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Digitalisation and just transition - Editorial

Digitalisation, agriculture, forestry and rural areas: methodological questions and research insights in a "just transition" perspective

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Digitalisation is increasingly portrayed as an important driver of change in rural areas and agriculture, together and in close combination with the ecological transition. International and European development organisations' efforts to foster digital-led transformations are growing considerably, in terms of financial resources, knowledge support and policy guidance (i.e. EU From Farm to Fork Strategy, Biodiversity Strategy). Digital connectivity and digital technologies are considered key enablers for food security improvement, bioeconomy growth, natural resources management, tourism development, energy production, climate change mitigation, and for supporting on-farm activities and the agrifood value chain. The benefits envisioned range from teleworking and e-services to biodiversity and land control, precision agriculture and inputs optimisation, animal welfare, farm work quality, access to markets, quality control and food traceability.

While academic debates and empirical research on the topic are increasing, they remain somewhat limited. Further research is necessary to assess the opportunities and limits of the efforts put into this prospect of change and to understand the criteria that need to be met in order to achieve the identified goals. Additional research is also required to explore the constraints, risks and contradictions connected to the tools, investment capacities and knowledge required, as well as to shed light on the potential dependency patterns and inequalities that might be fostered by digitalisation. Furthermore, it is crucial to embed the analysis of digital transformation and policy programmes in the broader context of socio-economic transformations of food regimes, changes in governance of the global value chain and the impacts of crises and shocks on food security.

Ongoing debates on the role of digital technologies in support of development goals heavily focus on the issue of "sustainability" but are often confined into narrow sectoral approaches. Analyses intending to critically examine the impacts of digital-driven transformations concerning ecological transition requirements should rigorously account for various variables, including actors, locations, resources, relationships and institutions. It is imperative to acknowledge that the integration of digital technologies into agriculture, forestry and rural areas does not inherently lead to positive sustainability outcomes.

Following this premise, the special issue suggests the necessity to explore digitalisation processes in local contexts from a "just transition" perspective aimed at ensuring that the shift towards more sustainable systems does not disproportionately harm certain groups, individuals or communities. Within this perspective, the articles included in the special issue pose methodological questions and propose frameworks to empirically explore the specificities of the different rural contexts, the challenges faced by local actors and their creative responses. Attention is also devoted to the potential of the diverse digitalisation strategies in terms of participation and conflict, bottom-up adoption, data access and control.

The initial article by Maura Benegiamo, Alessandra Corrado and Marco Fama reads agricultural digitalisation as a political and ecological process influenced by multiple dynamics, both global and local. Accordingly, the authors propose a theoretical-methodological framework inspired by the "just transition" perspective for equipping empirical research on digital agriculture with a more critical and comprehensive understanding of local contexts. As the authors suggest, the "just transition" approach can provide valuable insights into the socio-ecological impact of agricultural digitalisation. Furthermore, it can support the formulation of helpful policy recommendations.

A complementary perspective is developed in the article by Sabrina Arcuri, Gianluca Brunori and Silvia Rolandi, which builds on two European Horizon 2020 projects that adopt multi-actor approaches to inform research, practices and policies. The authors propose a conceptual framework encompassing three main domains of intervention: the digital divide (that is the difference in access to, and use of, information and communication technologies between urban and rural areas); the attractiveness of rural areas; and rural governance. For each of these domains, they provide case study examples showing the importance of recognising both the potential benefits of digital transformation and the critical needs that must be addressed to ensure equitable access and opportunities for all individuals, within and beyond rural areas.

The third contribution, by Mikelis Grivins and Emils Kilis, focuses on the barriers (socio-cultural, technical, economic, regulatory-institutional) that farmers encounter when implementing new digital solutions, exploring three cases in Latvia's beef farming sector. The article highlights the multiple creative strategies that farmers adopt for dealing with their practical challenges, often combining new solutions with existing practices and routines. In line with the two previous articles, the authors underline the importance of exploring the responses adopted at local level from a broader perspective focussed on pre-existing issues that may hinder digitalisation and its access to most vulnerable groups.

The last article, by Cristián Alarcón, shifts attention to the "politics of data". This term is used to illustrate the possibilities for "data innovations from below", i.e. the production and management of environmental data by citizens, associations and movements in support of struggles related to biodiversity, land and forests, in contrast with "data innovations from above", as in the case of data production linked to productivity-oriented forestry. This case study highlights different capacities and possibilities stemming from digitalisation and the related process of datafication (intended as the growing and intensive process of data generation). By analysing the Swedish Species Observation System (*Artportalen*), the author shows that digitalisation can serve as a means to intensify forestry operations and the use of forests or, conversely, to strengthen citizens and civil society participation in the sustainable management and monitoring of biodiversity or land uses. The outcome will depend on a set of factors that can be more comprehensively grasped through the lens of a "just transition" perspective, much like the results of the various strategies scrutinised by Grivins and Kilis.

In conclusion, all four articles emphasise the importance of conducting additional empirical research supported by appropriate frameworks enabling a more nuanced understanding of local contexts, while also retaining a wider perspective focused on the socio-ecological impact that digitalisation has on agriculture, forestry and rural areas in general.

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Digitalisation and just transition - Research article

Agricultural digitalisation and just transition: a framework for the analysis

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Abstract. Digital agriculture is generally depicted as a new technological frontier allowing both the efficiency and sustainability of the agri-food sector to be increased through the introduction of innovative "green" and cost-effective solutions. However, there is still little empirical evidence on the wider environmental and socio-economic implications of ongoing agricultural digitalisation processes. The paper makes the point that the digitalisation of agriculture is a political and ecological process representing an important element of the uneven and combined patterns of the capitalist development of agriculture. At the same time, the practices that inform agricultural digitalisation are shaped by social, economic and environmental factors that change according to the context. Starting from these premises, the authors propose a critical framework for equipping empirical research on digital agriculture with a more comprehensive understanding of local contexts, while also retaining a wider political economy perspective inspired by the concept of "just transition".

Keywords: agricultural digitalisation, food system, sustainability, agrarian labour, just transition.
JEL codes: O1, O3, Q1.

HIGHLIGHTS

- Agricultural digitalisation is a political and ecological process representing an important ingredient of the uneven and combined patterns of the capitalist development of agriculture.
- Empirical research on agricultural digitalisation is needed, as long as it is supported by appropriate frameworks enabling a more nuanced understanding of local contexts while also retaining a wider political economy perspective.
- The "just transition" perspective offers valuable insights into the socio-ecological impact of agricultural digitalisation.

1. INTRODUCTION

Agricultural digitalisation is generally portrayed as a necessary transformation for the agri-food system, allowing production targets to be reconciled with sustainability goals thanks to the diffusion of new cost-effective and eco-friendly farming solutions (OECD, 2022; Mondejar *et al.*, 2021; Lajoie-O'Mailey *et al.*, 2020). It is also presented as a process that can contribute to counteracting the rural exodus, establishing new connections between rural and urban areas, creating new opportunities for endogenous development, and improving food system outcomes (FAO, 2022; Trendov, 2019; Word Bank, 2017, 2019).

In line with these expectations, the European Green Deal attributes a central role to digital agriculture in the ecological transition and sustainable growth (European Commission, 2019). European Union (EU) Member States strongly envisaged "a smart and sustainable digital future for European agriculture and rural areas" (European Commission, 2020), and several EU policies, instruments and funds are currently serving the scope of digitalisation of agriculture (Reinhardt, 2022). Also the Farm to Fork (F2F) strategy, which is a pillar of the EU's Green Deal, places a strong emphasis on the role of research and (digital) innovation in addressing the challenges of sustainable food systems.

Notwithstanding the increasing enthusiasm towards digital agriculture, however, there is still little empirical evidence on its deepest environmental and socio-economic implications. The existing literature tends to focus on the potential outcomes of agricultural digitalisation in terms of productivity and market possibilities for farmers (Phillips *et al.*, 2019). Agronomic and engineering perspectives that focus on the pull and push factors of digital agriculture and its environmental impact understood as efficiency are not rare (Wolfert *et al.,* 2017; Bucci *et al.,* 2019). On the contrary, issues related to the broader effects that digitalisation may have on local ecosystems and agrarian structures are often neglected. For instance, there is still much to know about the potential role of digital technologies in reinforcing or contrasting existing power asymmetries and inequalities in agriculture and rural areas, as well as about their impact on the reconfiguration of the relationship between agricultural work and territorial sustainability (McMichael, 2023). Though several studies have explored the potential consequences deriving from asymmetries in digital technology adoption, as well as problems related to data access and control (Stone, 2022; Rolandi *et al.*, 2021; Dietz and Drechsel, 2021; Rotz *et al.*, 2019; Hackfort, 2011), there is still room to further problematise the role of digital agriculture (Brunori, 2022), especially with regard to labour issues and their intertwining with sustainability goals (Carolan, 2020).

Not surprisingly, institutional initiatives to promote digitalisation in rural contexts are usually based on a free-market rationale and rarely consider contextual specificities (Salemink *et al.*, 2017). In this respect, Alistair Fraser (2022) has warned against the risk of smart agriculture developing through the production of "misconfigured innovations", mainly due to the limited parameters within which innovations are set to operate. According to him, "agricultural innovation processes will continue to introduce new misconfigurations when they pursue discrete solutions to specific problems, rather than integrated developments based on incremental adjustments in information-intensive iterative processes that target systemic or structural change" (*ibidem:* 203).

To avoid this risk, in-depth empirical studies are very much needed, as long as they are informed by critical perspectives able to shed light on the expected and unexpected outcomes that agricultural digitalisation may produce in each particular context, while also connecting it with the broader picture of the socio-ecological agrarian system.

Our assumption is that the digitalisation of agriculture is a political and ecological process representing a further ingredient of the uneven and combined patterns of the capitalist development of agriculture (Alarcón *et al.*, 2023; Smith, 2020). As such, broader perspectives on political economy and critical agricultural studies are needed to address this transformation and can provide relevant insights into the process of digitalisation and its consequences (Rotz *et al.*, 2019; Dietz and Drechsel, 2023). At the same time, it is also important to consider that the practices and discourses that inform agricultural digitalisation are strongly shaped by social, economic and environmental factors that may vary enormously across different settings.

To account for this complexity and facilitate a socio-ecological analysis of how digitalisation impacts agrarian change dynamics at a local level we suggest the relevance of a "just transition" perspective (Morena *et al.,* 2020; Benegiamo *et al.*, 2023). The concept of a just transition (JT) is hinged on the idea of ensuring that the shift towards more sustainable systems does not disproportionately harm certain groups, individuals or communities (ILO, 2015). This implies recognising that the ecological transition may have disruptive effects on the livelihoods of workers and farmers, and leave vulnerable groups behind.

Considering all the above, the main goal of this article is to elaborate a framework for equipping empirical research on digital agriculture with a more nuanced understanding of local contexts, while simultaneously exploring ongoing dynamics of agrarian change from a JT perspective.

The article is structured as follows: in the first section we set the context of agricultural digitalisation from a political economy perspective, providing a review of the existing literature on critical agrarian studies; in the second section we briefly introduce the concept of JT and the ongoing debate surrounding its application in the agri-food sector, stressing the potential of the JT perspective in addressing the social impact of digital agriculture; in the third section, we propose a framework to support empirical research on agricultural digitalisation in order to overcome the existing knowledge and analytical gaps.

2. AGRICULTURAL DIGITALISATION AND DYNAMICS OF AGRARIAN CHANGE: A BRIEF LITERATURE REVIEW

Concepts such as "digital agriculture", "smart agriculture", "agriculture 4.0" are often used interchangeably in reference to a broad set of digital technologies, tools, software and data-driven solutions allowing agricultural processes to be optimised, from agricultural inputs (seeds, insurance and finances) and on-farm operations, to food processing, transport, storage, retail and consumption (Clapp and Ruder, 2020; Rotz *et al.,* 2019).

Here, we refer to "agricultural digitalisation" as a phenomenon that is far from being simply a further step in the process through which technology is incorporated within farming systems. From a wider political economy perspective, indeed, the penetration of digitalisation into agriculture can be understood as a socio-economic process representing an important ingredient of the development of the capitalist agrifood system in the context of multiple and systemic socio-ecological crises (Akram-Lodhi, 2021; Akram-Lodhi, Kay, 2010a, 2010b; Smith, 2020; Friedmann, 1993; McMichael, 2013b).

Agrarian development has long been driven by the goal of increasing productivity through mechanical technologies and chemical inputs, resulting in a deep reconfiguration of local agrarian structures. Pursuing the declared goals of "feeding the world" while also improving incomes at farm level, the productivist approach adopted by governments and key global development actors from the 1950s onwards has produced highly controversial outcomes. Although with some significant regional differences, the agricultural sector has been characterised by a dramatic decline in employment levels and an increasing concentration of arable land (Baglioni, Gibbon, 2013), combined with the diffusion of agro-industrial intensification and growing environmental degradation (Rasmussen *et al*., 2018). Especially with the rise of the so-called neoliberal "corporate-environmental food regime" (McMichael, 2005; Friedmann, 2013) – implying convergence of environmental politics and corporate power concentration – food crises have grown in frequency and intensity (Fama, Conti, 2022; FAO, 2021), exposing farmers to price-squeeze dynamics and making them increasingly dependent on the global value-chains controlled by transnational corporations (TNCs).

At the same time, as the limits of the efforts to modernise agriculture have become more evident, rising social claims and market tendencies have first pushed for a shift towards a post-productivist paradigm, finally setting the scene for an "ecological transition" within the context of market liberalisation. In the European context, the process for the Common Agricultural Policy (CAP) reform and its following implementation at the Member State level has displayed clear tensions between, on the one hand, the structural path-dependency and other mechanisms that lock entrepreneurial farmers into the dominant socio-technical regime, and, on the other hand, the ambition to support the transition towards more sustainable systems of food and farming, in line with the European Green Deal (Ploeg, 2020).

In this scenario, the role played by digital agriculture can be framed in highly different ways. Most enthusiastic narratives tend to depict it as a new technological frontier allowing the agricultural sector to be revitalised and sustainability improved through the introduction of innovative "green" and cost-effective solutions (Foresight. The Future of Food and Farming, 2011; Franks, 2014). To be sure, agricultural digitalisation as a support for precision farming can help farmers in optimising the use of chemical inputs and rationalising water consumption. Moreover, digital platforms can be used to reduce intermediaries, improve price transparency and ensure product traceability. However, the idea that digital innovation *per se* can provide effective responses to the ongoing "agro-environmental crisis" (Ploeg, 2018) and improve equity in the agri-food system has to be questioned.

According to critical agrarian studies, for instance, "green" technologies are a key component of neoliberal politics that is further exacerbating the socio-ecological contradictions of capitalism (Akram-Lodhi, 2021; Borras, Franco, 2018; Fairhead *et al*., 2012; Weis, 2010). From this point of view, the digitalisation of agriculture does not challenge the agro-industrial model and its socio-ecological lock-in but rather risks accentuating its matrix, encouraging a progressive increase in the agricultural scale and concentration of production means, with consequences in terms of rural dispossession and depopulation, a worsening of food security and the emergence of new problems of access to and control of production and reproduction factors for small farmers (Mooney, 2018; Rotz *et al.*, 2019; Benegiamo, 2023).

In this regard, Hackfort (2021) observed that the adoption and development of digital agriculture are embedded with power relations that end up feeding at least five patterns of inequalities: in digital technology development; in the distribution of benefits from the use of digital technologies; in sovereignty over data, hardware and digital infrastructure; in skills and knowledge; and in problem definition.

Along the same line, Rotz *et al.* (2019) identified three main challenges related to: data ownership and control; the production of technologies and data development; data security. The point made by the authors is that, since technological solutions are usually developed in ways that empower corporate actors rather than supporting independent farmers, the current paths of agricultural technology "may exacerbate inequities for marginalised food system actors, specifically between different sized farmers as well as farmers and agro-food corporations" (*ibidem*: 222). However, they do not consider agri-food digitalisation as something in sharp contrast with the possibility to engender greater equity in agriculture, for instance by supporting the diffusion of agroecological methods and approaches.

According to Glenn Davis Stone (2022), while digitalisation does not necessarily pose a threat to the autonomy of "industrialised farmers", it is likely to jeopardise that of "peasants" in the Global South, who still produce a relevant portion of the food consumed globally (Ricciardi *et al.*, 2018; Samberg *et al.*, 2016). For this vast class of farmers, Stone (2022: 610) argues, the penetration of digital technologies calls directly into question a set of "*informational relations of production*, defined as relationships that control the creation, interpretation, dissemination and deployment of information needed for productive processes" and there is no doubt that some of these technologies "can – indeed aim to – disrupt and reformulate such relations".

Against this background, it is important to distinguish the technologies that can support decision-making for small farmers from those that are used to appropriate their knowledge and increase their dependence on market dynamics (Lioutas *et al.*, 2019: 1). At the same time, a less technocentric and more holistic approach is needed, focused on digital agriculture as a multidimensional phenomenon in which different combinations of practices, actors and artefacts are established, transforming the social and physical structures of the agri-food system (Alarcon *et al.*, 2023; Higgins, Bryant, 2020; Lioutas, Charatsari, 2021).

3. PROBLEMATISING AGRICULTURAL DIGITALISATION FROM A "JUST TRANSITION" PERSPECTIVE

As already mentioned, the idea of digital agriculture is strongly framed within the debates and policies for the ecological transition in agrifood, made particularly urgent by the impacts of and contributions to climate change by industrialised agriculture. Despite this, the possible social implications and changes to farmers' and farmworkers' conditions and livelihoods driven by digital transformation are still poorly discussed. This, as noted by Aubert *et al.* (2021), can be partly comprehended as a lack of ecological macroeconomics frameworks for the agro-industrial sector able to capture the socio-economic impacts of the transformation needed to bring it back within planetary boundaries. As a reaction to this gap, recently, a burgeoning discussion on just transition (henceforth JT) in agriculture has been established (Blattner, 2020; Moilanen, Alasoini, 2023; Kaljonen *et al.*, 2023), based on the idea that a fair transition process is one that does not leave behind farmers and farmworkers and the communities concerned.

The idea of JT implies that the transition to a climate-neutral economy must at the same time secure the future and livelihoods of workers and their communities. This means that social justice, with a special focus on decent work and quality jobs, must remain at the centre of any environmental analysis and policy regarding the ecological transition (ILO, 2015; OECD, 2017). According to ILO, the vision of a JT is embedded with the notion of socioeconomic sustainability, and the ILO's guidelines state that: «a just transition for all towards an environmentally sustainable economy […] needs to be well managed and contribute to the goals of decent work for all, social inclusion and the eradication of poverty» (ILO, 2015).

The concept of JT originated with the United States labour movement of the 1970s and broadened as labour organisations forged alliances with environmental justice groups starting in the 1990s. Initially, the idea of JT emerged in response to increased regulation of polluting industries in the wake of the National Environmental Policy Act and the establishment of a federal Superfund law in the U.S. Labour unions like the Oil, Chemical, and Atomic Workers (OCAW), long vocal about the environmental impacts of their work, faced widespread job losses despite heavily funded cleanup efforts at contaminated work sites. Workers demanded a "superfund for workers" and a "superfund for communities" that included, in addition to retraining programmes and community support, broader efforts to plan and design a more environmentally-friendly approach to industrial production (Henry *et al.,* 2020; Mazzochi, 1993). Workers and their communities were called upon to play a leading role in this rethinking of work itself and of the relationship between the factory and the territory, based on the dual principle of the "right to know" and the "right to act" (Morena *et al.,* 2020).

Since 2015, with its inclusion in the Paris Agreement that resulted from COP21, the concept of JT has become increasingly widespread in the narrative used in the governmental arena. As concerns the agrifood sector, the 2015 Paris Climate Agreement already recognised the need for a "just transition of the workforce, and the creation of decent work and quality jobs, including in agriculture, forestry, and other land uses" (UNFCCC, 2015).

More recently, the principle of JT has also been adopted by the European Union as an important dimension of the European Green Deal[1]. However, as a recent report by the Institute for European Environmental Policy (IEEP) states, compared to other industrial sectors the concept of transition and JT "take on a distinctive character when applied to the agricultural and food sectors", making its realisation particularly challenging. Indeed, as stressed by the IEED, and with some exceptions in the meat value chain: "Unlike sectors facing redundant technologies and outright factory closure and cessation of production, agriculture and land use will continue in many cases but has to be transformed. Just transition for this sector will therefore go beyond the classical policy instruments for this purpose namely: financial redundancy payments, retraining and skilling, regional investment strategies and ensuring the mobility of the workforce" (Baldock, Buckwell, 2021: 2).

A further level of complexity arises from the diversity that characterises agricultural and food systems both globally and in Europe, where large commercial farms and highly industrialised monocultures contrast with the great fragmentation into small and micro family farms throughout rural landscapes. Moreover, in this context, as Van der Ploeg (2018) outlines, the industrial agricultural system is undergoing a process of disaggregation, with multiple trajectories of change coexisting, on which the processes of digitalisation are grafted, making it difficult to predict the overall outcome of ongoing transformations.

Against this backdrop very different patterns of transition and digital transition need to be imagined and it would be more appropriate to talk of plural transitions to digital agriculture (see also Bock *et al.,* 2020). This is also related to the diversity of socio-economic contexts, rural ecosystems, soils and climate in which farms operate. For instance, farmers in marginal or peripheral lands, or residing in regions with relatively limited government support for the transition, as well as elderly farmers, are less likely to establish a competitive position in the use of new technologies (Murphy *et al.*, 2022) and are at greater risk of being put out of competition by early adopters more able to bear the economic cost of digital investment.

The fragmentation and disaggregation of the agrarian landscape are also reflected in the presence of very different labour positions that may be uniquely impacted by transition processes, including the one envisaged by digitalisation. Entrepreneurs, consultants, families and seasonal workers often co-exist in the same sectors. Moreover, manual and seasonal jobs are often performed by irregular and poorly protected migrant workers, mostly in conditions of severe exploitation (Corrado *et al.*, 2016; Rye, Scott, 2018). At the same time, while taking into account the different and non-comparable labour positions, it is important to stress the general need, upstream of transition processes, to improve working conditions in a sector where they are often too poor.

Regarding the impact of digitalisation on farmers and farmworkers, two main scenarios can be outlined. On the one hand, there is the idea that digitalisation will reduce the need for physical inputs, with a consequent decrease in the demand for labour (Wolfert *et al.*, 2017; Gorbart, 2012), but also a qualitative reconfiguration of agricultural employment that may lead to the gradual elimination of most precarious job positions (i.e. seasonal pickers, shepherds and livestock workers) or a further casualisation of the same tasks. On the other hand, new forms of precarious work could be associated with the specific needs of digital technologies and their use (i.e. logistics porters and food delivery couriers). At the same time, economic burdens from investing in the transition to digital agriculture could exacerbate the labour-capital conflict, inducing farmers to rely on less fair work schemes.

Another aspect to consider is the potential for digitalisation to exacerbate power asymmetries between, on one side, large farmers and, on the other side, peasants and agroecological farmers. The latter are often excluded from funding and incentive programmes, and digital technologies may not be suited to them, as

[1] The Just Transition Mechanism (JTM) is based on a set of tools, including financial ones, that have been incorporated within the European Green Deal "to ensure that the transition to a climate-neutral economy happens in a fair way, leaving no one behind" (EC, 2020b).

they tend to be tailored to the needs of larger and more influential players.

Against this backdrop, assuming a JT perspective allows the potential impact of digital agriculture to be assessed on all the different players within the agri-food system, but also to consider farmers and workers as social actors who can be drivers of emancipatory technical innovation, counteracting the tendency to analyse labour, sustainability and innovation as separate issues (Rathzel *et al.*, 2021).

At a policy level, indeed, digitalisation can offer the opportunity to promote a rescaling of agriculture towards place-based models and practices that have proven to be more resilient and capable of ensuring food safety and security (Marsden, 2013). To this end, policy interventions should be informed by a JT approach that perceives work as interconnected with the community, both the place-based community of the surrounding area and the wider community that connects consumers to producers (Murphy *et al.*, 2022). Such an approach is crucial to consider the food system as a whole, also in order to avoid placing the burden of the transition solely on the shoulders of farmers.

The framework developed by Aubert *et al.* (2021) for the ecological transition of the French dairy sector is in line with these considerations. Based on the requirements of the French National Low Carbon Strategy the authors devised two different scenarios. The first one, associated with greater job losses, envisages an adaptation and compensation strategy for the industrial sector which is limited to obtaining results in terms of reducing the emissions of individual companies. The second scenario, on the contrary, simultaneously considers the effects on biodiversity, health and employment by integrating a JT perspective. This allows more integral policy measures able to support the ecological transition while also preserving employment levels.

4. A JT FRAMEWORK FOR EXPLORING THE IMPACT OF DIGITAL AGRICULTURE

As highlighted in the above-mentioned debates, the penetration of digitalisation into agriculture entails risks and opportunities for the sustainability of the food system, depending on various technological, economic, environmental and social factors. Therefore, more nuanced empirical research is required to observe how these factors are combined within each specific context. In order to shed light on the socio-economic implications of digital agriculture, it is also fundamental to grasp the drivers of the diverse digitalisation patterns, how these affect, and are affected by, the decisions made by the actors involved, and how these decisions are, in turn, influenced by the institutional framings of the ecological transition.

To better orient empirical research, a framework able to capture the interplay of all the dimensions of agricultural digitalisation can be helpful. The term "framework" refers to a heuristic model that can help guide empirical research and develop a comprehensive approach to understanding a complex phenomenon. It should by no means be considered as a rigid scheme to be followed strictly, but rather as a flexible tool to be adapted and refined according to the specific research question and context. It is also important to recognise that, while it can offer important descriptive information, a framework does not in itself provide a deep analytical understanding of the phenomenon being studied. Hence, it is essential to adopt it in conjunction with other analytical tools and approaches. A well-known example of a framework is the one developed by Ian Scoones (1998) for the analysis of sustainable rural livelihoods, where all factors affecting the subsistence of individuals are schematically illustrated in relation to five key indicators (context, conditions and trends; livelihood resources; institutional processes and organisational structures; livelihood strategies; sustainable livelihood outcomes).

In our framework, we propose to consider six dimensions, listed in Table 1. A set of questions is associated to each dimension. In addition, we have focussed on the idea of just transition, as an approach capable of combining work and territory within a transition perspective attentive to the intersectional impacts of transformations in industry sector models.

Building on Tribaldos, Kortetmäki (2022), for each dimension we have also identified criteria for just transition in food systems potentially applicable at a process- / policy-pathway evaluation level. These criteria are intended to provide guidelines and normative visions regarding desired directions of change, aiding clarification and discussion of what makes transitions just (see ILO, 2015; UNFCCC, 2020).

The criteria are derived from basic principles and fundamental rules of justice established in philosophy and social theories of social justice – corresponding to "A-level principles" in the model proposed by Tribaldos, Kortetmäki (2022)[2]. For each A-level principle, more practical rules of justice serving as an analytical lens to just transition can be inferred – corresponding to

[2] According to the two authors, these are: distributive justice, cosmopolitan justice, ecology and non-human beings, procedural justice, recognition justice, capacities.

