biodiversity
biologico	organic
bisognare	to need
buono	good
cambiamenticlimatici	Magazine (X account) (Literally: climate change)
campagna	countryside
cibo	food
commerciale	commercial
commissione	commission
concorrenza	competition
confagriassembleabruxelles	Confagricoltura (Farmers' Union)
conferenza	conference
conferma	confirmation
confronto	comparison
consumatore	consumer
consumo	consumption
contadino	farmer
dato	data
diffondere	to spread
direttiva	directive
diverso	different
economia	economy
economico	economic
ellyesse	Elly Schlein (X Account)
europa	Europe
europeo	European
febbraio	February
finanziamento	financing
garantire	to guarantee
giorno	day
impatto	impact
importante	important
in cui	in which
in modo	in a way
incontro	meeting
indicazionigeografiche	geographical indications
iniziativa	initiative
intervento	intervention
lavorare	to work
linea	line
lotta	struggle
media specializzati	specialized media
mercato	market
milano	Milan
mondo	world
multinazionale	multinational
nazionale	national
normativa	regulations
nuovo	new
ogm	genetically modified organism (GMO)
parlamento	parliament
parlamentare europeo	member of European Parliament
parti sociali	social parties
partecipare	to participate
pdnetwork	PDnetwork (Italian Party) (X Account)
per questo	because of this
plenario	plenary
possibile	possible
pratico	practical
primo	first
progetto	project
qualità	quality
rafforzare	to strengthen
reale	real

Italian	*English*
relatore	speaker
rendere	to make
riguardare	to regard
rischio	risk
risultato	result
russo	Russian
seguire	to follow
servire	to serve
settore	sector
sleale	unfair
sociale	social
solidale	in solidarity
sostenere	hold up
sostenibile	sustainable
sostenibilità	sustainability
stampa	press
strategico	strategic
strumento	instrument
tenere	to hold
territorio	territory
tutela	protection
tutelare	to protect
unico	unique
valutazione	assessment
vino	wine
volta	time
voto	vote

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