Table 1. Dimensions of agricultural digitalisation

Dimension	Description
Context	This dimension refers to all the context-specific factors that affect the adoption and outcomes of digital agriculture. Related questions should explore how the context shapes local agricultural practices, the strategies adopted by the actors and the different tools of agricultural digitalisation proposed and/or adopted.
Actors and socio-cultural dynamics	This dimension refers to the impact that digital agriculture has on social structures and rural communities as well as its relation with the symbolic and cultural spheres. Related questions should analyse the actors involved and the social networks in which their digital practices are embedded, the related processes of knowledge creation and transfer, and the factors (in terms of resources, values, beliefs) that affect digital agriculture tools adoption and impact.
Technological infrastructure	This dimension refers to the hardware, software and connectivity required for the digitalisation of agriculture. Related questions should explore the accessibility and quality of the technical options available in a given context, their potential socio-economic outcomes, as well as the factors that influence the extent of technology adoption, such as business structure, type of farm production, cost, perceived risks and benefits, cultural attitudes, literacy among farmers, etc..
Economic model	This dimension refers to the development model followed by the farms that innovate digitally, their scale and position within the value chains, and the broader economic implications of digital agriculture. Related questions should explore how digitalisation is connected with the different trajectories of agricultural development, its impact on value creation and distribution and the way it is affecting the labour market and the socio-economic structure of agri-food production. In a different vein, it is also relevant to grasp the economic context within which digital technologies are embedded, fabricated and promoted on the market. To assess the specificity of the technoscience market and its relations with, for example, financial tools or public incentives, on one side, and the specificity of the farm economy on the other.
Environmental implications	This dimension refers to how digital agriculture affects the "social production of nature" and the influence of nature over social production and reproduction. Related questions should investigate the immediate digital agriculture impact on the ecosystems, but also the unintended effects that the new practices induced by digitalisation can have in terms of biodiversity loss and ecosystem alteration, as well as the potential emergence of new consumption patterns and market dynamics that may have off-farms environmental implications. A focus on the entire value chain may also be relevant, including the impact of the agritech sector, as well as the underlying greenhouse gas and environmental footprint due to data mining and storage, which is becoming increasingly significant in terms of the overall footprint of IT.
Institutions, governance and policies	This dimension refers to the institutional processes, the regulatory framework and political dynamics governing agricultural digitalisation. Related questions should explore how the outcomes of digital agriculture are negotiated and affected by institutional factors, the influence exercised by policies and governance structures at local, national, and international levels, and the potential conflicts that may arise. This latter aspect is also related to the presence and type of participation mechanisms and the degree of inclusion of potential stakeholders, as well as their definition and relative power assimilations.

"B-level principles". In our case, we have identified a list of B-level principles that include, but are not limited to: 1. right to food, labour justice (incl. farmers, herders and fishermen); 2. just food-chain structures and livelihood opportunities, (distributive justice); 3. global fairness (cosmopolitan justice), intergenerational justice and fairness; 4. ecological integrity and justice for animals (ecology and non-human beings); 5. just processes and access to relevant information (procedural justice); 6. respectful pluralism and esteem recognition and non-discrimination (recognition and intersectional justice); 7. capacity building (capacities).

For each of the dimensions identified, and with the aim of substantiating and operationalising them, Figure 1 lists a set of potential questions whose articulation with the criteria in Figure 2 makes it possible to narrow the focus of the analysis, according to the political economy perspective of the JT approach.

Answering the questions listed in Figure 1 allows a more comprehensive understanding to be gained of how the digitalisation paradigm and specific digital technologies articulate into the research context, going beyond sectoral analysis about agricultural digitalisation. Taking into account the complexity of the analysed phenomena is indeed an increasingly recognised requirement of innovation and transition processes. This also includes the need to broaden the scientific capacity to include different perspectives and interests directly in the problem framing, as well as in the decision-making and implementation process, in order to recognise the systemic, normative and uncertain character of socio-technical transformation processes, such as those related to the challenges of climate change and sustainability (Funtowicz, Ravetz, 2003). In line with these arguments, once the above dimensions have been examined, we suggest integrating a political economy perspective based on the previously listed dimensions of justice as substantive elements for a JT approach. This makes it possible to develop a framework to assess whether and how, in a given context, the digital transformations of agriculture are

Figure 1. Exploring the impact of digital agriculture: potential questions.

DIMENSIONS	POTENTIAL QUESTIONS
CONTEXT	- Which are the features of local agrarian structures? - How is the context characterised from a geographical, morphological and natural point of view? - Which are the main local products and agricultural models? - What kind of infrastructures are available? - Are there producers organisations or bodies that connect farmers to each other? - Have local farmers access to global/local markets? - What are the connections between urban and rural areas?
ACTORS AND SOCIO-CULTURAL DYNAMICS	- Who are the actors involved in the different stages and trajectories of agricultural digitalisation, and how they are connected? - Who remains excluded? - Who does what, and why? - Are digital farmers increasing their know-how? - What kind of access do they have to the knowledge required and produced? - How is the existing set of resources affecting the diffusion of digital agriculture and its outcomes?
ECONOMIC MODEL	- How are the diverse digital patterns linked to the size and business strategies of the farms involved? - Are digital farmers more oriented towards multifunctionality or productivity gains? - Are they producing for local markets or for the agro-industry? - How are they performing, compared to non-digitalised farmers? - How is digitalisation affecting local agrarian structures and labour market in quanti-qualitative terms?
INSTITUTIONS, GOVERNANCE AND POLICIES	- How are the rules about funding, competition, data management, etc. established and negotiated? - Who has access to what kind of resources? - Is there any governance and policy framework to ensure that the outcomes are benefiting all stakeholders and are aligned with broader social and environmental goals? - Is agricultural digitalisation directly or indirectly creating new conflicts? Among whom, and how they are solved?
ENVIRONMENTAL IMPLICATIONS	- How is the management of land, water and other natural resources evolving as a consequence of the diffusion of digital agriculture? - How are the inputs used and the outputs produced by digitalised farms differ compared to other farms? - Is digitalisation prompting farmers to shift towards specific crop varieties or animal breeds? - Are new markets and consumption practices emerging as a consequence of digitalisations?
TECHNOLOGICAL INFRASTUCTURE	- Which technologies are available and to whom? - Who is adopting what technology, and why? - Is the technology adopted supporting or appropriating farmers' decisions-making?

Figure 2. Exploring the impact of digital agriculture: JT criteria.

DIMENSIONS	CRITERIA
CONTEXT	- The access to suitable farmland is protected. - Access to and safe use of water is guaranteed for all, regardless of economic status, gender, age or culture. - Multiple opportunities for livelihoods in rural areas are retained or designing them is supported. - Transition demands are designed in a way that different-sized food system actors are able to respond to them. - The access of the whole population to sufficient nutritious, adequate, and safe food at all times is protected.
ACTORS AND SOCIO-CULTURAL DYNAMICS	- People are not discriminated on ethnic-, gender-, age-related, or other grounds. - The established or supported food jobs have fair payment and working conditions. - Small farmers, communities and women may be identified as key actors in the process and their perspective included in policy design. - People are entitled to access tailored capabilities to guarantee their rights in the workplace and as food consumers. - Unionisation is guaranteed and promoted at all levels. - Workers participation is assured so that they can influence the decision taken by company boards or councils.
ECONOMIC MODEL	- The resilience of food supply chains towards shocks is increased. - Farmer resilience towards shocks is retained or improved. - Established food chain relations are reciprocally agreeable. - Social protection is guaranteed at all levels and social cohesion is promoted. - Wages are worthy and guarantee social reproduction and a dignified life. - Farmers, especially small farmers and workers are provided with effective positive alternatives and concrete possibilities to avoid corporate pressure on their labour and challenge food-system locks-in. - Real market and production alternatives to the corporate food system are guaranteed, which also guarantee climate mitigation.
INSTITUTIONS, GOVERNANCE AND POLICIES	- Decision-making processes are sufficiently transparent, inclusive, and provide a fair opportunity for different voices to be heard. - Decision-making does not create or intensify power disparities. - Reliable information about the impacts of food systems and different diets on humans and nature is available to all in decision-making and climate action. - Governments act as a lever for just transitions in food and agriculture, to facilitate ecological paradigm shift and effective transformations on the scale required. - A comprehensive just transition framework is adopted for policy making.
ENVIRONMENTAL IMPLICATIONS	- Ecosystem health is improved. - Biodiversity is protected or increased. - Soil, water, and air health/quality is retained or improved. - Natural (biotic and abiotic) resource use stays within planetary boundaries. - The inherent value of animals is respected, and they are treated respectfully. - The nexus between intensification, industrialisation and deforestation is taken into account in policy design to contrast climate change and promote an ecological paradigm shift. - Systemic responsibility of food chain actors for climate change and biodiversity loss are taken into account by agrarian policies so that farmers and workers are not burdened with an unfair responsibility for fixing the crisis. - Agricultural, energy and environmental policy are interconnected to provide farmers with the technical, economic and political support to work with ecosystems, including the promotion of agroecological practices and approaches. - Degraded environments are restored, and livelihood is guaranteed. - Place based politics and tailored responses to local crisis dynamics are adopted. - The caring of ecosystem services and landscape protection activities are considered as part of farm labour and services provided to community.
TECHNOLOGICAL INFRASTUCTURE	- Supported innovations are made available to interested actors, especially least-advantaged groups. - Developing individuals' skills for transition activities is supported. - Capacity building to engage people in collective action for transitions is supported. - Responsible research and innovation (RRI) principles are embedded into technological offer to anticipate their consequences, and to involve society in discussing how science and technology can help in responding to actual needs and create a desirable world. - Open access approaches to technology and data are promoted, as well as sharing usage and practices. - The point of view of workers and underprivileged persons is directly included in the framing of the problem, as well as in the decision-making and implementation process of the technology offer. - Dimensions of relatedness, adaptability, accessibility, bio-interaction and appropriateness are fulfilled in the technology design and output.

in line with the JT criteria in Figure 2 or whether they are exacerbating inequalities and leaving certain groups behind. The final step is to understand to what extent the different actors involved have the possibility to influence the ongoing digitalisation patterns, who bears the costs and who should benefit the most. The ecological dimensions of both labour and production process are also taken into account and articulated with the analysis of digital transformation.

5. CONCLUSION

The penetration of digitalisation into agriculture is a process entangled with the capitalist development of agriculture and the related politics of sustainability. Therefore, a wider political economy perspective is needed to shed light on the deepest implications of agricultural digitalisation, moving beyond most enthusiastic and techno-centric narratives portraying it as a win-win solution and a necessary transformation for the sustainability of the agri-food system.

From a theoretical standpoint, the existing literature has already outlined a number of potential risks surrounding agricultural digitalisation in the context of the "corporate-environmental food regime" (McMichael, 2005; Friedmann, 2013), especially for smaller farmers (Stone, 2022; Rolandi *et al.*, 2021; Dietz, Drechsel, 2021; Rotz *et al.*, 2019; Mooney, 2018; Hackfort, 2011). Nevertheless, it is important to take into account that the drivers and effects of agricultural digitalisation may differ enormously according to the specificity of the local contexts. While one must consider how the latter are structurally integrated into the existing food regime, it is also fundamental to keep in mind that the choice to innovate digitally is part of changing strategies adopted by farmers to cope with both endogenous and exogenous problems.

It follows the need for empirical research enabling a more nuanced understanding of local contexts while also retaining a broader political economy perspective. To this end, we proposed a framework aimed at exploring the different dimensions of agricultural digitalisation through a set of questions that, for the sake of conciseness, could be reframed as follows: a) what are the drivers of agricultural digitalisation and how is this process negotiated and affected by the context-specific strategies adopted by farmers? b) how are these trajectories of change connected to the long-term trajectories of the global agri-food system? c) how is digitalisation influencing the capacity of local ecosystems to sustain agriculture and vice-versa? d) who are the actors involved in the political definition of rural sustainability and who are those that remain excluded? e) what are the effects of agricultural digitalisation on existing power relations and socio-economic structures?

Answering these questions implies the adoption of a JT perspective focused on whether ongoing agricultural digitalisation processes are exacerbating existing inequalities or leaving vulnerable groups behind. At a policy level, such an approach is essential to gain valuable insights into how to mitigate the potential negative effects of agricultural digitalisation and, at the same time, reframe sustainability goals and practices in a more equitable way. To be sure, the digitalisation of the agri-food system is an ongoing and evolving process. New elements and dimensions are likely to emerge, requiring continuous adjustments to the proposed framework.

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Digitalisation and just transition - Research article

Digitalisation in rural areas: exploring perspectives and main challenges ahead

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Abstract. This paper offers a comprehensive critical review on digitalisation in rural areas, drawing on international and EU policies, scientific and grey literature and real-life examples from two European H2020 research projects. In doing so, it aims at providing a basic conceptual framework encompassing three main intervention areas, with relative sub-themes, identified as relevant for rural areas, namely: the rural digital divide, the attractiveness of rural areas and opportunities for strengthening local governance. For each of these broad themes, the role of digital tools is explored and supported by case study examples providing valuable insights and real-life applications in rural settings.

Keywords: digitalisation, digital divide, rural areas, rural policy, governance.
JEL codes: Q0, R00.

HIGHLIGHTS

- Rural and remote areas hold great potential to realise the benefits of digital transformation.
- The essential conceptual framework is composed by three main areas of intervention: the digital divide, the attractiveness of rural areas, and rural governance.
- Careful reflection on these areas should accompany any consideration about, and processes of, rural digitalisation.

1. INTRODUCTION

Since the launch of the initiative on the Long-Term Vision for Rural Areas (LTVRA) by the European Commission, rural areas have been gaining momentum as a core component of the European society. Being home to 30% of the EU's population (i.e. about 137 million inhabitants) and extending over 80% of the EU's territory, rural areas are, in the words of President Von der Leyen "the fabric of our society and the heartbeat of our economy. The diversity of landscape, culture and heritage is one of Europe's most defining and remarkable features" (European Commission, 2021).

The heterogeneity of rural areas has been long acknowledged (OECD, 2006), and it is also recognised that rural areas overall have been changing profoundly in the past decades as a result of trends occurring at global level (Bock, 2016), such as urbanisation, globalisation, environmental and technological change, as well as social, political, economic and ideological pressures (OECD, 2019; Woods, 2019). Population decline and ageing are particularly significant phenomena in rural areas compared to cities and towns (European Commission, 2021a), and are further exacerbated in the most remote areas due to the outmigration of economically active people, and especially of young women (European Commission, 2021a).

Life in remote areas is in general characterised by a low level of well-being, due to limited or difficult access to basic services such as healthcare, education, and transport (Casini, 2019), and ensuing dependence on private cars for accessing quality essential services at a distance (European Commission, 2021). Further issues related to climate change, environmental damage and biodiversity loss pose additional, significant threats to the quality of life in rural areas, potentially undermining their capacity to recover and progress (European Commission, 2021). The risk is that, if no decisive action is taken, the current loss of attractiveness combines with multiple problems, and eventually strengthens a vicious circle of marginalisation leading to rural areas' ultimate decline (Bock, 2016). The public EU Long Term Vision consultation has identified inadequate or lacking infrastructures, scarce employment, and poor digital connectivity as the most pressing issues to be urgently addressed (European Commission, 2021). As the latter is concerned, the EU Commission observed that only 59% of households in rural areas are provided with next generation access broadband (>30Mbps), a much lower share compared to the average EU level (87%) (European Commission, 2021).

Despite many challenges, numerous opportunities have been identified for the future role of rural areas in the EU, ranging from development of the bioeconomy and management of natural assets to tourism and climate change mitigation: digital connectivity and technologies, it has been emphasised, are key enablers for all such activities and sectors (European Commission, 2021). In the last couple of years, the COVID-19 outbreak had a role of accelerator of the use of teleworking, remote learning, and e-services, opening opportunities for settling in rural villages and towns, which have become more attractive at the prospect of long commuting and chaotic containment measures in urban centres (OECD, 2020; ENRD, no date).

However, these changes did not come without issues: the hard circumstances experienced by large shares of vulnerable people, notably the elderly, living in rural areas with little or no healthcare services (OECD, 2020) were in some cases exacerbated by the phenomenon of "coronavirus holidays", i.e., the mass move to second homes observed, for instance, in the Welsh countryside (Goodwin-Hawkins, 2020).

In the agricultural sector, the fourth industrial revolution driven by digitalisation has been prompting the development of digital solutions designed for activities on-farm (e.g., field sensors, GPS guidance systems) and for the whole food value chain (e.g., e-commerce platforms, food traceability systems) (Rolandi *et al.*, 2021). Such instruments may contribute to alleviate the impacts of depopulation and abandonment in rural areas, e.g., by ensuring access to markets, creating economies of scale, providing new job opportunities, and reducing the physical burden of farm labour (Ferrari *et al.*, 2022; Rolandi *et al.*, 2021; Popescu *et al.*, 2020). Nonetheless, "digitalisation is a socio-technical process" (Brunori, 2022), that involves the adoption and integration of digital technologies into various aspects of our lives, societies and organisations. As such, it may generate many expected and unexpected impacts which can affect the social, environmental, economic and governance dimensions (or domains) of rural areas (Rolandi *et al.*, 2021; Rijswijk *et al.*, 2021). Therefore, scholars suggest that the complexity of digitalisation impacts be considered when such processes are involved (Brunori, 2022; Klerkx *et al.*, 2021; Rijswijk *et al.*, 2021). Issues such as social exclusion of vulnerable and less educated actors, disparities between large and small economic players, dependency on technology and loss of skills, detachment from nature, privacy, data security and ethical issues are among the negative and interconnected impacts which may potentially affect rural areas if unmanaged processes of digitalisation were to occur (Ferrari *et al.*, 2022; Rolandi *et al.*, 2021).

In consideration of all the above, the present paper aims at appraising available scientific and grey literature on the role of digitalisation processes in rural areas and at putting forward a basic conceptual framework based on a set of three main areas of intervention which cannot be disregarded in any rural strategy. These areas' identification draws also on the preliminary reflections made in the context of two European Horizon 2020 projects adopting multi-actor approaches to collect research needs from practice and inform policy and practice in turn.

The remaining part of the paper is structured as follows: Section 2 provides a short outline of the EU policy context in relation to digitalisation objectives in rural areas. Section 3 illustrates the methodology used, while Section 4, 5 and 6 delineate the three intervention areas identified for supporting processes of digitalisation in rural areas, namely: the rural digital divide, the attractiveness of rural areas, and opportunities for strengthening local governance. Concluding remarks are given in Section 6, bringing the paper to a close.

2. THE POLICY CONTEXT

The Communication on the LTVRA (European Commission, 2021) has identified four primary areas of intervention with the goal of strengthening rural areas, with digitalisation acting as a cross-cutting factor. The first area of action is designated as "Stronger rural areas" and is meant to be the first step in achieving all other areas. Here, digital tools are to offer creative solutions for the delivery of services, opening the door to the possibility of developing rural communities that are desirable as a place to live. The second topic, "Connected Rural Areas", discusses the importance of digital infrastructure when it comes to the use of services like e-Health, home banking, digital administration-related services, and more services to promote the inclusion of women and vulnerable groups in rural areas. "Rural Digital Futures" is one of the nine flagship initiatives in this area of intervention. It aims at promoting rural areas' digital transformation by acting upon:

1. Digital connectivity, to bridge the gap between rural and urban areas and enable universal and affordable access to high-speed connectivity. To this purpose, a Broadband Competence Offices Network has been recently launched[1] to support EU countries in implementing broadband's rollout.
2. Digital technology, which refers to the digital innovation and new technologies that may contribute to the development of rural areas, through funding from Horizon Europe and Digital Europe Programme (DIGITAL).
3. People, by promoting the development of digital skills and entrepreneurship, so that everyone can benefit from the digital transition, through funding from the European Social Fund (ESF) and the European Agricultural Fund for Rural Development (EAFRD).
4. Measuring progress towards closing the digital gap, by rearranging existing indicators, and providing a Rural Digital Index (European Commission, 2021: 19).

The third intervention area outlined in the LTVRA focuses on developing "Resilient rural areas" that promote well-being. The primary objectives of this area are to preserve natural resources and create areas that are more resilient to natural hazards, climate change and economic crises. Digital tools are considered valuable instruments in achieving these goals, as the use of sensors can provide insight into soil characteristics and inform better decisions on potential interventions. In the fourth intervention area, "Prosperous rural areas", digital literacy plays a crucial role. The ability to use digital tools is considered essential for diversifying economic activities.

The LTVRA has identified nine flagships to guide its actions, which will be implemented through the Rural Pact and Rural Action Plan. The success of these plans will also depend on the involvement of the Rural Pact Community, who will contribute ideas and initiatives to help achieve the objectives of the LTVRA.

Rural areas' significance is also evident when considering other EU policies, such as the European Union's Green Deal and the current European Digital Strategy that falls under the digital agenda. For instance, rural areas are essential for achieving the EU Green Deal's objective of making Europe carbon-neutral by 2050 (European Commission, 2019). In addition, the circular and bioeconomy development, the preservation of biodiversity, and renewable energy production offer numerous opportunities for rural areas. In these sectors, the EU assigns digitalisation a significant role in policy implementation.

The current digital agenda in Europe is centred on the digital transformation envisioned for the digital decade (2020-2030). As part of this vision, the European Commission set out the 2030 Digital Compass: the European way for the Digital Decade (European Commission, 2021b), confirming the role of rural areas in achieving the objectives of the EU Green Deal, the Farm to Fork and Biodiversity Strategies. However, to reach a level of efficiency capable of significantly improving the quality of life in rural and remote areas, actions are needed, and what needs to be primarily eradicated is the digital divide and consequent "digital poverty" (European Commission, 2021b).

As a component of the current digital agenda, the EU Commission has recently introduced a Declaration on digital rights and principles, the aim of which is to foster a digital transition shaped by European values. The proposed rights and principles are structured around six key values that are fundamental to promoting a sustainable and human-centric digital transformation, namely:

1. Putting people and their rights at the centre of the digital transformation.

[1] Details are available at https://digital-strategy.ec.europa.eu/en/policies/bco-network

2. Supporting solidarity and inclusion.
3. Ensuring freedom of choice online.
4. Fostering participation in the digital public space.
5. Increasing safety, security and empowerment of individuals.
6. Promoting the sustainability of the digital future (European Declaration of Digital Right and Principles for the Digital Decade: 2-7).

In addition, the new Common Agricultural Policy (CAP) is one of the tools that will be used to implement the Farm to Fork and Biodiversity strategies in rural areas, as well as to promote knowledge and innovation. In the new CAP, Strategic Plans are demanded to each Member State to attain the specified targets through their National Digitalisation Strategies.

3. METHODOLOGY

The paper is structured as a critical literature review, and presents, analyses and synthesises material from diverse sources with the aim to develop a basic conceptual framework to support rural digitalisation processes. It therefore identifies a set of three main areas of intervention which should form the foundation of rural strategies.

Besides the appraised scientific literature and most recent EU policies in the field, the paper builds upon, and further expand, previous work carried out under the framework of two European Horizon 2020 projects, namely: DESIRA and SHERPA, in which the authors were actively involved, respectively as coordinators and partners.

DESIRA (Digitisation: Economic and Social Impacts in Rural Areas) involved 25 partner organisations (research institutes, NGOs and SMEs) coordinated by the University of Pisa and was completed in May 2023. It aimed to enhance the society and political bodies' capacity to effectively address the challenges arising from digitalisation in agriculture, forestry, and rural areas.

Sustainable Hub to Engage into Rural Policies with Actors (SHERPA) is a four-year project (2019-2023) with 17 partners. Approaching its final completion, SHERPA has been gathering knowledge to contribute to the formulation of recommendations for future policies relevant to EU rural areas. It has done so by creating a set of science-society-policy interfaces as a forum for two-way exchanges of ideas for co-learning and co-creation of knowledge at regional levels among a wide variety of rural actors.

By including cases from the two projects – namely: Multi-Actor Platforms (MAPs) and Living Labs operating at regional/national level for knowledge co-creation and sharing on digitalisation in rural areas – the review acknowledges the contribution of multi-actor approaches in generating and integrating different kinds of knowledge through collaboration (Lawrence *et al.*, 2022; EIP-AGRI, S. P., 2017). After the literature review, the cases were therefore taken in consideration to prioritise and identify the areas that are the main objective of the present contribution. The main key points as critical review emerged from previous academic contributions.

4. ADDRESSING THE RURAL DIGITAL DIVIDE

COVID-19 has exposed the digital divide as never before (Aissaoui, 2022), revealing many contradictions of the digital era. Aware that the concept has a vague and extensive nature, which make it applicable to very different contexts, we here refer to the digital divide as the difference in access to, and use of, information and communication technologies (ICTs) between urban and rural areas, that remains despite many advances in recent years (OECD, 2018). Townsend *et al.* (2013) point out that the rural digital divide is a complex issue caused by persisting challenges of connecting remote areas and the characteristics of rural populations that may hinder the adoption of technology. Rural areas tend to have weaker infrastructures and less human capital, both constituting critical barriers for engaging with the next phases of technological innovation (Cowie *et al.*, 2020). As urban areas continue to improve technologically leaving rural areas further behind, the digital divide constitutes a new layer of spatial inequalities in our society (Dubois and Sielker, 2022).

The UN-Habitat (2022) recognises that rural areas are affected by a 'triple digital divide', which encompasses broadband connectivity, skills, and uptake. Overcoming the rural digital divide will therefore depend on addressing the interaction among the following three determinants: connectivity, digital capital, and motivation.

4.1. Connectivity

An increasing number of daily activities and services, ranging from healthcare and education to work and social networking, are carried out online, making access to broadband "an essential tool for participation in modern society" (Townshend *et al.*, 2013). Although this is even more valid for remote rural areas, little information is available to measure the rural digital divide at the EU level. Among available data sources, the Digital Economy and Society Index (DESI; European Commission, 2022) analyses the state of digitalisation in Europe, and provides data on connectivity. According to the DESI report, while the internet gap on broadband has decreased in recent years, this is not the case for the fixed very high-capacity network (VHCN), for which the gap between rural and other areas has increased. This confirms that the digital divide is a complex and dynamic phenomenon (Van Dijk and Hacker, 2003), and that proactive approaches are needed for addressing it. The connectivity gap is a case of market failure: in sparsely populated areas, the demand is not sufficient to recover the cost of infrastructure investment. This can lead to a digital divide problem, as a lack of infrastructure can hinder the demand for internet-based services and the lack of demand may discourage investment from internet providers, leaving rural areas underserved (Malecki, 2003). Moreover, the problem is constantly evolving as technology advances, requiring an upgrade of infrastructure (Salemink *et al.*, 2017). To address these market failures, public support is required, which can come from either the government or local municipalities and public-private partnerships. These partnerships can play a crucial role in promoting digitalisation (Gerli and Whalley, 2021; Randall *et al.*, 2020): for instance, bottom-up models to finance and deploy high-speed networks led by municipalities or community-run enterprises have proved successful in Sweden, where nearly 50% of local fibre networks are owned by such enterprises (ENRD, 2018). Different policies exist in OECD countries for addressing the digital divide, which include the imposition of regulation for coverage of rural areas by providers, financial support, planning and monitoring (OECD, 2018).

4.2. Digital capital

It has been emphasised that "digital infrastructure is a necessary, but not a sufficient, condition for economic development" (Tranos, 2012: 332). Individuals or households need specific resources to use digital technologies, which can be referred to as digital capital. Digital capital encompasses digital competences (such as information management, communication, safety, content creation, and problem solving) and technology (Ragnedda, 2018). Literature on digital exclusion points out to low-educated people with little or no experience in using ICTs as those more at risk of offline exclusion and marginalisation and in need of empowerment (Salemink *et al.*, 2017). However, empowerment processes must consider the general economic and social conditions (Salemink *et al.*, 2017), and rural incomes are on average lower than incomes in urban areas, raising issues related to affordability of digital equipment and high tariffs for internet services.

The relevance of human capital retention and attraction in rural areas is recognised by the Centro Portugal Multi-Actor Platform operating within the SHERPA project[2]. Here, the Strategic Plan for Innovation of the Municipality of Fundão, in place since 2013, has introduced computer programming in all municipal schools, starting from children aged six and upwards, with the aim of targeting digital literacy (Mendes and Santos, 2022).

4.3. Users' motivation

The users' motivation for using digital technologies is another key determinant of the rural digital divide. It has been highlighted that the attitude towards digital technologies, and people's aspiration and usefulness in relation to their usage, are what eventually determines the level of acceptance of ICTs (Salemink *et al.*, 2017). In general, rural areas are known for displaying a lower attitude towards digital technologies compared to urban areas. However, in the face of clear needs and with knowledge about the solutions at hand, uptake by rural dwellers can be high, and motivation to learn and to use digital technologies can increase sensibly (Slätmo and Löfving, 2022). The use of internet-based instant messages, for example, responds to the need of social interaction and enables people who live far away to communicate with relatives, friends, and colleagues; online platforms and meeting spaces make possible to take part to virtual communities of interest, access resources and information (Wallace *et al.*, 2017).

However, motivation is related to the potential rewards in using digital technologies. For example, COVID-19 has functioned as a driver of motivation, e.g., in the case of the Living Lab of the Scottish Crofting Community in western Scotland activated within the DESIRA project[3]. Since the broadband was installed just before the outset of the pandemic, the inhabitants of this remote rural area were motivated to take up the advantages of digital tools at a relatively faster pace, although the oldest members of this community are likely to be excluded from the digital transformation (Townsend and Duckett, 2022). Also, digital technology design could influence motivation: low-cost, easy-to-use, compatibility with users' lifeworld would encourage technology adoption.

5. DIGITALISATION AS A DRIVER FOR IMPROVING THE ATTRACTIVENESS OF RURAL AREAS

The LTVRA envisages that, by 2040, rural areas will be "attractive spaces, developed in harmonious ter-

[2] https://rural-interfaces.eu_

[3] https://desira2020.eu

ritorial development, unlocking their specific potential, making them places of opportunity, and providing local solutions to help tackle the local effects of global challenges" (European Commission, 2021). One major challenge is therefore for rural areas to become places that are chosen to live, work, and visit, or all three. Four main components of rural attractiveness can be identified, and that digitalisation can support: the quality of the (rural) environment, the quality of social relations, the quality of work, and the quality of services.

5.1. Quality of the rural environment

The rural environment includes natural and cultural resources that offer a range of benefits to individuals such as clean air, water, biodiversity, and attractive landscapes. These qualities – which can be epitomised in the concept of the countryside capital – can be transformed into economic value through tourism and local products such as food (Willis *et al.*, 2015; Garrod *et al.*, 2006). Digital technologies can play a key role in promoting the rural environment by raising awareness and showcasing its offerings to a wider audience. For example, social media and geographical information systems can make the rural environment more visible and accessible to tourists, while virtual reality can create new experiences and support promotion strategies (Flores-Crespo *et al.*, 2022). Citizen science can also contribute to the accumulation of knowledge about the rural environment and encourage people's involvement in building a territorial identity (Tindale *et al.*, 2023).

On the other hand, rural areas are vulnerable to natural disasters, but digital technologies can aid in managing these challenges by providing real-time environmental information. This data can be used by public authorities, private businesses, and civil society to improve the management of natural resources and ensure their sustainability.

5.2. Quality of social relations

Rural areas may benefit from a strong sense of community (Townshend *et al.*, 2013), based on frequent face-to-face relationships, a reduced number of members of the community, and some shared "sense of belonging" they may attach to the place. However, this may be a limitation for some, and rural areas' physical isolation may turn into a set of challenges at the individual person, firms', and communities' level. ICTs can, on one hand, contribute to creating social capital within a community, reinforcing local social relationships; on the other, they can enable networking opportunities outside the local place of residence, especially for young people, those working remotely, commuters, and new residents (Zerrer and Sept, 2020; Wallace *et al.*, 2017).

One example comes from the case of Cloughjordan Ecovillage (Ireland) on which the DESIRA Living Lab[4] was based. Developed 10 years ago in an area with little employment opportunities ad low population density, this Ecovillage experienced significant positive impacts of digitalisation, including innovative projects, citizen-led innovation, reduction in travel to work, rural repopulation, and strengthening of local economies resulting in an improved quality of life (White, 2022).

5.3. Quality of work

The COVID-19 pandemic has prompted a re-evaluation of the role of rural areas in attracting working professionals who can work remotely. A study by McKinsey Global Institute (2020) found that more than 20% of the workforce can work remotely as effectively as they would in an office, which would result in a significant increase in the number of people working from home and have a major impact on urban economies, transportation, and consumer spending. Commuting has a relevant impact on rural economies, as it retains incomes and activates demand for goods and services (Andersson *et al.*, 2018) in areas traditionally characterised by a low users' base. Replacing commuting, especially in information-intensive work areas, with remote work would reduce carbon footprints (Bosworth *et al.*, 2023), lead to substantial savings in terms of time, energy, and improve the quality of life for workers (Adobati and Debernardi, 2022).

Significant improvements in digital platforms for real-time collaboration and communication and learning processes have contributed to reduce the productivity gap between working from a distance and working in person. However, to make rural areas attractive spaces for remote workers, both technological and non-technological factors are important: adequate connectivity is a prerequisite, and remote workers will decide to live in rural areas only if the quality and cost of living are competitive with other locations. The role of rural coworking spaces has been emphasised for its potential to increase rural areas' appeal. Bosworth *et al.* (2023) maintain that these spaces can play a role in creating rural-urban linkages and smart rural development as they combine local and extra-local networks, different sectors, and professions, with the help of social and digital infrastructures.

[4] *Ibidem.*

The potential of remote working hubs and location-independent work and study have been at the centre of Finnish and Swedish public debates in recent years. Initiatives promoted by national and regional authorities have been highlighted by the MAPs involved in the SHERPA project[5], ranging from the creation of networks of remote working hubs in Finland (Stjernberg, M., Salonen, 2022) to investments made in data storage, data mining and energy in the Swedish remote area of Norrbotten (Slätmo and Löfving, 2022).

Digitalisation plays a role also in traditional sectors, such as agriculture. In a whole range of activities, ranging from farm, crop and livestock management to the various stages of the supply chain and operations related to soil and water management, digital technologies can contribute to relieve the workforce and make agriculture more attractive (Brunori, 2022).

5.4. Quality of services

It is well-acknowledged that rural communities tend to face unfavourable living conditions, compared to urban centres, due to limited economic productivity, poor job prospects, and inadequate services and infrastructures. The closure of essential facilities such as schools, post offices, grocery stores, and healthcare services, often only available with extended travel times, has led to a decline in rural populations, especially of young and skilled individuals (Zerrer and Sept, 2020; O'Shaughnessy *et al.*, 2022).

Digitalisation is intended as a viable alternative for delivering cost-effective, remotely coordinated, public services in the most remote rural areas (Dubois and Sielker, 2022) and is gradually alleviating some of the traditional deficiencies, as e-commerce, home banking, and home entertainment provide access to commodities and services otherwise unavailable. Digital services provided by public administrations are reducing the need for in-person visits, and distant learning can be used to provide supplementary skills to children. Sharing models with app-based solutions, for instance, may contribute to address the lack of mobility services (SMARTA, 2019). E-Health can help bridge the gap between rural populations and the healthcare system, enabling self-monitoring and offering feedback to patients, if not considered just in terms of a reduction of costs. However, the perception of a lower quality of basic digital services may raise issues of territorial inequalities, if such services are compared to those available to urban dwellers: a sense of "reduced citizenship" and "less deserving" communities has been referred to by older adults experiencing digital healthcare (Lindberg and Lundgren, 2022). Likewise, digital services may benefit those segments of population with higher education and income level, who are more likely to benefit from ICTs, exacerbating existing inequalities.

One example of application of digital tools to provide specific services to vulnerable rural residents is the case of elderly care in Tamási, Hungary[6]. This small town implemented a sensor system to monitor the conditions of the most disadvantaged households and alert social workers if their homes are not heated. In this way, the municipality gained valuable knowledge about heating habits, which facilitates the planning of the social supply of firewood in winter (Gaál and Bálint, 2022).

6. STRENGTHENING LOCAL GOVERNANCE THROUGH DIGITALISATION

The LTVRA includes an area focused on improving the capacity of local actors to align their goals around strategic areas. On this purpose, one of the nine flagship initiatives included in the Rural Action Plan is «a rural revitalisation platform ... as a one-stop shop for rural communities, rural project holders and local authorities alike to collaborate», which should be especially targeting remote rural areas (European Commission, 2021).

Various sectors are impacted by processes of (rural) digitalisation, including infrastructure, education, data, healthcare, across multi-level and sectoral policies. It is therefore crucial to consider this interdependence the other way around, too: policies and programmes affecting rural digitalisation may go beyond the initiatives explicitly targeting digitalisation objectives, and include sectoral legislations, policies and funds which may go overlooked in the definition of strategies.

It is therefore valid also for digitalisation that traditional governance patterns that rely on sectoral specialisation, and hierarchical relationships are no longer sufficient for addressing cross-sectoral challenges (Gkartzios and Lowe, 2019). Instead, adaptive governance models are necessary, enabling the integration of knowledge from policy, civil society, and science, and fostering innovation while balancing power (Brunori *et al.*, 2021). Such *ad hoc* governance arrangements should acknowledge and value the contribution of all actors, as is the case with civil society organisations which, often informally, commit to bring fast broadband and digital solutions in underserved areas of Sweden, in the absence of

[5] https://rural-interfaces.eu

[6] A detailed account of the initiative is available at http://okosvaros.lechnerkozpont.hu/en/node/674

adequate responses from the public and private sector (Slätmo and Löfving, 2022).

Information and communication play a key role in improved governance, opening new ways for policymaking throughout the policy cycle, from problem definition to policy evaluation. At the problem setting stage, for instance, providing detailed information can change the way governments engage with citizens. The latter can take informed choices, raise issues in public debates and encourage administrators to act, while also providing feedback on plans and policies in development.

To effectively harness the potential of data, a strong coordination effort is needed to create a shared and integrated data space for public usage, wherein administrative, environmental, business, statistical and citizens-generated databases are made interoperable. Although requiring ad hoc governance arrangements – with clear rules and allocation of responsibilities, technical capacities, and specific data protection regulations – such integrated data systems would increase the value of single databases (World Bank, 2021).

The Living Lab GeoDesign in Rural Poland provides one example of how digitalisation has the capacity to potentially enhance participation in spatial planning processes, and eventually improve their transparency (Grzyś, 2022). However, the success of such process will depend upon digital skills of the stakeholders involved and the awareness of local authorities, who are to imagine new ways in which a community can become a partner in the planning process.

The role of participatory approaches and multi-actor platforms has been particularly emphasised in the SHERPA H2020 project, to reduce the gap and build trust between local actors and public authorities at higher level, but also to bring into view the specific needs of highly different rural contexts (Slätmo *et al.*, 2021).

7. CONCLUDING REMARKS

The image and public discourse about rural areas have been oscillating between that of a "rural idyll" (Bell, 2006), an idealised place where proximity to nature automatically translates as well-being and quality of life, and that of traditional places away from the vitality and innovation of their urban counterparts, which risks making it a self-fulfilling prophecy and feeding a vicious cycle of marginalisation (Bock, 2016).

Neither interpretation is real or desirable, nor is there an established path or instrument to address all the issues that affect rural areas. Recent years have shown that rural and remote areas hold great potential to realise the benefits of digital transformation and be no longer isolated thanks to the availability of digital tools (ENRD, 2021). However, it cannot be assumed that digital technologies alone will lead rural areas (and the agriculture and forestry sector) to a desirable outcome (Brunori *et al.*, 2021), and a growing body of literature raises concerns over the potential impacts – both positive and negative – of digitalisation, urging to move away from simplistic approaches (Rolandi *et al.*, 2021; Rijswijk *et al.*, 2021; Salemink *et al.*, 2017). In this awareness, Brunori *et al.* (2021) suggest a set of guiding principles for digitalisation processes in agriculture, forestry and rural areas, assuming as a starting point that digitalisation is no more than a means to an end.

Although significant efforts are being put forth to attain digitalisation objectives in European rural areas, unanswered questions remain about how digitalisation can function as a tool and a driver of transformation, and whether the envisaged "twin transition" will occur (Brunori, 2022). In addition, numerous policies may have indirect impacts on digitalisation processes in rural areas, extending beyond the specific initiatives that receive more attention in digital strategies, and should also be scrutinised (Arcuri, 2023).

In this paper, we proposed a simple and essential conceptual framework to accompany any reflection about, and processes of, rural digitalisation. It starts from acknowledging the role assigned (e.g., by policy) to digitalisation in revitalising rural areas, and assumes this role as always instrumental in achieving broader objectives. The available evidence emphasises the importance of recognising both the potential benefits of digital transformation and the critical need to address the risk of digital exclusion and exacerbation of the digital divide, especially among low-skilled and vulnerable groups. While exploring opportunities, it is therefore crucial to pay special attention to ensuring equitable access and opportunities for all individuals, within and beyond rural areas.

The main implication of the proposed framework is to give priority to strengthening strategic capacity for digitalisation, which, first of all, should be based on a diagnosis of the need of rural communities, an assessment of the digital readiness of the actors, the design of technological solutions appropriate and affordable, and the assessment of their potential impact on rural communities.

The role of public authorities is critical to ensure this strategic capacity, that is able to provide suitable infrastructures and essential services to rural residents. Coordination and cooperation among civil society, policymakers, businesses, and researchers is to be encouraged. Further inquiry will be necessary to address these concerns, as much is yet to be done to make sure that rural communities can leverage the benefits, and prevent the risks, deriving from digitalisation.

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Digitalisation and just transition - Research article

Engaging with barriers hampering uptake of digital tools

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Abstract. It is widely accepted that digitalisation can allow us to tackle the social, economic and even environmental challenges that agro-food systems are currently facing. There is a vibrant debate regarding the challenges one might face when adopting digital tools. This article engages in this discussion by exploring how barriers farmers encounter when implementing digital solutions manifest themselves as practical challenges farmers have to resolve. To do this, the article explores three cases in Latvia's beef farming sector. The article focuses on the following two questions: 1) what were the challenges that the groups of farmers faced while trying to implement the new solutions; 2) how did these challenges transform the initial solutions the farmers were trying to implement? The three cases represent three initiatives at various stages of development (an emerging cooperative of beef farmers; an unorganised attempt by farmers to develop joint digital marketing tools; an online shop developed and maintained by an individual enterprise). The article argues that there are multiple creative strategies for dealing with barriers to digitalisation, but studies focusing on different obstacles to digitalisation should also be mindful of pre-existing issues that hamper digitalisation, while simultaneously being impervious to purely digital fixes.

Keywords: digital tools, barriers, rural development, beef sector.
JEL codes: Q1, M31, O18.

HIGHLIGHTS

- Digital tools can be used to improve farmers' ability to reach out to consumers.
- Farmers have access to digital skills and technologies allowing them to implement digital tools in their daily activities.
- To benefit from the tools, farmers need a clear grasp of the links tying their business and the issues they are hoping these issues will resolve.

1. INTRODUCTION

It is widely accepted that digitalisation can allow us to tackle the social, economic and even environmental challenges that agro-food systems are currently facing (Barrett *et al.*, 2020; Fielke *et al.*, 2020). While there are more cautionary approaches listing the potential threats associated with the misuse of these technologies and overreliance on digital tools (Klerkx and Rose, 2020), the general agreement seems to be that these tools will play a pivotal role in sustainability transitions. Interest in and access to digital tools differs across various groups. This is likely to increase the digital divide – a situation where some parts of society benefit from these tools more than others (Schneider and Kokshagina, 2018; Dufva and Dufva, 2019). Thus, an in-depth understanding of how actors engage with and make use of these tools can help to limit misuse, and other potential negative side effects (especially those related to unequal adoption rate) of digitalisation, and to make use of the transformative potential associated with digitalisation. This highlights the importance of exploring how digital technologies are adopted by practitioners (Klerkx and Rose, 2020; Bronson, 2019). One area where the digital divide starkly manifests itself is when digital opportunities in rural and urban territories are compared.

There is a vibrant scholarly debate regarding the challenges one might face when adopting digital tools, suggesting a broad range of social and individual factors that can hamper the pace of the digital transition (see Bronson, 2019; Ferrari *et al.*, 2022). This article engages in this discussion by exploring how the various social, technological, commercial and regulatory (Ferrari *et al.*, 2022) barriers that farmers encounter when implementing digital solutions manifest themselves as practical challenges that must be resolved. To do this, the article explores three cases of digitally assisted commercialisation in Latvia's beef farming sector. The article focuses on the following two questions: 1) what were the challenges that the farmers faced while trying to implement the new solutions; 2) how did these challenges transform the initial solutions the farmers were trying to implement?

The three cases represent three commercial initiatives at various stages of development. The first case is an emerging cooperative of beef farmers looking for new retail channels (the cooperative). The second is an attempt to develop joint digital marketing tools by a group of farmers (the group). Finally, the third case is an online shop developed and maintained by an individual enterprise (the enterprise). In all three cases, the purpose of the practices and solutions that were adopted was to facilitate the farmers' ability to engage with customers and sell their products. The article has chosen to focus on the process of developing and implementing these solutions to illustrate the mundane entanglement of technological solutions, the specific needs of the farmers involved and the contextual arrangements in which their activities are embedded.

The article starts by providing a short overview of digitalisation and the beef sector in Latvia. It continues by outlining several groups of barriers that farmers can encounter when engaging with digital tools. The article subsequently describes the data used in the article and the three cases. This is followed by a section focusing on how different barriers manifest in practice. The article argues that there are multiple creative strategies for dealing with barriers to digitalisation, but studies focusing on different obstacles to digitalisation should also be mindful of pre-existing issues that hamper digitalisation, while simultaneously being impervious to purely digital fixes.

2. TRENDS OF DIGITALISATION IN LATVIA

Recent data suggest that rural digitalisation in Latvia can be viewed in contrasting ways. On the one hand, Latvia appears to be in a good position concerning digital infrastructure and e-services. On the other hand, digital transformation does not appear to be high on the policy agenda and some issues hamper rural digitalisation in particular. For instance, Latvia's digital strategy is outlined in the *Digital Transformation Guidelines for 2021-2027* (VARAM, 2020), a document that was prepared in 2020. However, while the guidelines mention the digital gap between rural and urban areas, little attention is paid to this issue in the descriptions of specific goals.

Similarly, the country performs well in rankings concerning digital public services and connectivity, but the population has comparatively poor digital skills (DESI, 2022). Furthermore, there are clear regional differences - skills are much better in urban centres. Likewise, despite overall broadband and mobile network coverage being high, there are pronounced differences in internet accessibility between rural and urban areas, largely determined by low population density and business activity. Internet usage in Latvia is increasing every year and 85.4% of the population used the Internet in 2019. However, there are regional disparities and, perhaps not surprisingly, regular internet usage is higher in urban areas, and lower in rural regions (Central Statistical Bureau of Latvia, 2019). What is more, Latvia is believed to be lagging in terms of the use of e-commerce by both businesses and individuals (OECD, 2021). DESI index illustrates that Latvia's enterprises are among the least active when it comes to integrating digital technologies into their everyday activities. This claim holds for most of the surveyed digital solutions (DESI, 2022). In fact, the digitalisation of the private sector is the worstperforming area of the overall digital transformation making the adoption of digital technologies in the private sector a prominent yet unexplored research topic.

Finally, despite the creation of numerous state municipal platforms for the provision of digital services, and policy measures and support programmes aimed at facilitating digitalisation, not all social groups have been reached, meaning that some do not benefit from these developments. In conjunction, these factors can hamper the capacity of rural communities to make use of the opportunities offered by digitalisation, while simultaneously making them more vulnerable to the risks associated with the digital divide (DESI, 2022). This raises the question of what can be done to maximise the socio-economic benefits of digital transformation in rural areas while countering some of the potentially negative impacts. However, in addition to structural obstacles, one must also consider micro and meso-level barriers that prevent rural businesses and people living in rural areas from making the most of digital tools.

3. ADOPTION BARRIERS

The willingness to adopt new digital tools can vary between farms and differ from technology to technology (European Commission, 2018b). Researchers have pointed to several factors that can affect this process, such as skills (Adão *et al.*, 2022), initial investments (Bronson, 2019), real-life conditions, perceived rewards, etc. The diversity of relevant factors underlines that digitalisation is a complex process and thus, the factors that are considered when exploring the process should go beyond the technical nature of implemented solutions (Rijswijk *et al.*, 2023). Based on the results of the DESIRA project, Ferrari *et al.* (2022) suggest that there are four major categories of barriers and five categories of drivers that impact the ability of stakeholders to benefit from digital tools. The barriers are socio-cultural (barriers: demographic, distrust, fear, values, competence, complexity), technical (barriers: connectivity, dependability, usability, scalability), economic (barriers: cost, scale), and regulatory-institutional (barriers: data management, regulations).

- *Socio-cultural* barriers incorporate aspects rooted in the social practices and beliefs of the actors involved. This group of barriers also includes the socio-demographic trends and organisational structures affecting uptake. For example, engagement with digital tools is interlinked with trust and distrust in technologies, yet the level of trust is strongly dependent on knowledge and experience (Rijswijk *et al.*, 2023). Likewise, there are studies illustrating an unequal distribution of digitalisation-related knowledge and advice (Fielke, 2020) facilitating the emergence of groups that might be harder to convince or might struggle to engage with emerging technologies.
- *Technical* barriers capture technical aspects that either require infrastructure that is not available to a farmer or is not compatible with the farmer's needs/ existing on-farm solutions. The concerns related to technical barriers are many and they can cover somewhat different issues. For example, some researchers have expressed doubts regarding the capacity of some technologies to sufficiently service the needs of farmers (Zhao *et al.*, 2019). Meanwhile, others have stressed the challenges related to access or unequal access to these technologies or the goods produced by the technologies (Fielke *et al.*, 2020).
- *Economic* barriers capture farmers' economic capabilities and economic needs. High costs are an issue for many of these technologies (see Zhao *et al.*, 2019), and developers of technologies primarily focus on farms that have the finances needed to adopt the technologies, resulting in different adoption rates among farmers (Bronson, 2019).
- The final group covers *regulatory-institutional* barriers. These mainly refer to a lack of a supportive regulatory-institutional environment (Hobos *et al.*, 2018). For example, as has been shown by Zhao *et al.* (2019) – transparency (an organisational approach that is often presented as a good practice in short supply chains) provided by blockchains can also be the source of a struggle to protect users' privacy.

The following chapters will explore how these barriers manifest themselves in practice.

4. THE DATA

The article is built on three cases that represent different attempts at commercially motivated digitalisation initiated by Latvian beef farmers. The three cases have been explored to a different level of detail, but they are connected via a set of discussions with the representatives of the beef farming sector organised by the authors between 2019 and 2022 as part of a living lab for the DESIRA project. The purpose of these discussions was to arrive at a joint understanding of how digitalisation could support the sector, strengthen its market position, and establish a more prominent position in the local food market. Thus, the selection of the cases was not motivated by pre-defined criteria. They were identified as part of a broader exploratory study and chosen postfactum as illustrative examples of different strategies and associated successes and failures.

The data was gathered in two focus groups, several workshops, and joint excursions between 2020 and 2022. The workshops and focus groups were supplemented with interviews with representatives of the initiatives and with experts operating in the sector, and participant observation during the workshops themselves (e.g. taking field notes about the interactions between participants). It should be noted that the focus groups and workshops were not case-specific and tackled broader questions pertaining to digitalisation. The interviews, however, focused explicitly on the process and experience the initiatives had while implementing the digital tools in question. The interviews differed in length, however, in general, they were around one hour long.

The data were then iteratively analysed to identify the challenges limiting farmers' ability to fully benefit from digital tools, with the four categories of barriers as proposed by Ferrari *et al.* (2022) used as the analytical frame. Thus, the subsequent analysis is structured along the lines of the major factors that hamper the adoption of digital tools.

5. THE THREE CASES

The three cases considered in this article represent three attempts by beef farmers to introduce digital tools in their activities for commercial purposes.

The first case is a farmers' cooperative established in 2021 (henceforward referred to as the cooperative). The case represents an attempt to introduce a joint trading approach with a focus on the members' push to develop an online platform to attract and communicate with customers and align production and demand. The cooperative was started by a group of farmers each of whom had a separate consumer group that was contacted via email, WhatsApp, SMS or other means. It is one of two cooperatives that have recently emerged in the high-price beef sector. The ambition of the cooperative was to develop a local high-quality beef market and improve the coordination between farmers working in the market. The cooperative has been exploring ways the members of the cooperative could benefit from joint digital solutions: the cooperative has been developing a joint database of clients and a joint ordering system that would allow the members to organise their trade, production and logistics together and would offer customers one entry point for purchasing the goods produced by the coop. It was hoped that such a system would improve the members' ability to plan their production processes. After making some investments in IT solutions and trying to develop the joint system, the coop has failed to centralise trade and farmers largely continue to engage customers separately. Thus, as it stands, the case has failed to reach its goals.

The second case is a group of farmers that came together to develop digital tools to communicate with customers (henceforward referred to as "the group"). Being part of the living lab in the DESIRA project, this group of farmers had a joint understanding of the challenge they have to address (inability to persuade consumers about the value [and associated price] of high-quality beef) and the instruments they could employ (the group was considering various digital tools). However, there was no shared vision of how exactly the issue could be resolved. While the group was interested in the issue (as attested by the personal experience of the participants with digital tools), the conversation was led by a small group of participants. Furthermore, discussions revealed important differences between participants – while some were looking for ways to use social media or similar tools to reach out to consumers, others were thinking about how state-run databases could be linked to increasing traceability of high-quality beef or discussing possibilities of using information exchange platforms to coordinate production planning (making production more efficient). Over time it became apparent that this group of farmers had a shared overall vision, but it struggled to agree on the details. Furthermore, the farms linked in the group represented substantial differences in size, technological sophistication, geographical location, etc.). Consequently, despite the time and effort invested, the group was unable to develop a plan that would be supported by everybody.

Finally, the third case is an individual farm that has developed an online shop (henceforward "the enterprise"). This online shop can be regarded as the next step in the shift of the farm towards trading their goods online. While the farm's products were initially sold via the owners' social circle, the reputation of its products grew, leading to increased demand. This increase in demand is primarily an illustration of strong market orientation and the in-depth understanding of market processes of the owners of the farm. This deep understanding was once again illustrated when the owners decided to streamline distribution and broaden the client base by creating an online shop. This initial investment has slowly grown into a much broader online system connecting trade and logistics into a joint system. Furthermore, the online system is now being employed by other enterprises that sell organic products, allowing the online shop to broaden the scope of products sold, satisfy the expectations of a larger group of clients and reduce the costs of logistics.

6. THE CHALLENGES OF IMPLEMENTATION OF DIGITAL TOOLS

In the following sections, the article will discuss how the barriers proposed by Ferrari *et al.* (2022) played out in practice.

6.1. Socio-cultural barriers

The three cases, while representing different approaches to introducing digital tools, illustrate similar motivations to explore the opportunities provided by digital tools. Specifically, the motivation was rooted in the scarcity of local clients and the need to find a more efficient way to attract more affluent customers living in the capital of Latvia. Demographic processes such as (peri)urbanisation and income disparity between urban and rural areas forced the rural entrepreneurs (in this case – farmers producing high-quality beef) to search for markets outside of their immediate surroundings and focus on potential customers in cities.

The depopulation of rural areas in Latvia has had several side effects, including higher per capita costs for new infrastructure projects and the loss of potential consumers in direct proximity. Digital means are perceived as a promising option to deal with some of these issues. The envisioned result of the three cases was an online solution (a mix of ideas incorporating online shops, Facebook groups, interlinked databases, etc.) that would enable all participants to reach out to potential customers, convince consumers that the products are of high quality, and allow farmers to commercially benefit from the newfound segment of buyers. The farmers involved already had a group of clients buying their products. However, digital solutions offered the possibility to broaden the customer base, increase the predictability of trade and a possibility to rethink the pricing of the products sold.

However, the solutions imagined by the initiatives required collaboration. Only the third case (the enterprise) decided to work alone – initially, just one farm was involved in developing the system. This case also was the only one among the three that managed to build a successful platform. The first and second cases involved negotiations between the different parties involved, and this ended up illuminating the internal challenges that these initiatives had to tackle. On the one hand, the two groups had to ensure that there was trust between the participants. On the other hand, they needed to secure trust in the system they were building.

The challenges rooted in a lack of mutual trust can be illustrated with an example from the case of the cooperative. Joint engagement with clients was linked to the idea of joint planning – pulling clients into one database and distributing them geographically was expected to improve the efficiency of logistics and processing. To make the system work, farmers needed to mobilise their existing customers to use the system – they needed to demonstrate their trust in the system (and the endeavour as a whole) by submitting the contact information of their clients for entry into a centralised database. However, the farmers involved chose not to do this. Insufficient mutual trust and lack of trust in the digital solution being developed turned out to be a substantial barrier. This hampered the group's ability to benefit from already existing resources present in the group. While the group as a whole supported the new solution in principle, many of the members were not ready to commit to it with their client base. It should be mentioned that insufficient mutual trust and willingness to cooperate was also evident in the case of the Group. This hampered the farmers' ability to reach an agreement on minor, yet key aspects needed to start to work on a more practical solution.

However, it was also apparent that stakeholders did not seem to be closed-minded or suspicious of digital tools in general. Instead, most of the farmers involved in our examples could be described as having a broadly pragmatic and open-minded outlook when engaging in the debate, especially as regards their business. This is attested by the fact that many of them were already experimenting with various digital tools (e.g. using communication tools, farm management systems, benefiting from databases maintained by the state, introducing sophisticated trading system to sell animals in auctions to customers from abroad etc.), some of which required shifting away from their typical practices. As one farmer explained – she felt she was too old to fully benefit from new communication tools and social media, and thus she felt that she was not sufficiently in touch with her clients. To counter this, she hired a part-time specialist who oversaw her communication channels. This illustrates that for at least some of these farmers entrepreneurialism and the need to make decisions that benefit their business outweigh discomfort with new technologies and new practices. However, failure to establish trust gave rise to anxiety and implicit suspicion. In the case of the cooperative, because farmers did not fully trust the introduced solutions or the group of farmers they were working with, they did not fully commit to the developed database. They feared that by committing to it they would lose their clients.

Cooperation (or lack thereof) is also relevant when thinking about competencies. Although competencies can be a barrier to implementation, evidence from all three cases illustrates that farmers who are looking for a way to benefit from digital tools are open to attracting support and assistance to facilitate the implementation of digital solutions and maintain them in the long term. In addition, the cases reveal widespread access to formal and informal consultations on technical issues related to these tools. For instance, the cooperative reveals how the networks of contacts within the cooperative are used to support the initial attempts to resolve technical issues with their tool – the initial system they built was mainly managed by friends and relatives who had the necessary knowledge. However, even though access to technical skills was not, in principle, an issue, understanding what exactly the farmers needed was, and this problem was dealt with differently in each of the three cases. In the case of the cooperative, the lack of clarity about what is necessary led to several unnecessary functions initially being envisioned for the tool; in the case of the group, it precluded farmers from agreeing on what to do; in the case of the enterprise, a professional was brought in to overcome the challenge.

The difficulty in identifying what solution would work best for these groups is strongly linked to another barrier – the complexity of non-digital issues farmers have to resolve. In the cases of the cooperative and the enterprise, work on the online system eventually led to a conversation about various other solutions the farmers have implemented or might have to implement, such as those related to logistics, common pricing, distribution, and common standards for various pieces of the meat they plan to sell together. While some of these issues were relatively simple to resolve, other issues – such as common pricing and joint standards – had been long-standing and had thus far been ignored. Now, however, the farmers had to address these questions and find a solution. The enterprise managed to avoid the socio-organisational challenges by building the initial solution on its own not consulting with other farmers.

6.2. Technical barriers

From the technological perspective, the three cases were relatively simple. Two of the three cases eventually developed an online shop (the cooperative and the enterprise). Meanwhile, the third (the group), despite countless ideas, never actually fully decided on what could be a workable solution. It also needs to be stressed that none of these cases was ever fully confident in where the borders of their needs lie and thus the perspective of what exactly the initiative represents changed during its development. Consequently, issues of various complexity requiring different skill sets and different technological facilities were encountered by the actors.

Connectivity can be an issue in rural areas and a noteworthy barrier to introducing new technological solutions. However, none of the solutions that are considered in these cases reported any issues related to access (to the internet) and connectivity that precluded the intended solutions from being implemented. Some of the solutions may have required constant access to high-speed internet. One of the solutions considered by the group and the cooperative – to have a live stream from the farm allowing potential customers to follow the daily life on the farm and the wellbeing of the cows in real time – required a stable internet connection. Likewise, the solution developed in the enterprise where the online shop exchanges information with the storehouse, thus constantly following the availability of products offered in the shop, also required a stable connection.

Nonetheless, the cooperative developed an online shop that does not presuppose a stable high-speed internet connection. Instead, the developed homepage is stored on the servers and all orders clients make are stored in a database located on the same server. The responsible person for advancing the project must access the database to review the orders and communicate them to the farmers. This solution does not require a fast internet connection. Thus, delays in processing the orders and can result in selling products that are no longer in stock. However, due to the relatively small scope of the operation, the group of farmers have not yet encountered any substantial problems with the solution. Consequently, for these cases, connectivity does not appear to be a limitation.

Due to the relative simplicity of the solutions under consideration, it is also not relevant to discuss the dependability of technologies. However, there might be a reason to discuss dependability in the context of trust. Trust in technology derives from trust in its ability to deliver the promised result. As has been suggested already, while the farmers were generally open to technological solutions, they were sometimes hesitant towards becoming completely reliant upon them. In the case of the enterprise, this was resolved organisationally – farmers choosing to sell their products to the online shop could still maintain their existing sales channels. Meanwhile, in the case of the cooperative farmers were expected to make the shift and sell their products via the online shop, thus demonstrating their trust in the technology and the cooperative. However, this is the step that created difficulties for the cooperative, as noted above. Furthermore, while the initiatives are working towards similar goals, they are very different. Usability is one of the dimensions where these differences are most clearly visible. For the cooperative, the solution has been arrived at via a process of trial and error. The cooperative eventually decided to go with a simple system that takes orders and can be easily maintained by people with limited IT proficiency. Although it has been described as an online shop – in reality, it would be more accurate to call it an ordering system where one expresses interest in the product, rather than buys it. Furthermore, instead of building it from the ground up, the coop decided to buy an already functional web page that was then adapted to the needs of the cooperative. Thus, it could be suggested, that the cooperative has not been affected by the potential challenges related to the technology – it just downgraded its expectations whenever it faced challenges. However, on the other hand, there are also questions regarding the relevance of the final system – has it managed to reduce the time farmers spend on engaging with clients and has it managed to attract additional clients? The challenges associated with the technical side of the online ordering system have encouraged the cooperative to abandon other additional functionalities initially envisioned for the website.

The group never introduced any specific solutions. In fact, it never got so far as to identify the best solution. In many ways, this was because the group was unable to agree on a solution that would benefit all the actors involved and could be equally efficiently introduced by all (due to differences in skills and technological facilities available). Thus, usability was a barrier in this case, and it even precluded the idea from "getting off the ground".

The enterprise chose a different approach – as the actor working to develop the online shop recognised that their knowledge was insufficient to build the necessary tool, they decided to hire an expert who could take care of this part. This may have been a more expensive decision, but it allowed the representatives of the farm to implement their original vision of what they wanted. This decision was perceived as an investment. Running the online shop gradually provided the farm with a practical understanding of how different systems can be linked together. Thus, the farm was able to build a much more complex system than its counterparts.

This leads to the final potential barrier related to the scalability of the solutions adopted, but it should be noted that none of the cases we have been looking at had a plan regarding the possibilities of increasing the scale of operation or of adding additional layers to the developed solution that would require better connectivity.

6.3. Economic barriers

The implementation of digital solutions is also directly linked to economic considerations. The possibility of engaging with longstanding challenges was the key motivation for the cases to consider the potential of digital tools. On the other hand, the actors trying to introduce new solutions had to consider the trade-offs, challenges and expenses associated with setting up and maintaining these new solutions. Costs are a significant barrier the cases had to overcome. All the solutions the cases were pursuing came with at least some investments at different stages of implementation. It is also worth noting that the cases illustrate that the notion of costs is not as straightforward as it might seem, and the actors looking to implement new solutions have the means to control the level of investments needed to implement the tools. Two of the cases considered in this article (the cooperative and the enterprise) that managed to implement a version of an online shop in their daily operations illustrate different strategies for dealing with costs. Actors looking for a way to implement a digital solution can look for a cheaper solution with the same functionality, or they might decide to cut the functionality of the chosen instrument. They have also the option to determine the balance between the work done internally and the work outsourced to professionals. The choices actors make in this regard are dependent on the competencies available in the organisation and the envisioned link between the challenges the organisation faces and the expectations it has towards the solution it is working with.

The cooperative offers an interesting insight into the trade-offs an actor has to consider. The farmers involved in the cooperative aimed at developing a system that would support trade and eventually allow them to integrate their activities and operate via this joint online platform. To achieve this, the cooperative initiated work towards several goals – creating joint logistical solutions (which meant both developing a logistics database and developing a solution for delivering the products), looking for joint processing facilities, implementing a joint marketing approach (organising shared off-line and on-line campaigns and maintaining shared profiles in social media) and designing an online shop. Initially, the vision was to integrate these different elements under the umbrella of the online shop. However, the partners could not agree on how to do it and lacked the expertise to make informed decisions in these areas. Furthermore, partners struggled to find common ground on how to resolve the issues they had encountered. Consequently, after the initial attempt to develop a joint logistical solution, this idea was shelved. The joint processing initiative suffered a similar fate – despite some internal disagreements, the cooperative was officially working with one slaughterhouse. It was expected that this solution would help to maintain the same standards for all pieces of meat sold by the cooperative and to improve planning. Still, some partners continued to use other services, thus contributing to mistrust among the members. Ultimately this meant that the cooperative had to focus on the online shop and online marketing. In both cases the cooperative mainly relied upon the internal capacity that has allowed it to technically achieve its goals yet has in general created obsolete solutions (as described previously) that will most likely fail to deliver the expected results. Partly this was because the initial budget of the investment shrunk as some of the farmers decided not to contribute.

Meanwhile, the enterprise decided to approach the challenge (development of the online shop and later – the supporting databases) from a different angle – it engaged professionals at all stages. This appears to be the reason why it ended up with a much more functional system that is more sensitive towards farmers' and consumers' needs. Instead of relying on internal experience, the enterprise decided to consult professionals. This, presumably, allowed them to identify potential pitfalls earlier.

The debate on the costs of these solutions can also be used as a starting point to address another barrier associated with economic performance – the scale of the adopted solution. It has been suggested that the size of rural businesses limits their potential income from any digital solution. This in turn leads to a situation where there are both few incentives as well as little funding to ensure that the digital solutions are properly maintained and adapted to the needs of rural businesses. This appears to be an issue for the cases considered in this article. However, a better explanation of why exactly this is an issue can be provided if the two relevant cases are considered.

In the first case, the idea was that a group of farmers working together could allocate resources to implement digital solutions. However, with time it became apparent that not all farmers were equally interested in developing the online shop and other envisioned solutions and, consequently, less than half of the initial group were willing to engage with the project. Consequently, any future costs had to be covered by a much smaller group of stakeholders. Furthermore, since the end result has issues, it is plausible that more farmers may be looking to leave the endeavour, potentially even withdrawing funding from the project. On the other hand, the case of the enterprise engaged with the challenge differently – it gradually attracted new enterprises that could make use of the online shop to sell artisanal organic products. This means that more actors became invested in maintaining the online platform, while simultaneously increasing the potential client base by providing a greater range of products.

6.4. Regulatory-institutional barriers

The final set of barriers to consider is linked to policies. None of the cases considered in the article has been pushing the boundaries of what is legal and what is illegal. The actors involved were not primarily interested in discussing issues related to how digital space is regulated. These questions are not among their priorities. Still, some issues that are regulated in real life cause consequences that shape the activities these groups are engaging in online.

The first potential barrier for the cases concerns data management and more particularly the protection of personal data. The question of data protection has many layers in this context. Farmers trading directly with consumers tend to store clients' contact information, yet few of them do this in a secure way or take the time to reflect on how the gathered data should be stored. Many of them have been using simple communication tools such as WhatsApp, email and others to reach out to their customers. The cooperative originally had an idea to develop an area on its homepage available only to registered users. The idea was temporarily dropped due to a shortage of funds as it became apparent that the idea was too expensive, and it could not be introduced solely relying on the skills of friends and relatives. Thus, somebody had to be hired to develop the area. Still, the idea has not been dropped and it could still be implemented sometime in the future. However, if the function were to be introduced, it would require storing much more data and consequently would require a more thorough approach to data management from the cooperative. So far, however, these issues have not been given much thought by the cooperative. With this being said, it is also worth noting that the stakeholders engaged in these activities are not ignorant of issues related to data protection. There were occasions when farmers expressed their concerns related to data management thus illustrating that they recognised the issue. For example, one of the participants from the second case raised several issues related to real-time video streaming during one of the discussions – what videos can be streamed, what would be the safety requirements for the stream, whether are there any limitations regarding who can access the stream, etc. Thus, there is awareness among the actors of data-related regulatory challenges. Yet it seems, that so far these questions have been regarded as hypothetical questions rather than real issues.

None of the cases assessed in this article were looking to develop something radically innovative. Instead, they were reintroducing solutions that were already well-known across various sectors and countries. The same could be said about the broader transition process in agriculture – most farmers looking for new digital solutions are working within the boundaries of innovation that have been tested and are based on numerous well-documented examples that have been implemented in various sectors. On the one hand, because of this, one could argue that the initiatives have information regarding the potential pitfalls and challenges they might face. On the other hand, and this is even more important, organisations and groups are in a place that can support farmers' attempts to introduce the attempts to change. For example, the farmer who raised the issue related to video streaming explained that the issue was explained to her by a professional organisation she represents. Later on, the same organisation helped her to identify potential solutions. Thus, a network of support groups and professional organisations along with a subsidised network of consultants that allows farmers to access consultations either free of charge or for a relatively small fee ensures that the information is available in various forms and those that are interested can easily access it. However, this does not remove the need for investments that are necessary to introduce proper data management practices.

Other specific regulations that were referenced by the participants did not concern digitalisation as such. Rather, the concrete examples of pertinent legislation concerned wider processes in rural development and agriculture that prevented the farmers involved in the cases from fully implementing their vision. For example, it was indicated that the support given to cooperatives is calculated based on the cooperatives' turnover in the previous year. This limited the immediate possibilities of the first case to attract funds and thus hampered its ability to make immediate joint investments in the system it was developing. This was one of the reasons why the initiative had to make gradual investments and rely on internal competencies that, as has been shown earlier, limited the functionality of the online tool. Another example is the restrictions imposed on slaughtering animals. However, again, these only have an indirect effect on the use of digital tools by creating challenges for developing joint logistical solutions.

7. DISCUSSION AND CONCLUSIONS

The different ways in which the three cases engage with new digital tools illustrate that there are multiple methods of dealing with barriers. In fact, as with many other issues related to rural development and agriculture, initiatives must find creative ways of dealing with the challenges they encounter and be open to improvising and ready to make smart use of the resources they have. This allows them to find strategies for dealing with potential challenges.

It also appears that knowledge and skills are available to people looking to benefit from digital technologies – actors trying to introduce digital tools can reach out to commercial providers offering insights on how to benefit from digital tools. However, they can also look for the skills needed in their own social networks or advisory services. There might be differences in the quality of the advice obtained, but this issue should be approached on a case-by-case basis, as digital competencies do not necessarily entail formal certification, especially if they have been obtained through practice.

What seems to be the real challenge for the actors is understanding the best way to benefit from these tools. Not just in the sense of building a set of individual instruments but developing a system that works well together and can be integrated with existing practices and routines, and deliver the expected results. However, at least two of the three cases struggled to build a system and did not have a coherent understanding of how different functions could be tied together and integrated with how the farmers generally approach their business. Consequently, the real challenge might not be to make the digital tool operational but to ensure that entrepreneurs properly integrate them into the way they think about their enterprise and then critically assess what the tool in question can deliver and what is needed for the tool to be able to deliver the expected benefits.

In addition, in the first and second cases, the main challenges that were tackled with digital tools were not, in fact, related to digitalisation but illuminated the unresolved issues farmers had in other areas, such as difficulties collaborating, agreeing on common goals or challenges agreeing on farming practices. Digital solutions would not be able to resolve these challenges. These social issues would likely have to be dealt with first, before introducing digital fixes.

It is also clear from the overview of the cases, that not all digital tools can be perceived as similar when it comes to implementation. The cases considered here were focused on marketing and the article has illustrated that to benefit from the tools one needs a clear grasp of the links tying their business and consumers and what it is that consumers are actually buying from them.

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Digitalisation and just transition - Research article

Politics of forests and environmental data: Innovation from above, innovation from below, and conflicts over land use and property in Sweden

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Abstract. This paper offers an exploratory analysis of the links between the politics of forest and struggles over environmental data in Sweden. The term politics of data is used to analyse data production orientated to productivity-oriented forestry and the use of digital technologies that allow ordinary citizens to produce data and knowledge on forests and biodiversity in Sweden. While both processes can be understood as innovation, they differ in terms of drivers and actors. The paper proposes to approach the former process as innovation from above, and the latter process will be understood as innovation from below. In this regard, the main argument to be developed in the paper is that these two forms of innovation reveal the key role of struggles on environmental data in the political interlinkages between contemporary land and property questions in forest and forestry in Sweden. By looking at data production from below, the paper attempts to bring a more dynamic understanding of the production, use and exchange of innovations for data production in environmental conflicts. The empirical analysis of the paper is based on cases where the role of data production in discussions on forestry in Sweden show contestation about the procedures to produce data and its use through digital transformations. These cases will serve to discuss the relations between political struggles over data and knowledge produced through digital tools, how land use and property are politically contested in the context of forestry, and how digital platforms for data production and management also become tools for incipient forms of democratization of knowledge production and innovation in decision making concerning forest and biodiversity.

Keywords: politics of forest, politics of data, forestry, land use, biodiversity, conflicts, digitalization and datafication.
JEL codes: Q23, Q24, Q34, P14.

HIGHLIGHTS

- Conceptual and empirical analysis of the links between the politics of forest and struggles over environmental data in Sweden.
- Analysis of how land use and property are politically contested in the context of forestry and biodiversity and analysis of structural conflicts in

relation to private property rights on land and forests.
- Possibilities for data innovations from below rearticulate in material and ideological ways conflicts based on divergent interests on forests.

1. INTRODUCTION

The recognition of the role of politics in the production of environmental data has generated an important discussion concerning how this type of data is used, who produces and who controls these data. To such questions it is possible to add that many times the public discussion has to do with the fact that there is data that is not produced or available to the public. On the other hand, the term datafication is widely used today to understand the growing and intensive process of data generation, which is part of and closely related to digitalization. In general terms, the new ways of producing data are related to the massive use of technologies based on sensors, microprocessors, computers, and the Internet. The OECD, an important global actor in the ongoing process of digitalization, defines datafication and data collection as

> […] *the activity of data generation through the digitisation of content, and monitoring of activities, including real-world (offline) activities and phenomena, through sensors. This also concerns the growing capacity of new actors to use digital means to produce data, to control data and also to permanently generate new data* (OECD, 2015, p. 32).

Yet, this phenomenon is not only about the production, storage and use of data, but also about the politics of data and the contestation of data production in specific social and ecological contexts (Dalton *et al.*, 2016; Iliadis and Russo, 2016).

All of the above has important consequences for the political discussion on forest and forestry today, and the environmental dimension of land use and management. In this regard, datafication is touted as a new key factor in environmental management, the understanding of the ecological status of forest ecosystems and the modelling of conditions and consequences for the current and future use of forests and land. In the European context, the new EU forest strategy for 2030 has incorporated digitalization and datafication at the center of the new vision about forest and forestry (European Comission, 2021). For this, and among other goals, the EU envisions the establishment of a

> […] *an EU-wide integrated forest monitoring framework, using remote sensing technologies and geospatial data integrated with ground-based monitoring, which will improve the accuracy of monitoring* (pp. 19-20).

At the same time, the EU forest strategy for 2030 aims to develop a citizens' science programme for forest biodiversity, through engaging citizens and civil society in monitoring forest biodiversity. In parallel to these policy goals for forests and forestry at the EU level, large forestry companies have also engaged in developing the potential of datafication and digitalization for their forestry operations. On the other hand, the new possibilities and capacities to produce environmental data are already an important tool for environmental activists and environmental organizations who through producing and accessing environmental data have new means to discuss the state of the environment or specific aspects of forest and land use and forestry. In this regard, the increasing use of data is closely linked to political relations in contexts of environmental conflicts and the very issue of datafication becomes part of the wider politics of forests both at national and cross-national political spheres. Thus, the aim of this paper is to discuss the politics of environmental data in relation to conflicts associated with forests and forestry in Sweden, with a focus on land use and property questions arising from such political context. In addition to this introduction, the paper is divided into four sections and concluding remarks. The first section offers the conceptual background for the paper. The second section presents the case study and the methodology. The third section offers the analysis of the case. The fourth section develops a discussion of the case study with a focus on the relations between property and data production in the case of forestry in Sweden. Finally, concluding remarks are presented.

2. CONCEPTUAL BACKGROUND: THE POLITICS OF DATA AND TECHNOLOGY IN THE SOCIAL CONTEXT OF ENVIRONMENTAL STRUGGLES

From a critical social science perspective on technology, data production through digital transformations cannot be separated from wider questions about the links between knowledge and power, the transformation of social relations associated with digital technologies and the basic dynamics of the development of capitalism (Sadowski, 2019). As Sassen states, digital networks are

> […] *embedded in both the technical features and standards of the hardware and software, and in actual societal structures and power dynamics* (Sassen, 2002, p. 366).

Recognition of power relations in the unfolding of datafication and digitalisation is key to also approach technology in a non-deterministic way and to also approach how different groups in society produce meaning and possible uses for new technologies. As Wajcman argues,

> […] *technological change is a thoroughly contingent and heterogeneous process. Interpretative flexibility refers to the way in which different groups of people involved with a technology can have different understandings of that technology, including different understandings of its technical characteristics. Thus users can radically alter the meaning and deployment of technologies* (Wajcman, 2002, p. 353).

However, for the analysis of datafication and digitalization under capitalism it is also important to consider what Burrell and Fourcade (2021) observe about the digital infrastructures: That they operate

> […] *in increasingly totalizing, continuous, and dynamic ways* (Burrell and Fourcade, 2021, p. 227).

In this regard, I argue that a critical analysis of datafication and digitalisation needs to approach both the totalising tendencies but also contingency in these processes of technological change. Also, within the specific contexts of digitalisation and datafication, a growing body of literature that has focused on the understanding of how digitalisation transforms social and ecological relations increasingly points to the link between socioenvironmental conflicts and digitalisation. Below, I present a brief and selective review of some recent perspectives on digitalization and on the use of new data in relation to environmental issues. This will serve to elaborate some conceptual perspectives for the analysis and discussion on datafication and conflicts associated with forestry and biodiversity in Sweden.

Karen Bakker (2022) has recently argued that in terms of biodiversity and conservation, a number of innovations based on data production and digitalization are creating a new context for the understanding of activism oriented toward environmental conservation objectives. For example, she links the technical capacity to discern patterns of communication by non-human species to a deeper knowledge of biodiversity. This would in turn provide possibilities for activists and civil society actors to mobilize large amounts of data in local struggles for environmental justice. In the case of biodiversity struggles, Bakker argues that this new wave of data production can to some extent determine new social arrangements for the preservation and conservation of the environment. In this context, data-led interventions regarding biodiversity and non-human species entail the potential of the political use of these new technological developments and a new form of politicization of datafication thereby. In terms of biodiversity, ongoing processes of datafication are associated with large databases, which are often open access data, and thus available for public use. Also, the availability of technological devises for data collection fosters political possibilities for the empowerment of communities in the preservation of their territories. As the work of Paneque-Gálvez *et al.* (2017) shows, the use of drones by indigenous communities has the potential to allow these communities to produce their own data on the local environment and use it in struggles for environmental justice and sustainability. This line of analysis highlights the possibility of an unprecedented production of knowledge about local ecosystems, which would give new bases for assessing biodiversity. In political terms, the knowledge base created through this use of digitalization and data production has the potential to transform knowledge and power relations (Goldstein and Nost, 2022). The use of drones for community mapping and the use of citizen science to understand local environmental realities are examples of this. In this context, the capacity of a plurality of actors for fostering community science or citizen science at the community level can also be linked to democratic innovations towards greater participation in data production and the democratization of data (Alarcón *et al*., 2021).

In the more specific case of forestry, Gabrys and and her co-authors (Gabrys, 2020; Gabrys *et al*., 2022; Urzedo *et al*., 2023) have analyzed different dimension of what they understand as Smart Forest:

> *By smart forests, we refer to the numerous digital technologies and infra-structures that are now monitoring, networking, managing, and remaking forests as they attempt to observe environmental change, optimize forests for resource management, and intervene in sites of forest loss* (Gabrys *et al*., 2022, p. 59).

In their view, the rise of Smart Forest brings new political contexts for the discussion about forests, which is also associated with questions concerning access to and production of data to intervene in the management of forest resources. As Gabrys (2020) observes in relation to the datafication of forests,

> *[d]ecisions about what to measure and monitor, the formation of evidence in support of environmental change objectives, and the extent to which this data is able to effect change are part of a complex set of social-political struggles about how to make forests matter* (Gabrys, 2020, p. 6*).*

For these authors, it is evident that the massive penetration of data production regarding forests entails the possibility that activists, organizations and civil society in the forest context can also make use of these new technological possibilities and even generate platforms to produce or use big data on forests.

In relation to the penetration of digitization and the process of datafication in agriculture, there is an abundant critical literature about digitalization. This is linked to the fact that important antecedents of the datafication of environmental processes as forestry can be found in the first attempts to implement and promote what is known as precision agriculture. Thus, questions concerning the consequences of datafication in agriculture precedes to an important extent the current discussion on data and digitalization of biodiversity and forests. Recently, David Goodman has contributed to this discussion by building on his earlier work on agriculture and biotechnology. Goodman now uses the concepts of appropriationism and substitutionism to analyze what he conceives in terms of a convergence between the digital transformation and the molecular transformation of agriculture. In this perspective, the trends toward using and controlling new data is deeply transforming agriculture at the basic level of the farm and farm practices. In parallel to that process, and hence the argument about a convergence of trends, there are also transformations at the biological level with respect to crops, the species used, and also the control of agricultural production through intervention and transformation of the biological relationship in the production of food or inputs for food production. Goodman's analysis, which places at the center of the discussion the historical commodification of agriculture and the new ways of commodifying agriculture, also focuses on the power relations between actors in agricultural development. This serves to focus the analysis on who has an interest in, and who controls, this molecular-digital convergence. Goodman connects this convergence to the analysis of the relations between datafication of agriculture and the interests of large agribusiness companies. In this sense, Goodman shows that one objective of these companies is to continue using datafication to deepen their efforts toward greater control of agriculture. In his view, this process is to at important degree discursively framed in terms of making compatible greater productivity and environmental goals for agriculture: "The closer, targeted digital control over farm inputs is represented in some quarters as a new paradigm of 'sustainable intensification' that promises not only to raise productivity and farm profits but also to mitigate global climate change and help feed the 9 billion" (Goodman, 2023, pp. 19-20. Kindle edition.). Goodman's analysis of agricultural companies harnessing datafication and digitalization for further commodification of agriculture contrasts with the growing literature briefly addressed earlier which focuses on understanding the use of data by activists who mobilize the capacity to produce new data to innovate in the production of environmental data and knowledge. For the analytical purposes of this paper, one process can be understood as innovation from above and the other as innovation from below.

Taking the previous insights into account, one issue that appears to be particularly relevant in the analysis of the politics of data in the context of forests and forestry in Sweden is the type of relationships between the different processes of datafication and the specificity of political processes regarding biodiversity and forestry. In this regard, questions concerning land use and property are a clear example where contemporary environmental conflicts are to an important degree conflicts on and over data. Thus, some conceptual elements for understanding datafication in forestry from the perspective of conflicts over property and in land use are important to guide the analysis of datafication in terms of processes of innovation from above and innovation from below, and for approaching the role of both types of innovation in the context of forestry and biodiversity conflicts. In this regard, I would argue that developing theoretical perspectives on the role of land control and property in conflicts over forest and the production and use of environmental data thereby is a key theoretical challenge for a deeper understanding of the context-specificity of innovation in data production and the political conflicts that this reinforces and/or creates.

Thus, to understand datafication from the perspective of conflicts in forestry, my starting point is historical materialist sociology which by drawing on some basic elements of Marx's theory of capitalism brings as a central theme for the analysis the specificity of social conflicts in capitalism. In this regard, understanding social conflicts means understanding conflicts generated through the structuring of different and divergent social interests. Therefore, as Burawoy and Wright point out, it is not simply a matter of conflicts originating in subjective identities that are related in a conflictive way. This emphasis on the structural dimension of conflicts is also related to a focus on the interests that are socially articulated in a capitalist society (Burawoy and Wright, 2002). Therefore, understanding conflicts implies analysing what the interests that exist in a society with respect to the materiality and meanings of certain resources are, and how interests and agency interplay in the maintenance or the transformation of determined social and ecological relations. In that sense, social conflicts are related to the reproduction of certain social relations and also to the establishment of new social relations based on the conflicting interests within society. Within this context, the role of property relations is key, and its analysis allows us to understand conflicts in forestry more specifically and contextually. For example, in environmental terms, a conflict can be the result of individual or collective actions that follow the interests of some actors to maintain property relations or land use based on those property relations. But there are also conflicts that can lead to the establishing of property relations as a political definition of a conflict, which in turn can generate other types of conflicts over those property rights.

In this regard, it is important to emphasise that a focus on the social conflicts that are inherent to the social structures of capitalism also means to take into consideration emergent social conflicts in capitalism. In the terms of Nancy Fraser's approach to what she conceives as boundary struggles, the institutional divisions of capitalism

> […] *often become foci of conflict, as actors mobilize to challenge or defend the established boundaries separating economy from polity, production from reproduction, human from nonhuman nature* (Fraser, 2017, p. 164).

Within this context, access, control and use of land is a particularly important foci of conflict. As Harvey M. Jacobs summarises one of the main points of an edited collection on social conflict over property rights in the US context, it is important to recognise

> […] *the complexity of land and how its noneconomic characteristics are so often the source of social conflict* (Jacobs, 1998, p. XV).

This, we can add, is today a fundamental dimension of many of the mounting local and global social-ecological conflicts (See for example: Swyngedouw, 2019, p. 549)

All this calls for an empirical and contextual analysis of the role of conflicts in the social structuring of capitalism, which serves to better understand conflicts as causes and/or consequence of the clash between different interests. In this sense, understanding data in terms of the politics of data and the contestation of data (Beraldo and Milan, 2019; Ruppert *et al.*, 2017) leads us to ask important questions about the political relationship between forests and biodiversity and the conflicts around forestry and land use. In fact, it is possible to observe today that particularly in countries with highly technologically developed forestry sectors, there are certain patterns of conflict regarding how the use of forests and land is determined by political struggles over data, which to an important degree are struggles entangled in contestation about property relations in the process of achieving, or redefining, environmental objectives. In this sense, innovation in terms of data production is entangled in sociopolitical contexts where property relations and land policies cannot be separated from historical conflicts that today have repercussions on the ways of understanding land ownership in relation to the environment. In this sense, it is important to highlight that datafication needs to be understood as a political process where we can distinguish different types of innovation and how the plurality of innovation processes interplays with different and conflicting interests and objectives for forests and forestry. Thus, for the argument of this paper, the basic theoretical point of approaching structural conflicts in capitalism, and the specific environmental conflicts within capitalist development, is to attempt an explanation of the relationship between conflict in forestry and datafication and develop an analysis of how this unfolds. As said earlier, this requires contextual analysis to identify the relationship between datafication and conflicts, and to better understand the specific contexts of those conflicts. To discuss the above, the paper will focus on the case of forests and forestry in Sweden.

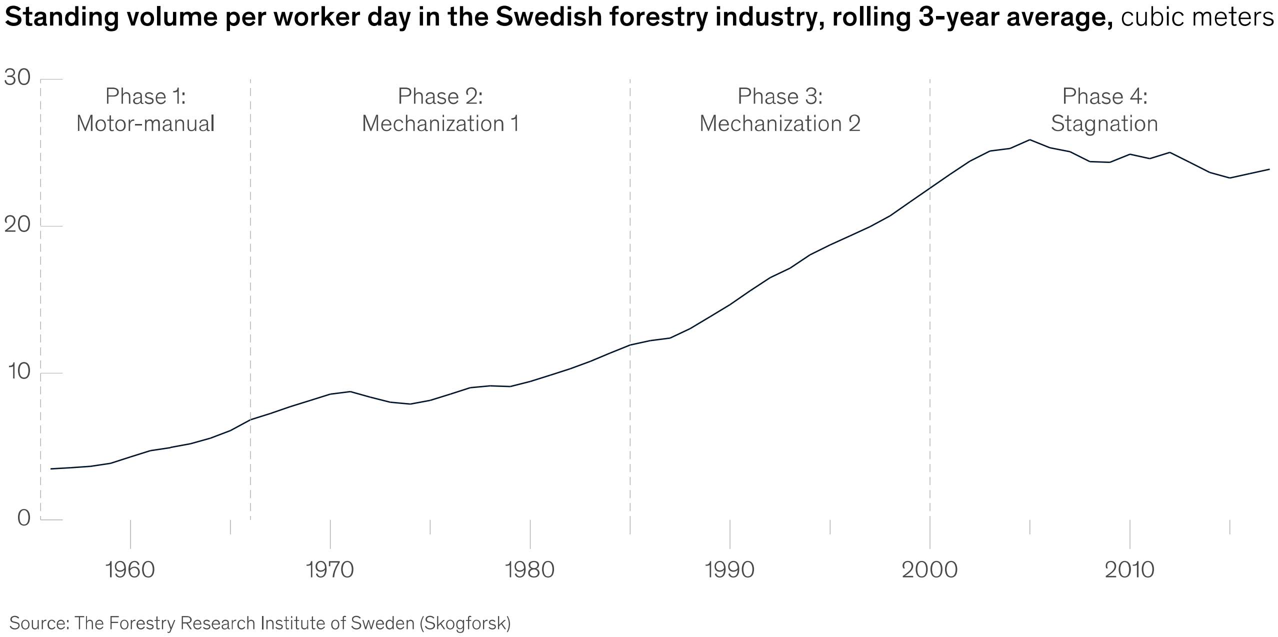
3. CASE STUDY AND METHODOLOGY

Sweden has one of the most developed industrial forest sectors in the world, and a large part of the forest products manufactured in the country are exported to international markets. Mechanization of forestry activities, and technological changes have greatly increased productivity in forestry operations. Yet, recently, there are signs of stagnation in productivity growth within forestry in the country. This is shown in the Figure 1, produced by the consultancy company McKinsey for its report *Data: The next wave in forestry productivity* in 2020, which uses data from the Forestry Research Institute of Sweden (McKinsey and Company, 2020).

Recently, a large new initiative involving forestry companies and universities was established to address and foster the digitalization of forestry in the country. The project has been labelled digital forests and it is organized as a research programme that

> *uses digitalisation to promote sustainable development in forestry* […] *by developing methods, models and digital tools that contribute to a digital forestry value chain that to pave the way for a circular bioeconomy* (MISTRA, 2021, 2020).

Figure 1. Sweden developed its forest-industry productivity through mechanization.



Source: McKinsey & Company report *Data: The next wave in forestry productivity,* 2020. (https://www.mckinsey.com/industries/paper-forest-products-and-packaging/our-insights/data-the-next-wave-in-forestry-productivity).

In this context, part of the diagnosis about digitalization in forestry is based on the notion of forestry is a traditional industry which would imply a challenge for digitalization (Torto and Kristofersson, 2023).

The *digital forests* programme takes place in a context where main political aspects of forestry in Sweden concern domestic contestation about the environmental sustainability of the sector and the political tensions unfolding through the interplay between sustainability goals for forests at the EU level and the impact of EU's regulations in Swedish forestry. In terms of contestation of the claims about sustainable forestry in the country, the work of NGOs, activists and academics highlighting sustainable problems associated with forestry play a central role. Environmental activism in this context has taken advantage of, and used, new possibilities for data production and has mobilized data in the discussion about the environmental status of forest in the country. In this regard, citizens' participation in monitoring of forest ecosystems has entered in a new phase of increasing use of public data and also data production. An initiative that has facilitated citizens' involvement in environmental data production is the Swedish Species Observation System (Artportalen), a large infrastructure for citizen science which is considered one of the largest infrastructures for citizen science in the world (Kasperowski and Hagen, 2022).

Based on previous work by Alarcón *et al.* (unpublished paper), we can highlight here some key aspects of the system for citizen science presented above. The Swedish Species Observation System is coordinated by the Swedish University of Agricultural Sciences' Swedish Species Information Centre (SSIC) (Artdatabanken, n.d.), which is tasked by the government and other authorities responsible for working with biodiversity (Alarcón *et al.*, unpublished paper). Thus, the SSIC provides an infrastructure with data and knowledge on biodiversity to support the work of public and private organizations. For over 20 years the SSIC has promoted and hosted the bottom-up development of the Swedish Species Observation System (henceforth SSOS) with funding from the Swedish Environmental Protection Agency (EPA) and Swedish University of Agricultural Sciences (Artportalen, n.d.). The SSOS has a significant number of users with about 11,000 users reporting species observations each year. To date, the database consists of > 80,000,000 observations together with > 2,000,000 images, video or sound files. Over 6,000,000 new observations are reported each year, the majority from the general public and biological societies (Ibid). These data are harvested by the Global Biodiversity Information Facility (GBIF) too, where it comprises almost 10% of the georeferenced data from around the world. The SSOS platform not only gathers biodiversity data from the general public but is also the main reposi-

Table 1. The use of knowledge provided by the Swedish Species Information Centre (SSIC) in relation to environmental governance and public participation in the Gävleborg region, Sweden.

Documents, identification of actions, plans, programs or decision-making process where information and knowledge from SIC and its CS platform is used in Gävleborg	Organizations or situations relying on information and knowledge from SSIC and its CS platform with regard to Gävleborg
Action program for sweet grass 2009-2013 (Naturvårdsverket, 2009)	Swedish Environmental Protection Agency, 2009
Traditional management of lower Dalälven's river meadows – economic and ecological opportunities (LEADER Nedre Dalälven., 2015)	Final report from a project with support from LEADER Nedre Dalälven in the context of the regional landscape strategy, 2015
Inventory of meadow fungi in Gävleborg County 2015 (Gävleborg County, 2016)	The County Administrative Board in Gävleborg, 2016
County program for regional environmental monitoring in Gävleborg County 2015-2020 (County Administrative Board in Gävleborg, 2014)	The County Administrative Board in Gävleborg, 2014
Analysis of Siberian jay in Gävleborg using the Swedish Species Observation System (SSOS) ("Lavskrikan i Gävleborg med artportalen - PDF Free Download," n.d.)	Report of a private person (former University professor) in the context of Siberian jay controversy in 2016
Environmental Impact Assessment for extension of concession for electricity power transmission line Stadsforsen - Hölleforsen – Untra (Svenska Kraftnät, 2012)	Assessment elaborated by the Swedish electricity transmission system operator Svenska Kraftnät in 2012
List of state forests worth of protection in Gävleborg (Naturvårdsverket and länsstyrelserna, 2004)	County Administrative Board in Gävleborg and Swedish Environmental Protection Agency in 2004
Information on species protection in Sweden and red listing and protection provided by ENGO The Swedish Society for Nature Conservation working in the municipality of Nordanstig in the Gävleborg region (Naturskyddsföreningen Nordanstig, n.d.)	Online communication informing that SSIC has a page where people can search for individual species
Biosphere nomination for the Voxnadalen area in Gävleborg region (Biosfärområde Voxnadalen, 12.05)	Nomination from 2018 where SSIC data was used for identification of 274 species that are nationally red listed
Natural value inventory regarding biological diversity (NVI) in a housing project outside of Gävle. Inventory ordered by the Municipality of Gävle and realized by a private consulting firm (Ekologigruppen AB, 2015)	Use of SSIC data for identification of red listed species in 2015

Source: Alarcón *et al.* (unpublished paper)

tory of data from professional, nationally financed inventories of biodiversity and other environmental parameters (Ibid). Within this context, the platform Artportalen allows citizens to provide information about species, which can in turn be used by scientist and experts in different forms of evaluation and monitoring of ecosystems at both the national and regional level. As the Tåable 1 shows, Artportalen is widely used at the regional level in the country.

The use of data produced and systematized through *Artportalen* has also been at the center of controversies concerning decisions for forestry operation. In some cases, decisions concerning forestry operations where knowledge from *Artportalen* has served as base for those decisions have imposed restrictions for planned forestry operations of individual forest owners. As we will see below, these cases have been especially relevant in the political discussion about new forms of environmental data production in the context of conflicts over land use and property in Swedish forestry. In what follows, empirical examples where the politics of data and the politics of forests intersect in Sweden are presented and analysed. For this purpose, the article uses and analyses a selection of documentary material to follow and reconstruct through secondary sources those empirical examples where conflicts on land use and property interplay with the different uses and interpretation of environmental data in the evaluation and discussion of forestry, biodiversity, and sustainability in Sweden.

4. DATAFICATION AND CONFLICTS OVER LAND USE AND PROPERTY IN THE CONTEXT OF FORESTRY IN SWEDEN

4.1. National and global ways of generating data on forests and forest use

A first example of the intersections between politics of data and politics of forests centres around the use of field inventories versus remotely sensed data in the assessment of forests and forestry. In this case, we can focus on the discussion started in Sweden after a scientific paper published in the journal Nature in 2020 assessed the state of forests in Sweden by using remote sensing technologies for data production. The paper was produced by Ceccherini *et al.* (2020) under the methodological premises that:

> *Currently, the combination of high-resolution satellite records and cloud-computing infrastructures that can handle "big data" provides a complementary asset for quantifying harvested forest area that is independent from official statistics and overcomes some of the limitations of national inventories. Using such data streams and information technologies, we assessed the recent changes (2004-2018) in harvested forest area based on the Hansen maps of Global Forest Change GFC), a map product with a 30-m resolution based on Landsat satellite data, which provides yearly estimates of tree cover and tree-cover loss* (Ceccherini *et al.*, 2020, pp. 7273).

For the authors of the paper, one result of the use and analysis of this big data was that,

> *The largest share of variation in harvested forest area during 2016-2018 compared to 2004-2015 among the 26 EU countries was recorded in Sweden and Finland, which together accounted for more than 50% of the total increase in harvested area observed in recent years (*Ceccherini *et al.*, 2020, p. 74).

The paper motivated a scientific debate in the journal Nature. One response to the paper stated that,

> *The GFC Landsat dataset that Ceccherini et al. use for their analysis is based on remote-sensing satellite data that does not give information on changes in forest density beyond a certain threshold. Although this data-collection method records sharp changes in the landscape from year to year, such as clear-cuts and large natural disturbances, it fails to capture the annual incremental growth in forest biomass. Man- aged forests, such as those in Finland and Sweden, deliberately aim for harvest cycles of several decades to maximize the volume of wood growth per hectare of forest. The increase in forest volume beyond tree cover is not captured by remote sensing and relies on estimates from the European Space Agency and other pan-European organizations. Better area estimation from sample data would reduce the discrepancy with national data sources (Wernick et al.*, 2021, p. E13).

As the case of forests in Sweden was at the centre of this discussion on data for the environmental assessment of harvested forest area in Europe, some Swedish researchers reacted to the assessment of forests in Sweden by Ceccherini *et al.* and argued that,

> *This reported dramatic increase in forest harvesting is not consistent with Sweden's national statistics. On the contrary, statistics from The Swedish Forest Agency and the Swedish University of Agricultural Sciences show that the harvested forest area has decreased within the studied time period* (https://www.slu.se/en/ew-news/2020/7/incorrect-figures-on-harvested-forests-in-nature-article/).

Within this context, the group of researchers added that,

> *According to the National Forest Inventory, a survey conducted in the field with objective statistical methods, the area of harvested forest in Sweden has been around 200 000 hectares per year during the past decade, while the volume of harvested wood has increased steadily during the same period.* (https://www.slu.se/en/ew-news/2020/7/incorrect-figures-on-harvested-forests-in-nature-article/).

In replying to the comments and doubts about their study, Ceccherini *et al.* argued that considering several issues raised by their critics, the

> […] *additional validation exercise for Sweden and Finland, — even if not conclusive for the large uncertainties in the estimates — supports our conclusions on the increasing area of clear-cuts* (Ceccherini *et al.*, 2021, p. E21).

Also, Ceccherini *et al.* closed their reply by stating that:

> *In conclusion, the comments by Palahí et al. and Wernick et al. gave us the opportunity to assess the effect of the change in the GFC algorithm on our results and to clarify several misunderstandings that led to interpretations of our study that were beyond our original intentions. We believe that these clarifications strengthen the main messages from our study — that is, that Earth observation and big-data analytics are very promising tools for a detailed and spatially explicit monitoring of forest resources (provided that a temporally consistent tree-cover map is available), and that an increase in clear-cut harvest has been observed in recent years in the EU. We are approaching a revolution for the integration of Earth observation in the monitoring of forest resources. The success of this integration, which is essential to the European ambitions on biodiversity conservation and climate-change mitigation, depends not only on the combination of ground surveys with modern satellites — such as the Copernicus Sentinel-1 and Sentinel-2 sensors that have up to 10-m spatial resolution — but also on the continued and effective cooperation among the various scientific communities involved, the national agencies responsible for forest surveys and the European institutions* (Ceccherini *et al.*, 2021, p. E23).

Within the context of this paper, this example shows two important things concerning the politics of data in relation to forest and forestry in Sweden. First, a main issue in the discussion is the possibility of relying upon big data produced through high-resolution satellite records, versus in site national inventories. The second issue has to do with recent political responses to the problem of discrepancies between diverging environmental assessments of forests, a response that has been framed in terms of harmonisation of forestry data. In relation to the latter, in 2023, and under the context of Swedish EU Council presidency, a workshop in Sweden continued with the effort to advance harmonised forest monitoring and reporting for the EU. One of the conclusions of the workshop was that,

> *It was concluded that many biophysical features of forests could only be monitored through field inventories. For several features, however, the combination of field inventories and remotely sensed data would allow for more accurate and frequent statistical estimates, as well as for mapping. Furthermore, field-collected data have an important role to verify remotely sensed data* (Towards harmonised forest monitoring and reporting for the EU, 2023).

This conclusion clearly resonates in the debate concerning the Ceccherini *et al.* paper from 2020 summarised above. One issues that becomes clear from the attempts to reach harmonised forest monitoring and reporting for the EU is the effort to reinforce the role of field collected data for forest assessment. That the Ceccherini *et al.*'s study led to strong criticism in Sweden cannot be disconnected from the fact that their assessment became entangled within political discussions on the state of forest in the country and the role of industrial forestry in the loss of biodiversity associated with forestry and industrial forestry practices. In this context, this discussion adds to the overall assessment of Sweden's Environmental Quality Objectives and the specific goal of Sustainable Forests, objectives that according to the 2023 assessment will not be reached (Skogsstyrelsen, 2022).

As emphasised in recent public debates about sustainability and forestry in Sweden, a main environmental problem of industrial forestry in the country is the impact on biodiversity of the extensive use of clear-cutting as logging method, which is the logging method in almost 97% of the forest lands used for forestry in the country (Arnqvist *et al.*, 2023). Though there are efforts to also use continuous cover forestry as a forestry approach, research has found that the forest sector predominantly and extensively continue using clear-cutting as logging method and also use tree plantations to maximize production:

> […] *sectoral culture, forestry education, legislation, research, timber market, and single-layered forest structure are both shaped by and reinforce a forestry sector that is heavily invested in clear-cut- forestry* (Hertog *et al.*, 2022, p. 11).

In this regard, one can observe that the way in which the forest industry is structurally and ideologically organised becomes a fundamental driver of local conflicts between the interests for the expansion and also intensification of logging on the one hand, and the interests for biodiversity goals on the other hand. Thus, in explaining the fact that the Environmental Quality Objective Sustainable Forests will not be reached, a key factor to be considered is the combination between forest policies oriented to increasing production of forest raw materials and the predominant role of clear-cutting as logging method within the forest industry. In this regard, the assessment of Ceccherini *et al.* contributed to strengthen the arguments about unsustainable patterns within forestry in Sweden. That the data leading to that conclusion generated a conflict of interpretations is not only a methodological discussion, but it is basically a discussion about the politics of data. In this case, datafication and efforts to harmonise forest monitoring and reporting must also be understood in the general context of the politics of forest in Sweden. In that regard, what needs to be understood here is that arising from the contradictions associated with forest management in Sweden, these new discussions and conflicts generated around and through the production of data are constitutive part of the politics of environmental data production and also the politics of forest in Sweden.

4.2. Use of citizen science to assess biodiversity in forest and its contestation

The second example of the interlinkages between the politics of data and the politics of forests centres around the role of citizen science in decisions on forests and forestry. As explained above, Sweden has a well-established digital infrastructure for citizen science (Alarcón *et al.*, unpublished paper). Yet, in a context of contestation about forestry, data produced through citizen science has become part of conflicts between different interests on forests as well. One relevant example of this is a Court ruling concerning a decision of the Swedish forestry service which did not authorize tree felling by private forest owners on their own property because of data about the presence in those properties of the Siberian Jay, which is a bird with significance in terms of biodiversity. One part of the Court ruling stated:

> *Information provided by private individuals can hardly be used as a basis for a decision to ban felling…* (Östersunds tingsrätt, 2019).

As observed by several actors, a decision in that regard becomes an important barrier for citizen science efforts to be a more relevant input in sustainable forest management regionally, and possibly nationally (Roos *et al.*, 2019). It was also argued during the public controversy concerning this case that the 2019 Court judgment went against a government policy that explicitly promotes the use of citizen science in Sweden. In fact, citizen science has been identified as a valuable source of data in an official investigation (SOU/Swedish Government Official Report) to provide basis for policies concerning environmental monitoring and assessment in the country. As one reads in the official investigation entitled *Sweden's environmental monitoring – its task and organization for good environmental management,*

> *Non-profit organizations such as ornithological societies, botanical societies and diving clubs are important resources for gathering information about the state of the environment. Within national and regional environmental monitoring, interest associations contribute with expert knowledge and inventories. Within some sub-programmes, the non-profit efforts via interest associations or the knowledge and commitment of individuals are absolutely decisive, e.g. within Swedish bird assessment and butterfly monitoring* (SOU, 2019, p. 454).

The case of the Siberian Jay is not the only case where the use of citizen science has been contested in the country. In 2022 a columnist of a national newspaper launched a harsh critique against environmental activists who, in his view, planned the production of data through citizen science using the Artportalen platform (Wennblad, 2022). For this purpose, the columnist identified a group of citizen activists who frequently report and deliver data for *Artportalen* and argued that these activists were in fact deciding about the forests and imposing their interests against the interests of the forest owners. This intervention led to a series of reactions where the role of citizen science was defended (Marissink, 2022). The argument against the role of environmental activists in providing data *Artportalen* echoed arguments expressed in a magazine of the forest owners association where a similar critique has been articulated (Aronsson, 2021). This critique of citizen science and the digital platform *Artportalen* also show that scientists and academics have counter-argued in defence of citizen science and the information and observations provided by ordinary citizens. These counterarguments are often based on recognizing that this type of data is generated from citizen action but given the quality of the infrastructure for this type of environmental science in Sweden, it is argued that this data and its use does not imply that only the interests of those citizens are reflected in the data.

In explaining the case of the local conflicts around the protection of the Siberian Jay, the role of civil society actors is key. On the one hand, a non-for-profit local bird club was among those providing information about the species observation, which in turn was taken as base for decisions by the Swedish forestry agency. But it is important to observe that in the view of participants of that local bird club, their activities were not primary oriented to stop forestry operations (Dagens Nyheter, 2020). What they argued is that they provide information for public use and then it is the role of the authorities to take decisions based on that information. The point is relevant because from the perspective of a forest owner involved in the case, the local bird club had become "a sort of authority in the case" (Landlantbruk, 2018). The two contrasting views on the role of the local bird club in this conflict shows how both the politics of forest and the local politicization of data production became integral parts of these local conflicts. Within this context, it is also important to pay attention to how another civil society actor, namely, BirdLife Sverige, which is larger non-for-profit association concerned with bird biodiversity, actively acted in the Court litigation motivated by the stopping of a forestry operation due to the protection of the Siberian Jay. In their public statements and in the appeal to higher Court, BirdLife Sverige argued for the validity of the data provided by the local bird club, and used by the authorities in their decision. BirdLife Sverige also argued that stopping the logging operations was necessary to preserve the Siberian jay and that it was the state that should have more responsibility in finding ways for making more attractive to forest owners to avoid logging of forests of significance for biodiversity (BirdLife Sverige, 2019a, 2019b) . Thus, it is important to highlight that the actions of these civil society actors are often framed as a call for state regulation and action in the protection of biodiversity. Within this context, both everyday observation of species and active participation in litigation can be seen as an important aspect of civil society mobilization for biodiversity and the key role that production of data play thereby.

These examples of citizen science data and its contestation in the context of the politics of forest and biodiversity shows again that the discussion about the validity of data becomes a public discussion about how the data is produced, who produces the data, and why the data is produced. This is further amplified when, as in the Court decision mentioned above, this data have an impact on administrative decisions regarding the management and private use of forests. In these cases, we can observe the increasing political relevance of how data is produced and used to make decisions on land use and how these interplays with property relations on forests. While this example shows that there are innovative ways to produce and use environmental data on forests and biodiversity, it is also important to understand that these innovations become entangled in a context where forest conflicts and the politics of data are interlinked. As I will discuss below, these are cases where we can also see that the key role of property rights in the discussion about how these new forms of data production are used in the context of forestry. In fact, to an important extent, producing and using environmental data on forests and forestry create new political contexts for the discussion about private property rights on land. As I will discuss below, it is analytically important to place these conflicts over property rights on land in the political context created by the defence and contestation of property rights on forests and their impacts on biodiversity, and how this runs today in parallel with the ongoing datafication and digitalization of forests and forestry in Sweden.

5. DISCUSSION: THE POLITICS OF DATA AND FOREST CONFLICTS

The examples analysed above suggest that interlinkages between datafication and the politics of forest can be seen in terms of conflicts between different interests in forests and forest management in Sweden. These examples also show new political terms through which different processes of environmental data production concerning forests are articulated in a context of growing datafication and digitalisation of and for forestry and forest assessments. In the case of data produced through citizen science and its contestation, we see how this makes visible conflicts deeply entangled in the clash between forest landowners' property rights on forests and environmental activists' use of various mechanisms to produce data and question the use of forest resources as a matter of private decision making. Within this context, in a comprehensive analysis of property rights in relation to forestry and agriculture published by Royal Swedish Academy of Agriculture and Forestry in 2020 one reads that:

> *The Forestry Agency's routines for supervision also include follow-up of felling carried out and rejuvenation measures. Rejuvenation felling is the occasion when the forest owner reaps the fruits of the investments made in the forest stock. At the same time, the forest environment is changing drastically. It is not surprising that contradictions can then arise and that the forest owner can feel that his right of use has been curtailed. The web publication of logging notifications opens up opportunities for a wide circle of stakeholders to, for example, make their own inventories and report any findings to the Forestry Agency. This can be perceived as violating privacy and creates uncertainty for the forest owner about the possibilities of getting income from the forest. The fact that new key biotopes are sometimes registered in connection with the review of logging notifications contributes to this uncertainty. So do checks against the Artportalen, where anyone, amateur or expert, can enter species finds. The quality of the reports can therefore vary greatly and the registration of findings is affected by how many committed reporters there are in an area. The biggest point of concern is logging bans based on the species protection ordinance because the authorities have so far not considered that such bans give the right to compensation.* (Pettersson, 2020, pp. 88-89).

In the case of the scientific and methodological discussion about big data and national inventories of forests which are based on in site and field inventories, we can observe a tension between the traditional link between nationally produced data and political assessment of forest resources and sustainability based on new global technologies for data production. In more general terms, the examples analysed above show that the politics of data and forests are entangled in the already problematic relation between private decision on forest use and forestry and how they interplay in sustainability questions in Sweden. This question is today to an important degree mediated by data-driven information about the state of the forests and what are the possible consequences of industrial forestry development in the country. In this sense, the proliferation of innovations to produce and use data also brings possibilities for transformation in the terms of the discussion about forestry, biodiversity and property. Here, one could argue that while datafication operates within forestry development as a mean to intensify forestry operations and the use of forests, data production outside the logic of industrial forestry development also takes place in innovative ways. This ongoing transformation of the procedures for environmental assessment of forestry development and the state of the forests shows that the use of new data and the aggregation of existing data with new data is both part of the agenda for a new stage in industrial and productivity-oriented forestry development and it is also part of more democratic production and use of environmental data concerning forests and forestry. While datafication from below broadens the potential for democratic use of data, datafication is also basic to the development of what might be called innovation from above. This process of innovation concerning the environmental assessment of forestry brings new conflicts over data. Thus data-driven development of forestry and forest digitalization cannot escape political questions about land use based on private land ownership. This is especially relevant when one thinks of conflicts at the structural level, and which lead to constant politicization of data in these conflicts. In this sense, these conflicts shape and are shaped by the different interest in datafication and how this develops politically in areas such as forestry. In these contexts, possibilities for data innovations from below rearticulate in material and ideological ways conflicts based on divergent interests on forests, and this also interplays with new forms of land control. In these cases, I would argue, it is possible to observe the reproduction of a historical tension between private property as an articulating social relation in forestry management and the interests of actors that articulate a critical perspective on private property on forests.

At this point, it important to note that along with the existence of different interests in the forests, a key aspect in these conflicts is how property in land as a social and structural relation is defended and contested. In line with the conceptual framework elaborated above, material interests in the access and use of forests and land, and conflicts arising from the clash between these different interests are deeply associated to the social structure of private property rights on land and forests. Thus, and notwithstanding contingent elements in these conflicts, such conflicts arise from, and are inherent to, the structures of private property relations on land and forests. Finally, I would argue that understanding the process of datafication and data innovation from below and above in relation to forests, land and biodiversity in Sweden requires analysing how these processes shape and are shaped by the structural conflicts that characterise the development of capitalism in general, and the role of private property relations thereby.

6. CONCLUDING REMARKS

This paper has explored the process of datafication and digitalisation of forests and forestry in Sweden to show some key political dimensions and conflicts associated with that process. The empirical examples used to explore the intersection between the politics of environmental data and forests show that data production and their use is particularly contested in the context of forestry and biodiversity in the country. In this regard, environmental data production shows a plurality of actors innovating in data production, and claiming validity for data in a context where there are emergent conflicts concerning forestry development and the assessment of the consequences of forestry development on biodiversity and sustainability. Here, what is referred to as digital forests cannot be understood simply as the opportunity to move forestry into a new phase of capitalist development with the goal of increased productivity and new sources of growth. In fact, the struggle over environmental data concerning forestry in Sweden shows that efforts to increase digitalisation and datafication for forestry development run in parallel with civil society actors' participation in data production, which gets entangled with new tensions and conflicts over forests and forestry. As the example of citizen science shows, interests in forests and biodiversity are in practice a process of innovation in the production of data that comes from below. In this context, the understanding of datafication and digitalization within forestry need to be also understood by taking into consideration both the historical trajectory of capitalist forestry, where data production is today part of a process of qualitative change and quantitative increase in the use of forest, and also, the movements and actors that reclaim forests as a matter of public concern and in doing so put into question private property rights on land and forests.

Finally, and based on the nature of the cases analysed in this paper, I would like to highlight some important avenues for future research. First, more research is needed to add knowledge about the capacity of civil society actors' engagement on environmental data production to influence environmental policy in effective ways. Second, it is important to gain a deeper understanding of the different strategies for environmental data production that different actors employ today and to assess whether these strategies can also lead to wider participation and democratic innovations that contribute to sustainability transitions. Third, and considering that the cases presented in this paper are from a context where civil society actors have comparatively more possibilities to engage in environmental data production, context-specificity is important to be considered in future research about the intersection between the politics of data and the politics of forest across different geographical and socio-economic contexts.

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Keynote article

Valuing for sustainability: hidden costs and benefits in multidimensional agriculture

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Abstract. The concept of agriculture has changed over the years. Whereas it was once considered simply a "means" for the production of goods (food and non-food), today, its multifunctionality, understood as the ability to also provide environmental and social services, takes on greater importance. The concept of multifunctionality is intended to change the conception of the agricultural sector and make it more suitable for the historical period of transition we are currently experiencing, for which it is essential to abandon old paradigms in order to create new ones. An unresolved challenge is providing value for each of the multifunctional services. This article provides a brief review of studies dedicated to identifying the main market and extra-market effects of multidimensional agriculture and describes some approaches used to adopt (monetary) quantification of related and secondary activities to facilitate the adoption of more sustainable practices. Special attention is given to payments for ecosystem services, true cost accounting, and true price tools to analyse the positive and negative externalities of multifunctional agricultural systems.

Keywords: multifunctional agriculture, true cost accounting, true price, payments for ecosystem services, sustainable development.
JEL codes: Q11, Q15, Q57.

HIGHLIGHTS

- Multidimensional agriculture is a complex topic.
- Providing value for each externality is fundamental.
- Payments for ecosystem services can be used to support positive externalities.
- True cost accounting and true price are tools for assessing negative externalities.

1. INTRODUCTION

The agricultural economics research agenda is constantly evolving (Brunori, 2022; Malorgio, Marangon, 2021; von Braun, Sheryl, 2023). One of the issues that still attracts special attention, particularly in light of the significant institutional implications that can be assumed, is identifying and quantifying the (monetary) effects of the related and secondary activities (market and non-market) of agro-zootechnical productions. The theme has been at the centre of analyses for a long time, according to different perspectives. Among these emerges the relationship between the social functions (sectorial contribution to collective well-being) and the multiple methods used by the public decision-maker for its support. In particular, in recent years, a significant debate has resumed around the justification of public policies for agriculture, especially the Common Agricultural Policy, as an intervention well-versed by a sort of "Public Money for Public Goods" (PMPG) principle (Kam *et al*., 2023).

The image of a "multidimensional agriculture" that guides this contribution is linked to the path that emerged with strong and superior evidence in Europe starting from the 1980s (Marangon, 2008) – one from an agriculture intended for the production of goods (food and non-food) to one that has become a complex and multifunctional sector – capable of offering the community other goods and services aimed at increasing social welfare. This sphere of activities determines the articulated family of social functions of agriculture. The Italian agrarian economy tradition has long supported the primary sector's ability to provide important social outputs. In recent times, however, we have been witnessing a process of rethinking the contents that this role assumes at the current juncture of socio-economic development (Corsi *et al*., 2023; Malorgio, Marangon, 2021; Sivini, Vitale, 2023).

The theme of the social functions of agriculture has been addressed by economic analysis, mainly using the concept of market failure due to the existence of phenomena known as externalities (positive and negative) and public goods (OECD, 2001, 2003, 2005, 2008). Agricultural economists have tackled the problem in connection with the theme of the multifunctionality of agriculture and the instruments of public intervention support of the social functions recognised in the primary sector. The activities provided by "multidimensional agriculture" require economic assessment and incentive-based instruments in supporting public goods and providing positive externalities or reducing negative impacts. It is fundamental to have a good knowledge of the potential and dynamic connections between natural capital for production, its stock changes, and its capability to impact on human well-being that arise because of farming/agriculture and more in general agri-food value chain activities.

Van Huylenbroeck *et al*. (2007) examined the intricate connections within a farm system and presented a fresh perspective on the role of agriculture in rural areas. They proposed the need to reconsider and redefine the concept of multifunctional agricultural production as well as the analytical frameworks used to study it. The re-evaluation of existing evidence on the various functions performed by farming is of importance, as previous research has shown that agriculture goes beyond producing marketable goods. It also provides non-market benefits that contribute to rural prosperity. These contributions can take different forms, such as directly increasing property values or generating economic advantages in sectors like tourism. Moreover, agriculture indirectly helps preserve the rural heritage and promote agroecological systems. The multifaceted nature of these contributions highlights the importance of understanding and assessing the multifunctionality of farming within rural contexts. Since multifunctionality could be a unifying principle to bring productive and non-productive functions into harmony, Van Huylenbroeck *et al*. (2007) pointed out that a fundamental intervention referred to how this multifunctional role of agriculture can be supported and incentivised, requiring the development of new institutional arrangements and a major change in policy incentives.

Compared to the past, today's agricultural and food companies are even more involved in the processes that regulate the dynamics of the production system, within which they have the task of developing a strategy that keeps economic vitality and environmental and social sustainability unchanged (Malorgio, Marangon, 2021). Therefore, it is not simply a question of producing quality goods and with a level of differentiation capable of distinguishing them on the national and international markets but of providing services to individuals and the community. Furthermore, it is a matter of developing organisational and technological knowledge that guarantees an efficient relationship with partners in the supply chain and at the same time adopts sustainable production techniques for environmental protection, rational use of natural resources, protection of biodiversity and valorisation of local resources. Overall, all these positive impacts of multidimensional farming/agriculture are able to improve human well-being.

The aim of this paper is to provide a brief review of studies devoted to identifying the main market and non-market effects of multidimensional farming/agriculture with a description of some approaches used to adopt a (monetary) quantification of the related and secondary activities in order to facilitate the adoption of more sustainable practices. The paper is structured as follows. A brief introduction to the concept of the multifunctional role of agri-food systems is provided in the first section.

The main literature on multifunctionality and its presence and diffusion is described in Section 2. Section 3 presents the positive effects of multifunctionality and the role of payments for ecosystem services, while Section 4 analyses the negative impacts and the true cost and true price of food approaches. The final section offers some conclusions.

2. MARKET AND NON-MARKET AGRICULTURAL MULTIFUNCTIONALITY: THE CONCEPTUAL FRAMEWORK

The literature on the multifunctionality of agriculture is vast and detailed, as can be deduced at an international level from, for example, what was produced by the OECD in terms of documents (OECD, 2001, 2003, 2005, 2008). According to the OECD's perspective, multifunctional farming involves the production of commodity and non-commodity outputs, which may be both public goods and externalities.

Besides this definition, there are different interpretative approaches to multifunctionality (Sivini, Vitale, 2023). Agriculture can be considered a multifunctional activity since, as is known, it is capable of producing a complex set of products that go beyond satisfying the traditional demand for food and fibre (Aguglia *et al.*, 2008; Bonfiglio *et al.*, 2022; Henke, Vanni, 2017; Roep, van Der Ploeg, 2003; van Der Ploeg *et al.*, 2009; van Der Ploeg, Roep, 2003; Van Huylenbroeck *et al.*, 2007; Wilson, 2007, 2008). If these are the "primary" products of agriculture, providing a positive anthropic value, the "secondary" products can be characterised by both negative (e.g. all forms of pollution and natural resources depletion), and positive (in the case of landscape maintenance, biodiversity protection, environmental risk prevention, cultural heritage conservation, rural development, food safety and animal welfare) values (Van Huylenbroeck *et al.*, 2007).

According to Sivini and Vitale (2023), the above-mentioned positive values can be provided by farmers producing both social and environmental services (e.g. tourism, educational, recreational, and supporting environmental resources management). The focus of these approaches is mainly on the opportunity to gain by producing goods with a market, and, consequently, non-productive functions (i.e. non-marketable) are often undermined (Nowack *et al.*, 2022). Furthermore, the literature includes studies focusing on more integrative approaches to the analysis of multifunctional roles, with the aim of redefining the concept. According to what is called the "new" rural development paradigm, which implies reconnecting agriculture with nature and society at large, van der Ploeg *et al.* (2003) pointed out three groups of strategies. "Deepening" strategies include all farm practices that can offer high value-added production, such as organic production or the development of local supply chains. "Broadening" strategies involve new services (e.g. tourism services or social farming) resulting from the creation of partnerships within the rural area. Lastly, "regrounding" strategies are organisational in nature and involve the mobilisation of internal resources in farm production.

Using this framework, and according to van der Ploeg *et al.* (2009) and Aguglia *et al.* (2008), the analysis of multifunctionality also refers to the creation of synergies between the different agricultural functions and the development of relationships between agriculture and society. Considering normative conceptualisations of multifunctionality, Wilson (2007, 2008) described farm-level multifunctional agricultural transitions. Adopting a productivist/non-productivist multifunctionality range, Wilson categorised a number of farm types and identified different farm-level transitional potentials from weak to strong multifunctionality between different categories and ownership types of farms. Strong multifunctionality was described as "characterized by strong social, economic, cultural, moral and environmental capital" (Wilson, 2008, p. 368). It includes farmers who are closely connected to the community in which they operate (hence, outside global capitalist networks), sensitive to environmental issues (hence, well predisposed to organic farming and the development of local supply chains), and aware of the importance of farm household knowledge.

Conversely, weak multifunctionality rises in productivist logic. Institutional support for multifunctionality warrants farmers' income diversification by capitalising on positive externalities provision (Potter, 2004). Moreover, Wilson (2007, 2008) conceptualised multifunctional transitional procedures at the farm system level over time. To better describe the complexity of multifunctionality, path dependency and decision-making processes were introduced. The decision-making procedure was assumed as groups of decision-making opportunities bounded by productivist and non-productivist action and thought, while path dependency suggested that system memory contributes to defining the likelihood of multifunctional activities, arguing that quick transitional breaks in transitional processes often characterise farm-level transitions.

More recently, a growing interest in agroecology has been observed as a model for multifunctional agriculture (Wezel *et al.*, 2009), as it is capable of fusing ecological and biological principles/methods with sustainable agriculture design and management practices. Agroecology, in fact, requires a holistic, systems-level understanding of agri-food system sustainability (Gliessman, 2021). Due to specific local developments, a number of differences exist, but there is agreement in the conviction that agroecology combines scientific discipline, social movement and cultural practice that, together, can lead to the achievement of multifunctional agricultural practices. However, with the exception of France, which has good experience, the European Union (EU) has no clear strategy to support agroecological practices and action plans. In Italy, a number of initiatives were developed following the universal exhibition "EXPO 2015 Milan", and the experience of the bio-districts helped the promotion of agroecological practices. According to Gargano *et al*. (2021), Italian multifunctional farms adopted a model that can be considered a precursor of this approach. The Italian farm diversification system effectively anticipated the European Green Deal strategy because of the simultaneous presence of key elements concerning both agricultural practices and ethical and social aspects. Their findings underscore the characteristics of farmers who enhance the agroecological orientation and put it into practice in a more conscious manner (i.e. educational level, economic sector of previous employment, and ability to create multi-actor and multi-level networks).

Finally, adopting a territorial approach can help identify a number of recent studies about multifunctionality that focus the analysis on more "traditional" geographical contexts in emerging areas. Indeed, attention to multifunctional agriculture seems to have recently shifted from the specifically European framework (Nowack *et al*., 2022) and/or the OECD countries (OECD, 2001, 2003, 2005); recent studies now include other rural contexts, such as farming regions of China (Song, Robinson, 2020; Zhang *et al*., 2023), with original insights into the role of primary activities in guaranteeing the well-being of local communities.

3. "UNINTENTIONAL" MULTIFUNCTIONALITY AND POSITIVE EXTERNALITIES

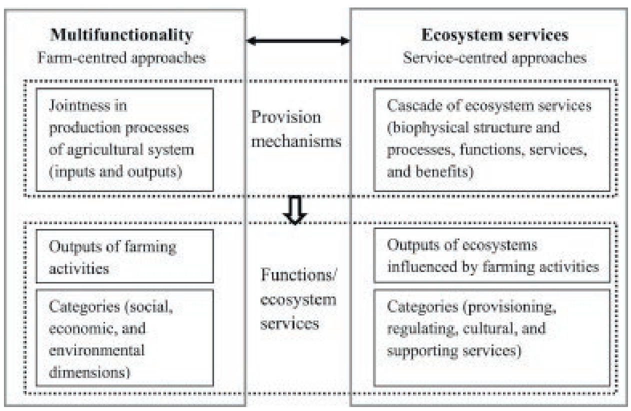
3.1. The provision of ecosystem services

Agri-food systems have both positive and negative impacts on planetary health and human well-being (TEEB, 2018; Hendriks *et al*., 2023; Michalke *et al*., 2023; FAO *et al*., 2022). According to Rovai and Andreoli (2016), the post-conflict period (which saw the emergence of agricultural multifunctionality and the provision of ecosystem services) was marked by an intense process of urbanisation, the abandonment of rural areas, and the concentration of agricultural practices on the most fertile lands, resulting in significant negative environmental and socio-economic impacts (Hendriks *et al*., 2023; Michalke *et al*., 2023). However, over time, there has been increasing knowledge and awareness of the opportunities and benefits associated with sustainable production methods and ecosystem services provided by farmers, for example, risk reduction from environmental disasters or extreme weather events. Huang *et al*. (2015) stated that, since being promoted by international programmes, multifunctional agriculture and ecosystem services are considered two important concepts for sustainable agricultural research and policy making. They provided a synthesis of the different interpretations of the relationship among the multifunctional role of agriculture, ecosystems, functions and ecosystem services provision (Figure 1).

Furthermore, Bernués *et al*. (2019) found that citizens prefer a multifunctional configuration of agricultural systems oriented towards a mix of quality products, landscape management, biodiversity conservation, and further improvement of ecosystem services. Consequently, interventions in favour of activities that produce positive benefits need to be enhanced (Eigenraam *et al*., 2020).

A number of pragmatic and innovative projects have been implemented in diverse and heterogeneous areas, combining multifunctional agricultural diversification strategies with the provision of ecosystem services related to the environmental protection of land (Bretagnolle *et al*., 2018; Tran *et al*., 2023). For example, we know that the community can obtain better services by offering farmers custodianships in the territory.

Figure 1. Fundamental differences between multifunctional agriculture and ecosystem services in agricultural research.



Source: Huang *et al*., (2015).

Such an approach generates significant benefits, such as lower costs for environmental prevention organisations, increased consumer appreciation/satisfaction and willingness to pay (Tempesta, Vecchiato, 2022), and increased chances of survival for local farms.

The mismanagement of environmental resources for agricultural economic development has also reduced the natural capacity of the ecosystem to provide ecosystem services. The opportunity to counteract this negative effect comes from the enforcement of the benefits produced by agricultural multifunctionality by adopting measures (e.g. restoration of carbon rich habitats, or conservation of biodiversity) that can play a crucial role in improving the provision of ecosystem services (Bernués *et al*., 2019), building resilience to negative impacts derived from developing anthropic activities, and, more generally, potentially contributing to the United Nations' Sustainable Development Goals (SDGs) for 2030 (Boix-Fayos, de Vente, 2023). When these benefits are not marketable, it is essential to find other means of estimation and remuneration, except in the case of purely voluntary production strictly linked to more sustainable attitudes, which does not require any kind of incentives. The search for the best set of instruments to ensure a satisfactory level of ecosystem service provision is increasingly high on the political agenda.

To motivate land managers or owners to engage in the provision of socially valuable ecosystem services and make decisions based on social, environmental and economic aspects, it seems useful to employ incentive-based tools (Jack *et al*., 2008). Indeed, Piñeiro *et al*. (2020), who analysed 17,936 studies, stated that farmers' decisions to adopt sustainable agricultural practices in response to incentive interventions depend on many factors; however, the researchers demonstrated that, given an appropriate design, incentive-based programmes are able to produce environmental benefits. According to White *et al*. (2022), schemes with sufficient levels of financial incentives could increase the provision of quality ecosystem services, at least among some types of farmers, since a number of them may continue to be more attracted by more conventional practices able to provide only provisioning ecosystem services. Tanaka *et al*. (2022) discussed the importance of adequately encouraging landowners and farmers to promote ecosystem service provision due to the complex context they have to manage (e.g. evolving socio-economic conditions, increasing risks and uncertainties). Further, Hayes *et al*. (2022) pointed out the need to counteract the incentive uncertainty linked to temporary financial supports used to promote the desired resource-use behaviours.

3.2. Payments for ecosystem services

Incentive-based tools can be classified into three categories: i) market-based instruments, providing incentives through market signals; ii) regulatory measures (e.g. certifications); and iii) cross-compliance financial supports (i.e. direct payments linked to basic environmental standards) (Marangon, Troiano, 2017). The first category offers adaptable adoption to incentivise particular behaviour changes; however, it needs to be planned and correspond to the intended crucial direction (Piñeiro *et al*., 2020). Among market-based tools, payment for ecosystem services (PES) consists of a remuneration scheme for land managers or owners to embrace activities restoring, safeguarding, or enhancing ecosystem services and biodiversity (European Commission, 2021; Salzman *et al*., 2018; Wünscher, Engel, 2012), including some farmers' multifunctional practices (Boix-Fayos, de Vente, 2023; Marangon, Troiano, 2017).

Although many different denominations (i.e. the Italian "Payments for Ecosystem and Environmental Services") and definitions for PES coexist (Yan *et al*., 2022), an influential reference model is that of Wunder (2015). This model focuses on market mechanisms and conceives PES as «a voluntary transaction between service users and service providers that are conditional on agreed rules of natural resource management for generating offsite services» (Wunder, 2015, p. 241). According to this financing mechanism, the supplier has to be paid to provide a service. The beneficiaries (i.e. individuals, communities, businesses, or government acting on behalf of various parties) make the payment in favour of land managers or owners who supply the ecosystem service (Wunder *et al*., 2008). With PES, a market is created, and prices are placed on non-market ecosystem services deriving, among others, from agricultural multifunctional practices (Rovai, Andreoli, 2016). Bringing them into the market potentially allows their value, which is typically not "visible", to be expressed in monetary terms. This internalisation of the positive externalities of land use decisions allows land managers or owners to assess the benefits derived from developing multifunctional activities and compare them with the value of the costs of their supply (Smith, Sullivan, 2014).

According to the literature following Wunder (2015), PES can be considered a market-based or market-like instrument created to internalise benefits, which are externalised, with the aim of bringing marginal costs into line with marginal benefits with the aim of increasing economic surpluses. Due to the difficulties in implementing PES in favour of certain ecosystem service provisions, some scholars have proposed alternative definitions. For example, Farley and Costanza (2010) proposed an original approach to PES that differentiates ecosystem goods as stock-flow resources and ecosystem services as fund services and provides a definition of ecosystems as a special configuration of stock-flow resources able to supply a flow of services. Consequently, PES schemes paying for land uses linked to generating ecosystem services are payments for ecosystem funds. Given the complexity of ecosystems and the flow of services they generate, Farley and Costanza (2010) stated that payments for a group of not-strictly defined services are more likely to maximise social benefits than a market-like payment for a well-identified ecosystem service.

Neoclassical environmental economics provides a conceptual framework for the PES instrument. According to Engel *et al.* (2008), it is essential idea is linked to the Coase theorem, which assumes that, given certain conditions, the problem related to the existence of external effects can be directly surmounted through private transactions negotiated between the affected parties without considering the initial allocation of property rights. Moreover, the results will lead to enhanced economic efficiency, as stated by Pascual *et al.* (2010). The idea of developing private market negotiations, providing direct compensation to multifunctional farmers, and influencing the supply of ecosystem services presents probable great cost-effectiveness gains (Engel *et al.*, 2008). Farmers with higher marginal costs for providing ecosystem services will be included to provide fewer services than farmers with lower costs. However, the presence of large transaction costs, power imbalances, or poorly identified property rights could hinder the adoption of this kind of Coasean solution (White *et al.*, 2022). Consequently, the planning of PES tools, which are potentially also adaptable and cost effective, is not a simple task and requires a jointly run effort and good information to estimate ecosystem services (Havinga *et al.*, 2020). Furthermore, the analysis of all contextual conditions as conditioning factors is fundamental (Haile *et al.*, 2019).

PES tools have been used in many areas of the world with varying degrees of acceptance. A number of PES developed to encourage the supply of ecosystem services provided through the multifunctional role of agriculture can be identified. One of the well-known examples is the Vittel PES (Perrot-Maitre, 2006), localised in northeastern France, where a water bottling firm paid local farmers to adopt sustainable production methods able to provide ecosystem services. Similarly, in Italy, some PESs linked to agricultural multifunctional practices can be identified, and their positive effects have been pointed out (Gaglio *et al.*, 2023; Schirpke *et al.*, 2018).

An analysis of different PES case studies reveals certain types of institutional intervention schemes in favour of multifunctional agricultural practices included among PES as PES-like mechanisms, which are more similar to the Pigouvian environmental instruments used to correct negative or enhance positive externalities (Troiano, Marangon, 2011). Indeed, some governmental payment programmes that offer payments to farmers deciding to adopt sustainable production activities on a voluntary basis could be identified as the Pigouvian concept of PES (Gaglio *et al.*, 2023; Schomers *et al.*, 2021). Agri-environmental schemes that compensate farmers for the provision of non-commodity outputs could also be included in this concept.

Both Coasean and Pigouvian types of PES are useful for quantifying, in monetary terms, the effects produced by the multifunctional role of agriculture. However, in Coasean-type PES, there is a private negotiation between the beneficiary, who pays directly and on an exclusively voluntary basis, and the service provider. Instead, in the Pigouvian approach of PES, governmental interventions may focus on either paying or making others pay on behalf of the direct beneficiary to spur ecosystem services provision. Although both have pros and cons, Pigouvian PES schemes have often been criticised for their low level of effectiveness (Galler *et al.*, 2016). Moreover, the development and implementation of Pigouvian PES programmes usually depends on complex governance structures involving several diverse actors; nonetheless, they keep transaction costs reasonably low (Schomers *et al.*, 2021). Furthermore, they prove to act better with benefits produced on a large scale and beneficiaries that are not directly and easily identifiable. However, the opportunity offered by Coasean-type PES approaches to directly involve the actors who benefit and perceive the value of the provided ecosystem services increases the probability of using a well-functioning incentive mechanism (Marangon, Troiano, 2013). Beneficiaries can also directly observe whether the service is delivered, eventually taking into consideration a renegotiation or conclusion of the transaction.

At the international level, most PES programmes follow the Pigouvian approach, and several studies have described and analysed the Pigouvian PES scheme, which is effectively the most diffused approach (Schomers, Matzdorf, 2013). However, the Coasean-type PES seems to be promising, considering the need to adopt innovative sustainable business models to support multifunctionality in order to help revitalise rural areas, according to the European Union Green Deal (Boix-Fayos, de Vente, 2023). Furthermore, the failure of indirect mechanisms adopted during the 1980s and 1990s to incentivise land managers to adopt environmentally sustainable practices suggests that incentive approaches require the implementation of innovative tools to support the multifunctional role of agriculture, and Coasean-type PES is suited to achieve that purpose.

Nonetheless, PES tools are only one of the solutions for market failure linked to the undersupply of ecosystem services, as the creation of markets is not possible in certain circumstances, and other economic incentives may be necessary to support an adequate provision of these benefits (e.g. financial incentives given to areas with natural handicaps to maintain agricultural activities and guarantee environmental and social benefits).

4. NEGATIVE EXTERNALITIES AND TRUE VALUES OF FOOD

4.1. Hidden costs of agri-food systems

Currently, the need to provide food according to sustainability is a priority identified by all institutions. Moreover, the importance of identifying, assessing and managing negative externalities is fundamental to reduce tomorrow's business risk (TEEB, 2018). On the one hand, unhealthy food consumption habits are responsible for a number of negative social and environmental impacts produced along the agri-food supply chain (World Health Organization, 2019). On the other, developing sustainable agri-food systems would ensure that all people have access to healthy and affordable food while respecting planetary and social boundaries (Hendriks *et al*., 2023).

To move towards more sustainable food provision, an ecological transition is needed (Bertossi *et al*., 2023). According to some estimations (Food and Land Use Coalition, 2019; Steiner *et al*., 2020), the transformation of these systems by 2030 would cost more than USD 300 billion per year. These investments would be divided in detail into 10 key aspects: promoting healthy diets, supporting productive and regenerative agriculture, protecting and restoring nature, ensuring healthy and productive oceans, diversifying the protein supply, reducing food loss and waste, fostering local loops and linkages, harnessing the digital revolution, promoting stronger rural livelihoods, and addressing gender and demography (Food and Land Use Coalition, 2019). To support this kind of transformation, it is necessary to understand the hidden costs and benefits of agri-food systems, which is an essential step forward towards the kind of new policies, practices, science and community engagement necessary to achieve SDGs.

Current agri-food systems have huge and invisible externalities that are usually not revealed in market prices (von Braun, Sheryl, 2023). The "hidden costs" of global food and land use systems are estimated to be US$19.8 trillion per year: $7 trillion of environmental costs and $12 trillion of health costs (TEEB, 2018). Furthermore, many hidden benefits, such as healthy and nutritious food, are also not accounted for. However, this type of benefit seems to be somewhat challenging to appraise (Clark *et al*., 2022). These statistics provide a rough evaluation of the global investment needed to transform agri-food systems into resilient and sustainable entities, taking into account the challenges posed by climate change and other environmental risks. While these estimates act as a driving force for urgently required action, it is important to highlight some important findings from Thornton *et al*. (2023), who estimated the annual cost of implementing 11 essential measures required for the restructuring of food systems (e.g. ensure zero agricultural land expansion in high-carbon landscapes, or enable markets and public-sector actions to incentivise climate-resilient low emission practices) to be approximately US$ 1.3 ± 0.1 trillion (accounting for less than 7 percent of the negative externalities produced annually by existing food systems).

4.2. True cost accounting and true price approaches

To support the ecological transition among agri-food systems, an adequate framework and a systemic approach to change the instruments used to measure and value the environmental, social, health and economic impacts of food systems is an immediate way to take action and promote human, animal and planetary health.

Since the launch of the TEEBAgriFood Scientific and Economics Foundations report in 2018 (TEEB, 2018), the TEEBAgriFood Framework has become a reference for the true cost accounting (TCA) framework in agri-food systems. The concept emerges from increasing awareness of the negative externalities of agri-food systems (Hendriks *et al*., 2023), which form a significant barrier to the transition of these systems (Galgani *et al*., 2021). The consensus among scientists is that current agri-food systems are not sustainable because they use a lot of resources, contribute greatly to global emissions, and cause a significant loss of biodiversity. Additionally, these systems put a lot of pressure on Earth's planetary boundaries, as von Braun and Sheryl (2023) have pointed out. These systems, in which the erosion of natural capital, breaches of human rights, and unhealthy food are permissible and strongly incentivised, were increasingly considered conflicting with policies aiming to foster sustainable agri-food systems. Furthermore, the food products that are lowest in price come at the highest cost to human health and the environment (Aspenson, 2020).

According to a report by Von Braun and Sheryl (2023), the global external costs related to the health and environmental impacts of agri-food systems are estimated to be roughly twice the value of food products in terms of market prices. Specifically, these externalities are valued at around US$ 20 trillion, while the market value of food products is estimated at US$ 9 trillion. To address these externalities, the first step involves disclosing and redefining the value attributed to food. This can be achieved through the use of true cost assessment (TCA), a tool that systematically measures and evaluates the environmental, social, health and economic costs and benefits associated with food production. A study conducted by Baker *et al.* (2020) emphasised the crucial role of TCA in transforming policies, products, organisations, farms and investments. In fact, there is a call for the agri-food system to further advance the research agenda on TCA by identifying practical approaches to internalise a portion of the significant externalities generated by the system. However, a successful transition towards internalising externalities requires the involvement of multiple stakeholders, as it necessitates collective support and collaboration.

A number of case studies have been conducted and analysed, and a growing and diverse community including several heterogeneous stakeholders has been seeking to improve, strengthen and mainstream the adoption of TEEBAgriFood. The Global Alliance for the Future of Food supported the development of this overarching reference method to ensure consistency and coherence across TEEBAgriFood applications.

The TCA framework allows different types of impacts to be assessed, including different aspects of the matrix that make up the food system (Minotti *et al.*, 2022). It could be considered a useful instrument to help the global community better understand the impacts of food systems, address the practices producing negative effects, and find new positive pathways to follow. TCA is the process of creating a framework that differs from the current conventional framework. In transforming agri-food systems' externalities into monetary terms, institutional decision makers cloud the capitalist politics they seek to remedy by suggesting that, once a better assessment is adopted, turning numbers into action will become the responsibility of other actors.

Under the framework of the TCA, different methods and tools have been developed with the aim of spreading a systemic and multilateral approach to reach transparency and participation, achieve transformative governance, and redirect structural power towards food sovereignty and agri-ecological principles (Hendriks *et al.*, 2023a, 2023b). TCA can be considered a structured methodology from an ideological and visionary point of view. This innovative framework was born to be transparent, participatory, democratic, with a multi-criteria perspective, and able to assess the externalities of an alternative reference system in all the dimensions considered. Although economic accounting is important, as it conventionally assigns a common unit of measurement to several variables, TCA aims to assess all impacts, both market and non-market effects, including among the conventional economic aspects and social and political perspectives.

Despite its innovation and usefulness, the TCA approach also has some weaknesses. Indeed, it contains a vast range of methods, tools and calculators that are difficult to summarise or replicate in different contexts (Minotti *et al.*, 2022). In addition, this kind of internalisation of food systems' externalities carries economic and political risks (Patel, 2021). Its complexity lies mainly in the inclusion of indicators other than the exclusively economic ones that touch all those parts of the food system that are difficult to quantify. Furthermore, it is difficult to use data of a different nature within a single reference system, which presents very different units of measurement, and needs to find methodological compromises with the risk of invalidating the findings of the study itself. These difficulties have created a misuse of TCA, and some case studies have identified "greenwashing" activities. A leakage problem can also be created by assigning an economic value to a non-economic externality and moving the problem from one unit to another without actually solving or reducing the problem or risk in the system.

The Accelerator of True Cost Accounting, a community of practice born within the "Global Alliance for the Future of Food", was developed to address the lack of principles, frameworks, parameters and coherent operational guidelines of TCA. This community is enhancing the dissemination of the TCA approach in shaping all decision-making processes underpinning the transformation of agri-food systems. Although the role of decision makers in agri-food systems, both public and private, is relevant, the demand side proves to be fundamental. Economic theory posits that food prices are determined by supply and demand equilibrium. However, failing to account for negative external effects often results in prices that do not accurately reflect "true costs". To rectify this situation, enhancing transparency by incorporating TCA is fundamental (von Braun, Sheryl, 2023). The study by Michalke *et al.* (2023) is quite important in this context. By combining Life Cycle Assessment (LCA) methodology with TCA, the authors translated the environmental damage associated with conventional and organic production into economic terms. The results showed that, on average, production generates more negative externalities per kg for conventional products than for organic products. Nevertheless, this environmental impact does not translate into a price increase.

One challenge, among others, to support TCA is consumers' acceptance, which can be promoted by practitioners. However, consumers' acceptance of true-price (TP) food products is still scarcely explored. A recent empirical study by Taufik *et al*. (2023) demonstrated that Dutch consumers' trust in true pricing characteristics and the actors implementing this pricing approach, along with their intention to purchase true price food goods, increased when they perceived value in terms of social status and positive environmental impact. In other words, appealing to social and environmental values enhanced by true pricing can encourage consumers to buy such products for which externalities are internalised. Similar results were obtained by Michalke *et al*. (2022) regarding animal-based foodstuffs.

However, the TCA and TP innovative approaches require more research. According to von Braun and Sheryl (2023), agricultural economics will need to accompany its adoption with scrutiny in terms of the efficiency, welfare, ecological and distributional effects of institutional interventions. In the implementation of TCA and TP and their acceptance among consumers, the role of transparency and just distribution of wealth is perceived as fundamental, proving that measures that are socially cautious and backed by relevant legal framework conditions are relevant to adopting and accepting a polluter pays context with a clear assignment of responsibilities among stakeholders.

5. CONCLUDING REMARKS

The opportunity to assign a price to each cost and benefit produced by an agri-food system is still one of the main challenges that agricultural economics has to tackle. This paper discusses the multifunctional role that agriculture can develop through its multidimensional activities and its capability to provide society with a number of ecosystem services. By considering non-market goods and services provided by agriculture, the opportunity to enhance their provision with devoted tools emerges. Non-market goods can be rewarded using incentive instruments.

The role of "pricing" seems to be profitable (Galgani *et al*., 2021, 2023), but it presents a number of conditions to be implemented and accepted among stakeholders. Different approaches and instruments could be adopted to provide compensation in favour of the benefits' provision and identify "true prices". This paper discussed PES, TCA and TP tools for analysing the positive and negative externalities of multifunctional agricultural systems. Despite their role in economic analysis, each of these tools presents both strengths and weaknesses, highlighting the need for additional studies to improve their knowledge and support implementation.

One of the main limitations of this paper is linked to its aim, which is only to stimulate scholars. It underscores enhancing opportunities to enforce the multifunctional role of agriculture by adopting different market-based instruments and economic tools, which seem to still be "innovative" approaches or only attempts to support multifunctionality. Future research studies could use this review as a starting point for the development of more detailed economic analyses capable of exploring the dynamics governing the use of one instrument rather than another.

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Research article

The air quality benefits of electric vehicles' adoption in the short food supply chain

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Abstract. Concerns continue to rise about environmental sustainability and the impacts of traditional transportation systems. Exploring alternative solutions therefore becomes imperative. This paper aims to investigate the potential advantages of integrating battery electric vehicles into the agricultural short food supply chain with a specific focus on air quality improvements. In order to reach the research goal, this study gives a thorough and comparative environmental analysis based on a real-world test conducted under the EnerNETMob project financed by the InterregMed programme, in contrast to other studies that primarily relied on general parameters and simulations. This study illustrated that using an electric vehicle (EV), like the Nissan e-NV200, for short-distance transportation of agri-food products is not an environmentally sustainable solution instead of using a petrol-powered vehicle. However, as the distance travelled increases, the environmental impact of electric vehicles diminishes, surpassing that of internal combustion vehicles. This study holds significant theoretical, practical and policy implications that are worth considering.

Keywords: Bactery electric vehicle (BEV), Environmental cost, food delivery, logystics, sustainable food supply chain, carbon footprint.
JEL codes: Q01, Q52, L94.

HIGHLIGHTS

- Transitioning towards sustainable distribution models is crucial to reduce environmental pressures caused by transportation.
- Sustainable measures in goods distribution, like optimized routes and zero-emission technologies, reduce transport-generated greenhouse gas emissions.
- Environmental costs of electric vehicles decrease compared to petrol-powered vehicles as the distance travelled increases.
- There is a need to address challenges in the production of batteries with better performance, considering also the significant emissions generated.

1. INTRODUCTION

1.1. Research background

The distribution of products is among the primary factors contributing to environmental concerns linked to the emissions of GHGs in the various phases and in particular that of transport (Validi *et al.*, 2014). According to the latest data from the International Energy Agency (IEA, 2022), transport generates almost a quarter of global CO_2 emissions, and after a sharp drop recorded in 2020 due to the COVID-19 pandemic, emissions have started to increase again, reaching 7.7 Gt CO2 in 2021 (+8% compared to the previous year). The significant contribution of the transport sector to overall emissions and its negative impact on the sustainability of the global supply chain has placed the issue of transport at the centre of the international and European political debate. In the 2030 Agenda for Sustainable Development of the United Nations (UN, n.d.), transport is, in fact, integrated into various objectives, particularly those relating to energy efficiency (7.3), sustainable infrastructures (9.1) and the need to guarantee access for all to a safe, convenient, accessible and sustainable transport system. In line with these objectives, EU policy, through the Green Deal and Paris Agreement, has also introduced measures to reduce the carbon footprint of the transport sector, which, compared to other sectors, has seen a rise in emissions of CO_2 since the 1990s (EC, 2022; Schulthoff *et al.*, 2022).

Agri-food products, in the broader context of freight transport, represent one of the most significant items. The carbon footprint generated by the distribution of agri-food products through the main options to move freight from one area to another (road, shipping and air) presents a wide variability in relation to the characteristics of the agri-food chain, the phases of the chain under study and the geography of the distribution. Indeed, on the one hand, Aikins and Ramanathan (2020), in their study on the key factors affecting the carbon footprint of the agri-food supply chain, show that transport and sales/distribution are the main determinants of CO_2 emissions in the UK. On the other, Vitali *et al.* (2018), looking at a local organic beef supply chain, find that the distribution activity accounts for only 1.1% of GHG emissions for the whole supply chain. In light of these considerations, it is clear that local supply chains can play a key role in reducing GHG and CO_2 emissions through a change in the supply networks and in reducing the kilometres/miles travelled, producing social and environmental benefits (Hendry *et al.*, 2018). From this point of view, the short food supply chain (SFSC), recognized by EU Regulation 1305/2013, plays an important role not only because it puts producer and consumer in contact but also because it helps to reduce transport costs and consequently emissions of CO_2 with a positive impact on public goods and the environment (Canfora, 2016).

1.2. Extant gaps

Much of the economic literature on the SFSC has focused on consumer perception by analysing the main factors affecting their choice to pay a price premium for foods delivered in the SFSC (Galati *et al.,* 2022; Lombardi *et al.,* 2015) These studies highlight that consumer participation in SFSC initiatives is guided, on the one hand, by benevolence and universalism values and in particular by the desire to preserve, protect and support the environment, and improve people's well-being and, on the other, by the belief that products delivered in the SFSC are healthier, as they are obtained through sustainable and responsible production methods (Lombardi *et al.,* 2015; Morris and Kirwan, 2011). There are also numerous studies on the contribution of this specific way of distributing agri-food products to the sustainable development of rural areas (Galati *et al.*, 2020; Deller *et al.*, 2017; Fiore, 2016). The results demonstrate that the SFSC is the most appropriate channel to increase the sustainability of agricultural production and to generate positive environmental, economic and social effects for the area (De Fazio, 2016). Indeed, SFSCs not only reduce prices but also have a beneficial impact on the environment, and they notably help to strengthen regional and local identity because there are fewer intermediaries between producer and customer (Paciarotti and Torregiani, 2021). However, some authors find that the SFSC has some weaknesses linked, in particular, to logistics which create negative externalities that make it in some ways less sustainable than the global distribution system (Malak-Rawlikowska *et al.,* 2019; Nsamzinshuti *et al.,* 2018; Coley *et al.,* 2011).

Despite the importance of distribution logistics for the environmental sustainability of the SFSC, few studies to date have focused their attention on the impact that the mode of transport can have on the carbon footprint of this supply chain and on the strategic solutions that can be taken to reduce CO_2 emissions. The study of Pirog *et al.* (2001) compares the CO_2 emissions of local and conventional supply chains, demonstrating that distribution over short distances, particularly in farmers' markets, contributes to reducing fuel consumption and in particular CO_2 emissions by about eight times compared to the conventional supply chain. Consistent with this, Torquati *et al.* (2015) find that the distribution of fresh milk at a regional level, compared to the national supply chain, represents an advantageous solution from both an economic, thanks to the higher profit margins for farmers, and an environmental point of view, thanks to the reduction of CO_2 emissions, which drop from 0.1255 to 0.0516 kg CO_2 per litre of milk. However, other studies analysing the transport phase of the SFSC find conflicting results. If, on the one hand, the reduction in kilometres travelled, compared to the global supply chain, helps to reduce greenhouse gas emissions, on the other, the frequency with which farmers participate in farmers' markets can generate a greater carbon footprint (Galati *et al.*, 2021; Giacomarra *et al.*, 2019; Schmit *et al.*, 2017). Indeed, as pointed out by Malak-Rawlikowska *et al.* (2019), conventional agri-food supply chains, even if developed over a long distance, have, per product unit, a lower impact in terms of food miles and carbon footprint than short supply chains. To this, some scholars add that goods may generate a bigger carbon footprint than non-local commodities if they are preserved and bought out of season (Edwards-Jones, 2010; Cowell *et al.*, 2003). It is clear that the results obtained are contradictory and that further analyses are necessary to better understand the effective contribution of the SFSC to environmental sustainability and the possible strategic solutions to be adopted to reduce the carbon footprint. From this point of view, as Kneafsey *et al.* (2013), underline, identifying appropriate logistics arrangements can help improve the sustainability of the agri-food short chain. With reference to this matter, a recent literature review on the short food supply chain (Paciarotti and Torregiani, 2021) identifies a series of actions at the logistical level aimed at improving the efficiency of the SFSC, including the careful choice of vehicle for transport. In this scenario, the adoption of electric vehicles (EVs) also for the distribution of foods can be an opportunity to achieve the strategic objectives set at an international and European level and make the SFSC increasingly sustainable.

1.3. Research aim and value

This work proposes a logistics solution based on the choice of adopting an electric vehicle for the transport of food products along the SFSC in Italy. The study's specific objective is to evaluate the environmental costs associated with using electric vehicles to distribute agri-food commodities compared to an internal combustion engine vehicle (ICEV) with similar features. Compared to previous studies based on national or international databases, or on technical information provided by car manufacturers (Fevang *et al.*, 2021; Hoekstra, 2019), this research is based on empirical data and in a real-world setting during the testing stage of a research project that took place in Sicily and that was financed by the European Interreg Med Programme.

The results of the study provide an important theoretical contribution on the logistics of agricultural products' distribution within SFSC and on the carbon footprint of the transport phase in relation to the type of vehicle used. From a managerial point of view, the results can be an important decision support tool by providing useful information for a comparison between electric and conventional vehicles on the basis of the contribution to emissions generated. Finally, this study may be of interest for policymakers, constituting an empirical basis of information, useful for defining reasoned actions and directing future measures in support of greater sustainability of the supply chain.

The article is organized as follows. In the second section the methodological approach used to achieve the aim of the study is described. Results are presented and discussed in the section below. Final considerations close the article.

2. METHODOLOGICAL APPROACH

The empirical analysis conducted compared the environmental costs caused by the adoption of a commercial BEV (Nissan e-NV200) and that produced by an ICEV, with comparable features (Fiat Doblò 1.4 T-jet Pc-Tn cargo Easy) in the SFSC. The BEV has a cargo capacity of 4.2 m^3, which is equivalent to 2 pallets of 705 kg, which, according to previous findings (Giacomarra *et al.,* 2019), satisfies the needs of farmers participating in SFSC initiatives (Giacomarra *et al.,* 2019). Specifically, we estimated the environmental cost associated with the distribution of foods from farms to local retail stores and farmers' markets. This analysis was conducted using the approach recommended by Costa *et al.* (2021), which takes into consideration only the emissions produced by the EV battery and assumes that the end-of-life impact on emissions for both vehicles is small (<3%) and similar between them (Hawkins *et al.*, 2013). The formula may oversimplify the complexity of real-world EV dynamics and may not capture all the relevant variables and factors that affect the environmental impact, potentially resulting in incomplete or biased conclusions. Nevertheless, the formula takes into account a variety of variables, offering a comprehensive assessment of the environmental aspects of EVs. This enables a more complex assessment of their sustainability.

In terms of battery emissions, a study of the Swedish Institute for Environmental Research (Emilsson and

Dahllöf, 2019) states that the production of a lithium-ion battery for an BEV could lead to a total emission of 66-106 kg CO_2-eq per kWh of battery capacity. With a 40 kWh battery for the BEV studied, this means a total emission of about 3.44 tons of CO_2-eq in total. To assess the environmental cost of the BEV the following formula was used:

$$E_{EV}(gCO_2eq) = E_{mix}\left(\frac{gCO_2eq}{kWh}\right) * EC\left(\frac{kWh}{km}\right) * \Delta x(km) + BPE(gCO_2eq).$$

E_{mix} stands for the emission cost of the Italian energy mix; *EC* for the BEV energy usage; Δx for the number of kilometres covered; *BPE* for the emissions value throughout the battery manufacturing. *Emix* was obtained on the basis of data provided by Nowtricity, a private company that provides EV charging solutions and services, in their 2022 report (Nowtricity, 2022). Besides, Nowtricity, being a company whose solutions are based on the high amount of electricity usage, is actively involved in the research of the impact of different sources of energy on the CO_2 emissions generated by electricity usage.

The data used for this empirical analysis are the result of the pilot action of the EnerNETMob project "Mediterranean Interregional Electromobility Networks for intermodal and interurban low carbon transport systems", funded under the European Interreg Med Programme, which tested "last mile" delivery of agricultural goods across short distances between rural areas, metropolitan and urban areas. More specifically, the testing phase of the project took place in Sicily by connecting the municipalities of Acireale, on the eastern coast of the region, and Troina, in the Sicilian hinterland, using the Nissan e-NV200 vehicle for the transport of local agricultural commodities. The vehicle, exclusively powered by electricity, was used by Rete Fattorie Sociali Sicilia, a social farm, and its associated partners, to transport agricultural goods in the study area for a four-month timeframe. For the investigation's needs, vehicle movement tracking records were used to collect pertinent data. In particular, the drivers of the vehicle recorded the following data: date, departure time, mileage at departure (on the odometer), place of departure, arrival time, mileage on arrival (on the odometer), destination, active electrical devices (AC, heating), vehicle load (% of total volume), and type of products transported, charging start and end date and time; total mileage (on the odometer); place of charging; type of charging (domestic, normal, fast); battery level at the start and end of charging (percentage). The energy used to recharge the battery was obtained through a digital infrastructure of an energy distributor, which provided, in addition to the kWh of energy used for recharging, other information related to the recharging times in relation to the plug used.

3. RESULTS AND DISCUSSION

3.1. Environmental costs in numbers

The Nissan e-NV200 testing phase of the EnerNETMob project lasted for four months (from November 2021 to February 2022). During this period, the vehicle completed 59 journeys of freight transport and was used by Rete Fattorie Sociali Sicilia to deliver local foods covering from 5 to 123 km for each journey and more than 1500 km in total. The vehicle was charged 21 times during this period with energy from 0.05 to 25.35 kWh and with 279.32 kWh in total. Thus, the energy consumption of the vehicle per km has been calculated and the value is given in Table 1.

Besides, the examined vehicle (Nissan e-NV200) has a battery capacity of 40 kWh. As suggested by Emilsson and Dahllöf (2019), the GHGs generated during the production of the vehicle battery is calculated by multiplying the battery capacity with the average emission for each kWh of the capacity. The value is given in Table 1.

Additionally, emission cost of the Italian energy mix was obtained from the 2022 report by Nowtricity (2022), and was calculated by multiplying the contribution of each energy source in Italy with the average emission of GHGs per kWh of electricity used, making it possible to determine the CO_2-eq emissions for each kWh (ISPRA, 2021).

Last but not least, the table does not include the emissions generated by the vehicle production, since it is considered that, except for the battery, the end-of-life impacts of other parts are similar for corresponding BEV and ICEV. Therefore, this component can be excluded from the analysis, according to the formula proposed by Costa *et al.* (Costa *et al.*, 2021; Hawkins *et al.*, 2013).

After collecting all these data, it was possible to calculate the environmental cost of using the Nissan e-NV200 of Rete Fattorie Sociali Sicilia with the formula provided by Costa *et al.* (2021). The total emissions of this vehicle for 1505 km covered is 3 548 655.03 g, thus about 3.55 tons of CO_2-eq. It worth noting that this result is different from the previous study (Galati *et al.*, 2023) since the Emix value has been updated and some corrections have been made to the empirical collected data. Thus, changes in the variables' values result in different outputs of the research.

A similar analysis has been conducted for the corresponding ICEV (Fiat Doblò 1.4 T-jet Pc-Tn cargo Easy).

Table 1. Components of the formula of BEV's environmental cost.

Variable	Abbreviation	Calculation	Value
Emission cost of the Italian energy mix	Emix	gCO_2eq/kWh	389
Energy consumption	EC	Total *kWh* / total *km*	≈ 0.1856…
Consumed energy	kWh	*sum*	279.32
Travelled distance	Δx (km)	*sum*	1 505
Emissions generated by battery production (g)	BPE	Average of 66 000-106 000 gCO_2eq per *kWh* of battery capacity	3 440 000
Nissan e-NV200 battery capacity	-	-	40
Total emissions (g)			3 548 655.03

Table 2. Components of the formula of ICEV's environmental cost.

Variable	Abbreviation	Value
Emission cost of the Italian energy mix	Emix	-
Emissions	EC	165
Travelled distance	Δx (km)	1 505
Emission generated by battery production	BPE	0
Total emissions (g)		248 325

In this case, the data have been obtained from secondary sources. Precisely, the median emission value per vehicle is 165 g/km according to car-emissions.com (Car Emissions, n.d.). In order to compare that with the corresponding BEV, the same distance has been taken for the analysis: 1505 km. As for the E_{mix}, it does not make sense for ICEV, since the vehicle uses fuel instead of electricity. Besides, it does not contain any battery, so the BPE is equal to 0. Finally, the end-of-life impact on emissions of the entire vehicle has not been taken into consideration, since it is similar for both vehicles (Costa *et al.*, 2021; Hawkins *et al.*, 2013).

Consequently, the same table for ICEV has the values shown in Table 2.

Applying the values listed above in the formula proposed by Costa *et al.* (2021), we obtained 248 325 g of total emissions of this vehicle for the covered distance of 1 505 km, or 0.25 tons of CO_2-eq.

3.2. Environmental impact analysis

The environmental costs of utilizing an BEV and a corresponding ICEV have been calculated for the 1 505 km travelled. The results show that for this short distance, the ICEV has significantly lower (about 14 times less) environmental impact compared to the BEV. However, it should be highlighted that at the end of their life, commercial vans have passed much greater mileage than 1 505 km. According to the Department of Transport (DfT) of the UK (DfT, n.d.), the average annual mileage of vans is 13 200 miles, or 21 243 km. Moreover, for the vans used for "delivery/collection of goods", this number is 21 200 miles, or 34 118.1 km. On the other hand, according to the S&P Global (S&P Global, 2022), the average age of the vehicles is increasing, and in 2022 this represented 11.6 years for light trucks. This means that during the life-cycle of commercial vans, they cover approximately 395 759.96 km of distance. Therefore, it is interesting to compare the environmental cost of the BEV and ICEV for this distance.

Furthermore, it has to be noted that the 40kWh battery life of Nissan e-NV200 guaranteed by the manufacturer is 160 000 km (Nissan News, n.d.). Thus, for covering 395 759.96 kms, the Nissan e-NV200 will need two additional batteries, which will generate 6.88 more tons of CO_2-eq (Emilsson and Dahllöf, 2019).

By recalling the formula of Costa *et al.* (2021) and inserting new data into it, we obtained absolutely different results. Specifically, the total emissions of the examined BEV are 38 892 298.17 g of CO_2-eq, while the same value for the corresponding ICEV is 65 300 393.40 g of CO_2-eq, thus about 38.89 and 65.3 tons of CO_2-eq for the BEV and ICEV, respectively. It means that, at the end-of-life cycle, the ICEV has made 40.44% more harmful impact on the environment than the corresponding BEV (Figure 1).

As Figure 1 illustrates, for the short distance run by the vehicles, the environmental cost of the BEV is higher due to the battery production. Consistent with this, Bieker *et al.* (2021) noted that emissions generated during the manufacturing of BEV and ICEV is similar and that the most relevant influence is related to the battery manufacturing, due also to the energy required to acquire raw materials, which has a more significant environmental impact than petrol-powered cars. However, the situation is reversed when the distance covered is longer and nearer to the average of the entire life cycle mileage of commercial vans used for "delivery/collection of goods". The study outcome is in line with a number of

Figure 1. Comparison of environmental costs of BEV and ICEV.

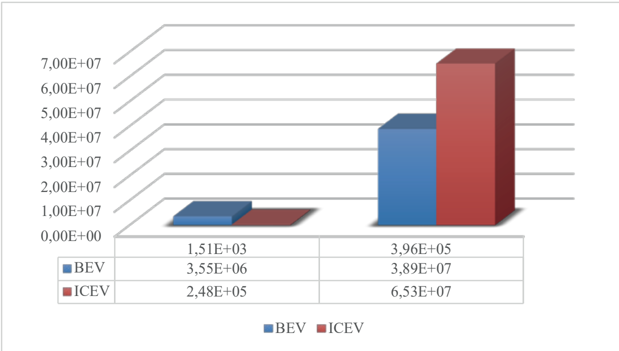
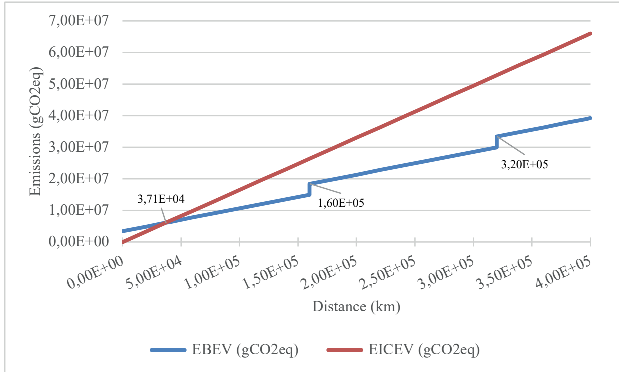


Figure 2. BEP of CO_2 emissions of BEV and ICEV.



previous studies, which argue that, potentially, the adoption of EVs reduces the harmful environmental impact through minimizing the CO_2 emissions. Indeed, De Santis *et al.* (2022) prove that BEVs can be considered less impactful vehicles for the environment than ICEVs in terms of CO_2 emissions. Consistent with our work, Canter (2022) studied the case in the US in more detail, and observed that at the production level, BEV generates significantly more CO_2, but after 1.2-1.6 years ICEV reaches the same amount of CO_2 emitted by BEV and, at the end of its life cycle, it is substantially lower. Similarly, Kawamoto *et al.* (2019) investigated more regions, including the US, EU, Japan, China, and Australia, and they confirmed that the harmful environmental impact of an BEV is higher than an ICEV, since more electronic components are needed to be produced, generating higher CO_2 emissions. But the authors also declare that the more distance the vehicles cover, BEV has less and the ICEV has greater impact per km.

The break-even point (BEP) – i.e., the lowest distance travelled in kilometres after which the BEV is considered more environmentally friendly than the corresponding ICEV – has been calculated. In our case, BEP is equal to 37 068.97 km (Figure 2). In Figure 2, the function of environmental cost of an ICEV is represented by the red line and the following equation: Y=165x. While, another equation stands for the environmental cost of an BEV: Y=72.20x+3440000. Where x is number of kilometres travelled; 72.20 is obtained by multiplying E_{mix} and *EC*; and 3 440 000 is BPE. Besides, after covering every 160 000 km, the maximum range capacity of a 40kWh battery of a Nissan e-NV200 (Nissan News, n.d.), additional emissions generated by battery production are taken into consideration. These findings are consistent with previous studies which showed that the environmental advantage related to the CO_2 reduction increases when the distance travelled rises, additionally providing the possibility to lower the emissions of NOx, CO, VOCs and PM2.5, compared to the ICEV (Kawamoto *et al.*, 2019; Pipitone *et al.*, 2021).

In accordance to our results, Joshi *et al.* (2022) argue that production of BEVs, due to the necessity of having a battery, generates considerably higher amounts of CO_2. The authors also conclude that the CO_2 emissions over the life of an BEV can be significantly lower than an ICEV if renewable energy sources are used. Indeed, if the emission cost of the energy mix is equal to 0, it will make the usage of BEV more environmentally friendly, since, for any distance travelled by the vehicle, the environmental cost of the vehicle will remain constant and equal to the BPE, or 3 440 000 g of CO_2-eq for every 160 000 km, while the same value for an ICEV will continue to increase, with 165 g of CO_2-eq per km (Figure 3). Similarly, Puricelli *et al.* (2022) prove that an BEV generates 41% less life cycle emissions compared to the corresponding ICEV, which is almost the same number as our result – 40.44%. Still, this difference can be increased if renewable energy sources are used for charging. Haase *et al.* (2022) studied the adoption of BEV or ICEV in Germany, and they found that the BEV powered by wind energy is the best option for the country in 2020 as well as in 2050. Similarly, Winkler *et al.* (2022) studied the food retailing industry in Berlin and revealed that in the circumstances of a given energy mix in Germany, an BEV reduces CO_2 emissions by 25% compared to an ICEV, while they can be reduced by 92% if the energy sources are fully renewable. The result of our simulation, in agreement with what has been found by other authors, shows that the sustainability of the adoption of EVs cannot be separated from investments in renewable energies.

Using renewable energy sources slightly changes the breakeven point, as it will shift from 37 068.97 km to 20 848.48 km (Figure 4). In Figure 4, the function of the environmental cost of an ICEV is represented by the red line and the following equation: Y=165x. The blue line

Figure 3. Comparison of environmental costs of BEV and ICEV (renewable energy sources).

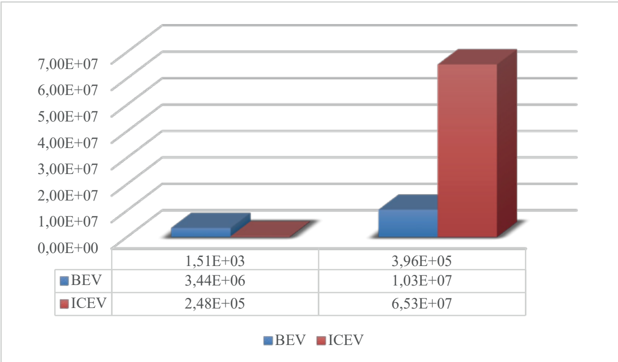
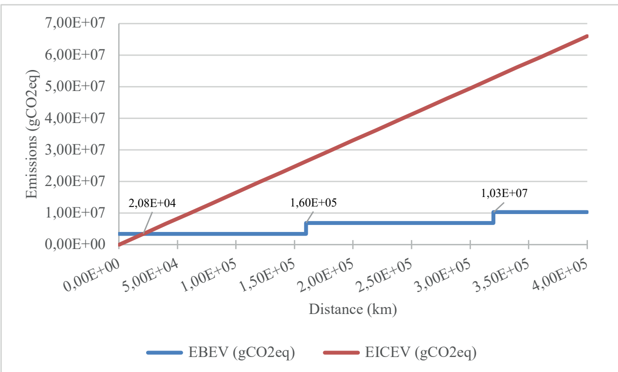


Figure 4. BEP of CO_2 emissions of BEV and ICEV (renewable).



stands for the environmental cost of an BEV and represents 3 440 000 g of CO_2-eq for every 160 000 km. In other words, the larger is the proportion of energy generated from renewable sources in the energy mix, the less distance is needed to be covered in order to make up for the significant environmental impact associated with the battery production phase (Cao *et al*., 2021; Alp *et al*., 2022). A virtuous example in this context is that of Norway which bases its energy mix on renewable sources with a considerable reduction in the environmental costs of EVs (Costa *et al*., 2021).

Table 3 summarizes the CO_2 emissions generated by the investigated BEV and ICEV for 1505 km (experiment data) and for 395759.96 km (average end-of-life milage for commercial vehicles) in the case of the actual Italian energy mix and when the energy is obtained fully from renewable sources.

Studying the environmental impact of the "last mile" delivery distribution with EV or ICEV in the case of different distances covered and different circumstances in terms of energy sources, illustrated how the output of the study, thus the environmental impact may differ if the conditions are different and the input variables of the formula given by Costa *et al.* (2021) change.

4. CONCLUSIONS

The transition towards increasingly sustainable distribution models in order to reduce the environmental pressures generated by transport is today one of the cornerstones of the 2030 Agenda for Sustainable Development, reiterated at the Sustainable Innovation Forum held during COP26. The need to reduce greenhouse gas (GHG) emissions generated by transport has led to the definition of measures and strategies focused on sustainability also in the goods distribution sector, whose contribution to the ecological footprint is increasingly significant. The solutions being adopted range from the optimization of routes to the adoption of transport management systems in all phases of the value chain, and up to the adoption of zero-emission technologies such as electric batteries. In particular, the adoption of BEV provides an occasion for companies to achieve sustainable development objectives by offering advantages that include environmental concerns, such as lowering CO_2 emissions. Our study, aimed at comparing the environmental costs, in terms of GHG emissions, of an electric commercial vehicle and a petrol-powered vehicle in the distribution of agricultural commodities in the SFSC, fits into this scenario. In particular, this study gives a thorough and comparative environmental analysis grounded in an actual real-world experiment conducted as part of the EnerNETMob project financed by the InterregMed

Table 3. Emissions by distance and energy sources.

	Vehicle	Actual energy mix		Renewable energy	
		1505 km	395759.96 km[1]	1505 km	395759.96 km[1]
CO_2	BEV	3 548 655.03 g	38 892 298.17 g	3 440 000 g	10 320 000 g
	ICEV	248 325 g	65 300 393.4 g	248 325 g	65 300 393.4 g

[1] End-of-life of the vehicle.

initiative, in contrast to earlier studies that were mostly focused on general parameters and simulations.

The study's findings, which are supported by actual evidence, show that deploying an electric commercial vehicle, Nissan e-NV200, for the transportation of agricultural commodities is not an environmentally sustainable option for short distances compared to the petrol-powered vehicle. However, as the kilometres travelled increase, the environmental costs of the EV decrease, to the disadvantage of the ICEV. This finding supports prior research which showed that the benefits of driving an BEV over an ICEV rise with the number of kilometres travelled, also contributing to reducing NOx, CO, VOCs, and PM2.5 emissions. The study highlights some relevant aspects that deserve particular attention. On the one hand, the significant weight of the emissions generated in the battery production phase, which is still too significant today, reduces the environmental convenience of using EVs. In this area, considerable effort has been made and is continuing to produce batteries with better performance, also from an environmental point of view. For example, numerous researches are trying to identify solutions for the recovery of precious battery materials to generate greater sustainability over the entire life cycle. On the other hand, there is the influence of a country's energy mix on the environmental cost. From this point of view, our study, starting from empirical data, simulated the effect of an energy mix composed of entirely renewable energy sources. The data corroborate preceding research which found that the higher the proportion of energy from renewable sources is in the energy mix, the shorter distance is needed to be covered by EVs in order to make up for the significant impact of emissions generated by their batteries' production.

The study's findings must be understood and interpreted in the light of the scenario being looked at, especially in the light of the features of the transportation methods used during the project testing phase, the nation's energy mix, features of the road infrastructure, etc.. However, the proposed methodological approach can also be replicated in other geographical contexts, making it possible to evaluate its effectiveness for environmental convenience analyses and increasing real-life research on the adoption of battery-powered vehicles compared to petrol-powered vehicles.

Several theoretical, practical and policy implications can be envisaged. The study enriches the literature in this research field by presenting a comparative environmental analysis between battery-powered and internal combustion vehicles based on a real-life test. On a managerial level, the results of the study provide insights and suggestions to various stakeholders. For farms participating in the short supply chain, the study demonstrates that the adoption of EVs can contribute to the SFSC philosophy as a highly sustainable agri-food product distribution model, albeit still hampered by high vehicle costs. For manufacturing companies, these results are useful because they trigger a reflection on the importance of identifying more sustainable solutions, improving the environmental performance of current batteries on the market. This obviously also requires investments in R&D aimed at identifying solutions for battery recycling. Finally, the results can represent a guideline for policymakers in order to concentrate their efforts on measures capable of supporting the sector and transitioning towards increasingly sustainable distribution models. In particular, as emerged from the study, it is essential to move towards an increasingly greener energy mix, increasing the share of energy from renewable sources and supporting the diffusion of charging stations powered by renewable energies and not by fossil sources in order to reduce environmental costs.

5. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Despite considerable theoretical and practical implications of this research, the study has several limitations that indicate the need of future researches in the field. First of all, the formula used may require further clarification regarding its applicability and limitations. For instance, it does not include the error rate that would compensate for uncertainties. Furthermore, the end of life of the batteries should be taken into account when assessing the environmental impact of the use of EVs. Future research could focus on refining the formula and conducting the analyses to determine its range of applicability.

Besides, the study does not include monitoring data related to the use of diesel vehicles, which are common in Italy and Europe. To address this limitation, future research could incorporate data and analysis specifically focused on the environmental implications of diesel vehicles. This would provide a more comprehensive assessment of the entire vehicle landscape and enable a comparative analysis between diesel, ICEVs, and BEVs. Furthermore, additional experiments with different vehicles and in different regions will provide a wider picture of the feasibility of EV adoption in SFSCs.

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Research article

Why cassava processors will patronize mechanized cassava peeling machine service

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Abstract. Cassava peeling machines are available but are inaccessible and prohibitively expensive, especially for small-scale processors to acquire. This paper examines the perception and willingness of smallholder cassava processors to pay for cassava peeling machine services using data from 300 cassava processors in the Bono East Region of Ghana. A perception index from a 5-point Likert Scale and Cragg's Double Hurdle model were the methods of analysis. The results revealed a perception index of 2.54 and this implies that cassava processors have neutral perception about the cassava peeling machine service. Also, it was found that majority of the processors (75.33%) are not aware of existence of the cassava peeling machine. In addition, we find that 99.63% of the cassava processors are willing to patronize the services of the cassava peeling machine. Moreover, cassava processors are willing to pay an average amount of GH₵ 4.21 for a 50 kg bag of cassava peeled using the services of the cassava peeling machine. Furthermore, the study revealed that factors such as educational level, quantity produced per processing cycle and the dependence on cassava processing as the main source of income positively and significantly influenced willingness to pay for the services. Finally, the amount processors were willing to pay was influenced by educational level, household size, source of income, perception about machine's complications and group membership. The study recommends that investors consider installing cassava peeling machines to provide commercial cassava peeling services in processing areas. While generating income to investors, it will contribute to reducing postharvest losses during cassava processing. Future efforts should focus on raising awareness about the availability and benefits of commercialization of mechanized peeling of cassava.

Keywords: cassava peeling machine, cassava processors, Ghana, perception, willingness to pay.
JEL codes: C21, C24, D71, O14, O33.

HIGHLIGHTS

- Cassava processors have neutral perception about the cassava peeling machine service.
- Majority of cassava processors are not aware of existence of the cassava peeling machine.
- Cassava processors are willing to patronize the services of the cassava peeling machine.
- Educational level influences both processors' willingness to pay and the amount they are willing to pay.

1. INTRODUCTION

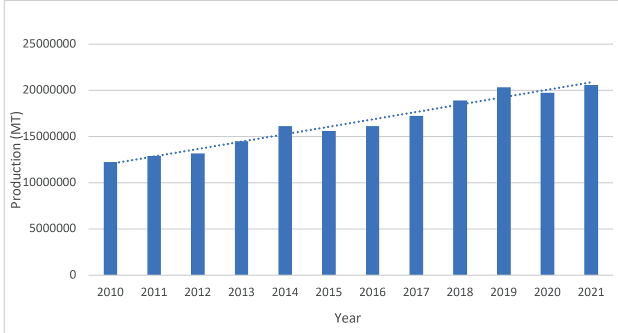
1.1. Cassava production and patronage of the cassava peeling machine

Cassava is one of the important staple food crops and a major source of income for rural households (Rozi *et al.*, 2023). According to FAOSTAT (2023), there has been a significant rise in global cassava production with an increase of 240 million metric tons since 2010. This increase is due to global demand for cassava as a raw material for the production of several industrial products (Hafif *et al.*, 2023; FAOSTAT, 2023). FAOSTAT (2023) projections indicate that by 2025, approximately 62% of the world's cassava production will be sourced from sub-Saharan Africa. Ghana is the sixth highest global producer of cassava in terms of value, and the third in Africa, with about 70 percent of local farmers producing over 20 million metric tonnes every year (Adjei *et al.*, 2023; FAOSTAT, 2023). Cassava produced in Ghana increased to a total of 17,212,760 metric tonnes in the year 2015, 17,798,220 metric tonnes in 2016, and over 20,000,000 metric tons in 2021 (Figure 1).

One disadvantage of cassava production as a commercial crop is its short shelf life (Zainuddin *et al.*, 2023). Cassava roots are extremely perishable as deterioration starts immediately after harvest. Once harvested, it has to be either consumed immediately or processed into more stable product forms (Okeowo, 2016). Due to its highly perishable nature, harvested cassava roots are mostly processed to curb post-harvest losses (Davies *et al.*, 2008; Mbinda and Mukami, 2022). Food and Agriculture Organization (2005) observed that the increase in production of cassava has caused widespread cassava processing into various shelf-stable and semi-stable products by traditional cassava processors and small-scale commercial processing units.

In Ghana, cassava roots are processed into four main products namely, gari, cassava chips (konkonte) or flour, starch and semi-fermented mash (agbelima) (Sackey and Bani, 2007). The first operation in the processing of cassava for human consumption is the removal of the cassava peels. Osei (2020) stated that cassava peeling in the olden days was done by the use of stones and wooden flint before evolving to the simple household knife. Several problems are encountered during indigenous processing which has created an urgent need for mechanization and upgrading of processing (FAO, 2015). Traditionally, cassava peeling is known to be done manually by slitting along the length of the cassava with a sharp object and removing the peels with the help of the hands. The manual approach of peeling cassava has been characterized by drudgery, high rate of injury and also places a limit on the peeling speed (Diop and Calverley, 1998; Osei, 2020). Regardless, this method is preferred by local processors and small-scale farmers because they believe it yields the best of results and it is the only method available to them. In an attempt to enhance the peeling of cassava, other methods have been introduced. According to Osei (2020), cassava can be peeled mechanically, chemically and by steaming. Chemical peeling of cassava was identified to be costly and can lead to food poisoning whereas steam peeling can lead to premature cooking of the cassava tuber (Kadurumba and Aririguzo, 2021). Manual peeling of cassava has been a serious global challenge to cassava processors, especially to large scale processors (Mensah, 2017). According to Kolawole *et al.* (2010), processing cassava cannot be done without peeling and a number of cassava peeling machines with different efficiencies are on the market. Regardless of the numerous global improvements made in cassava peeling, cassava processing in Ghana is fraught with the lack/limited availability of mechanized peeling machines that could help boost the operation. Even when available, these efficient technologies cannot be afforded by many and are inaccessible to those at the farm level where most of the cassava root processing takes place (Mensah, 2017).

Figure 1. Cassava Production in Ghana.



Source: FAOSTAT, 2023.

Despite the fact that some studies analyzed the design (Gumanit and Pugahan, 2015, Nwaigwe *et al*., 2012), construction or fabrication (Gumanit and Pugahan, 2015) and performance (Gumanit and Pugahan, 2015; Mensah, 2017; Nwaigwe *et al*., 2012; Osei, 2020) of the cassava peeling machine, there is limited or no information on cassava processors' perception about the cassava peeling machine and their willingness to patronize the technology. This paper addresses three questions, viz. Q1: Are cassava processors aware of existence of cassava peeling machine? Q2: what is the perception of cassava processors on the cassava peeling machine? and Q3: What factors influence cassava processors' willingness to pay for cassava peeling machine as well as the amount they are willing to pay? Cassava processors play a crucial in the cassava value chain by adding value to raw fresh cassava, and converting it into marketable products such as cassava flour, starch, chips, and gari. They often operate small-scale processing units which employs various techniques and technologies to enhance the quality and shelf life of the cassava products. The focus of this study is to examine how these cassava processors in the Bono East Region of Ghana perceive and express their willingness to pay for the services provided by a cassava peeling machine.

The contributions of this paper are twofold. First, to improve and facilitate the processing of cassava into various commodities in order to improve its shelf-life, there is the need for the introduction of appropriate cassava processing technologies. With the Government of Ghana interested in improving the production and processing of cassava in the country, this research will inform policy makers about cassava processors' readiness for technologies aimed at improving their ventures. Secondly, despite the introduction of improved cassava processing technologies in Ghana, there is inadequate information related to the awareness, perception and use of these improve cassava processing technologies. Since most cassava processors are used to the indigenous processing methods, it is imperative to assess the willingness of these processors to pay for the services of introduced technologies and gauge the amount they are willing to pay. This information will aid the government and all other stakeholders in formulating policies and strategies to help promote the use of improved cassava processing technologies. The study will serve as a foundation for evidence-based decision-making and the formulation of policies and strategies aimed at promoting the adoption of improved cassava processing technologies. By aligning the efforts of the government and other stakeholders, Ghana can enhance the competitiveness and sustainability of its cassava processing industry, leading to economic growth, increased employment opportunities, improved livelihoods for cassava processors as well as help improve product quality, decrease processing time and reduce tuber losses. The remaining sections of the paper are structured as follows. In the next section, we complete the introduction by presenting the underlying theoretical framework of the study. This is followed by a literature review on the topic in section two. Following that, the research methodology is presented in section three. The results and discussion are presented in section four and in section five, we present the conclusions and make recommendations for policy.

1.2. Theoretical Framework

Economic theory and behavioral economics were considered the theoretical underpinnings of this study. The decision-making process of the processor was explained using a few essential concepts:

1. Cost-Benefit Analysis: It is evidently clear that cassava processors and other interested parties would weigh the costs and advantages of purchasing a cassava peeling equipment. The benefits of greater productivity, time savings, enhanced product quality, and potential increases in market prices for processed cassava products would be weighed against the cost of the machine, maintenance costs and operating expenses. Whether the apparent benefits outweigh the price of the machine would determine whether or not to purchase the technology.
2. Technology Adoption and Innovation: According to Jain *et al.* (2023), farmers' decisions to accept new technologies are impacted by how beneficial and simple such technologies are regarded to be. Cassava processors may be more inclined to pay for the peeling machine if they believe it is a useful invention that will increase their production and profitability. Adoption may also be influenced by factors including training, technical support, and demonstrations of the machine's efficacy.
3. Market Demand and Price Premium: The high demand for cassava products can have an impact on processors' willingness to pay for the services of a cassava peeling machine. The purpose of the machine is to reduce the drudgery and time involved in manually peeling of cassava. If there is significant demand for cassava products like gari, flour, and starch, processors may see investing in the machine as a way to meet consumer preferences and capture higher prices in a shorter period of time.
4. Social Norms and Peer Influence: According to Gächter *et al.* (2013), peer behavior (behavioral economics) and social norms might have an impact on

decision making. Other processors could be more likely to use cassava peeling machines if nearby farmers or significant community members have done so effectively and reaped the rewards. Farmers' willingness to pay for the technology can be influenced by peer pressure, social learning, and shared experiences.

5. Risk and Uncertainty: When making an investment in procuring a cassava peeling machine, investors and processors may take into account the risks and uncertainties involved. Their decision-making may be impacted by uncertainty over market demand, machine dependability and financial hazards. Investors' trust and desire to invest in the technology might be boosted by providing them with information and support about potential dangers and mitigation techniques.

2. LITERATURE REVIEW

Ghana is second to Nigeria in cassava root production in West Africa, and produces about 15,113,000 metric tonnes of cassava annually (FAO, 2015; Richards, 2023). Cassava is now cultivated in every region in Ghana. Based on the average volume produced by each region between 2012 to 2014, Bayitse *et al.* (2017) indicated that the five principal regions in terms of cassava production in Ghana are the Eastern, Brong Ahafo (now Bono, Ahafo and Bono East regions), Ashanti, Central and the Northern regions.

Anning-Dorson (2023) maintained that about one-fifth of Ghana's agricultural GDP is made up of income generated from cassava production and post-harvest processing. Acheampong *et al.* (2022), stated that 60% of the daily caloric intake of the Ghanaian population is obtained from cassava. FAO (2015) reinforced the fact that cassava is an important source of farm income particularly in Ghana and Nigeria. Income from cassava was higher for farmers that had access to mechanized cassava processing equipment for the preparation of gari in Ghana and Nigeria (FAO, 2015). MoFA (2021) also added that cassava is a major source of income and food security in some districts in Ghana, particularly Suhum-Kraboa-Coaltar District. Cassava is of significant importance to the economy of Ghana and accounts for 22% of the national GDP (Anning-Dorson, 2023).

The key focus of cassava production is for human consumption, as more than 90% of cassava produced is intended to be consumed by humans (FAOSTAT, 2023). Asogwa *et al.* (2013) and FAOSTAT (2023) argue that, with an annual output exceeding 34 million metric tonnes, cassava is one of the most important food crops in the world. According to Ani *et al.* (2013) and Hafif *et al.* 2023, processed cassava is not only used for household consumption but also serves as livestock feed and industrial raw material used for producing bakery products, adhesives, dextrin, dextrose glucose, lactose and sucrose that can be transformed into ethanol. Cassava products in Africa can be classified into five common groups: fresh root, granulated products, dried roots, pasty products and cassava leaves (FAO, 2015).

Peeling is the first and major operation unit in cassava processing and is still mainly done manually using a knife (Bayitse *et al.*, 2017). The increasing demand for cassava products has caused the need to design technologies to improve cassava processing. Cassava processing thus deserves serious attention in order to meet the local and international demand for cassava products. The unit operations involved in the processing of cassava includes peeling, grating, boiling/parboiling, drying, milling, sieving, extrusion and frying. Several processes for the above-mentioned operations have been mechanized successfully. However, cassava peeling remains a serious global challenge in cassava processing (Kadurumba and Aririguzo, 2021).

According to Amoah *et al.* (2022), there is a relatively higher adoption rate of modern cassava processing techniques, mainly because the operation is quite easy. A major factor influencing adoption of postharvest cassava technology is the level of awareness of the technology. Amaza *et al.* (2016), indicated that the knowledge and level of awareness of the mechanized processing technology has a correlation with rate of adoption of the processing technology. Amaza *et al.* (2016), also added that factors such as the processor's gender, distance from processing site to the nearest tarmac road and the cost of capital do influence the decision to adopt a High-Quality Cassava Flour (HQFC) processing technology. A study by Udensi *et al.* (2017), also revealed that the adoption of post-harvest processing technology among cassava farmers is influenced by factors such as the household size of the farmer, income of the household head, the number of processing equipment and the years of experience. Ehinmowo and Fatuase (2016) also added educational level, source of information, source of raw materials and source of credit as key determinants of adoption of improved cassava processing technologies.

Once we have considered the determinants of adoption of cassava processing technologies, the next step is to analyze processor's willingness to pay for the technologies. Willingness to pay (WTP) is defined by Gunatilake *et al.* (2007), as the economic value of goods or commodities to an individual or a household under given conditions. Dimitri and Greene (2002) added that it is important to distinguish between willingness to pay and willingness to accept. Contrary to willingness to pay, willingness to accept describes the maximum amount a person is willing to take in order to give up a good (Dimitri and Greene, 2002; Martín-Fernández *et al.*, 2010). Two sequential processes, which can be considered as either a joint or separate decision, can be used to address the decision to pay or not pay a given premium. Most literature (Adepoju and Oyewole, 2013; Bhatta *et al.*, 2009 and Meenakshi *et al.*, 2011) indicated that either a linear model such as Ordinary Least Squares (OLS) or Dichotomous models, such as the Logit, Probit and Tobit, can be employed in assessing the determinants of willingness to pay. The current study employed Cragg's double hurdle model because different factors influenced processors' willingness to pay as well as the amount they are willing to pay and also because of the insignificance of the Mill's ratio of the Heckman's model (Okoffo *et al.*, 2016; Wodjao, 2008).

3. METHODOLOGY

3.1. Methods

The study was undertaken in the Bono East Region of Ghana. The region is referred to as the "food basket" of Ghana as most people in the region are farmers. Generally, these farmers produce cash crops like coffee, tobacco, cashew and rubber. Food crops such as beans, cassava, yam, maize, plantain, rice, cocoyam and tomatoes are also grown. Cassava processing is one of the predominant industrial establishments that serves as a source of livelihood to most people in the region (BERCC, 2020).

Descriptive statistics comprising means, standard deviations and percentages were used to analyse and describe the socioeconomic characteristics of the processors. Also, a perception index was used to assess the perception of processors about the cassava peeling machine. A five-point Likert scale (1 = Strongly agree, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Strongly disagree) was employed to obtain the perception level of the respondents on various statements relating to the cassava peeling machine. The mean scores of all the processors with regards to each of the perception statements was then calculated. The mean score of each perception statement was computed as follows:

$$Mean\ score = \frac{[(fsa\times 1)+(fa\times 2)+(fn\times 3)+(fd\times 4)+(fsd\times 5)]}{x} \quad (1)$$

where,

fsa = frequency of strongly agree,
fa = frequency of agree,
fn = frequency of neutral
fd = frequency of disagree
fsd = frequency of strongly disagree
x = number of cassava processors who responded to the perception statements

The overall perception index was finally computed as the average of all the mean scores for all the perception statements ranked by the processors. This was calculated as follows:

$$Perception\ index = \frac{1}{n}(\sum_{i}^{n} \mathrm{MS}_{\mathrm{PS1}} + MS_{PS2} + MS_{PS3} + \cdots \ldots \ldots \ldots .. MS_{PSn}) \quad (2)$$

where
n = number of perception statements,
MS = mean score of each perception statement and
$PS_{1\ldots n}$ = each perception statement.

The willingness to pay for services of the cassava peeling machine was analyzed using descriptive statistics. In the survey questionnaire, the double bound contingent valuation approach was used to evaluate the processors' response in the absence of an actual price in offering the cassava peeling service. The double bound contingent valuation (CV) model was introduced by Mäler and Vincent (2003), which aims at introducing a second bid as a follow-up question to the initial bid. The second bid is a higher amount if the respondent answers yes to the initial bid. However, if the response to the first bid is no, a lower amount is asked as the second bid. According to Fonta *et al.* (2011), contingent valuation method is important in assessing the level of readiness of communities or groups of individual participants in community-based projects or services aimed at improving welfare. Also, the CV approach has the potential of resolving the issue where there is lack of knowledge or exposures of existing technologies or methodologies. Taneja *et al.* (2014), stated that the contingent valuation (CV) method makes use of surveys that are particularly intended for measuring preferences and willingness to pay. It helps in estimating the amount processors are willing to pay using various elicitation techniques. The method, which has been used by several researchers, is rated as the best choice especially in situations of little or no market information (Okoffo *et al.*, 2016). The implication is that it helps in simulating the concept of choice in market situations as processors have the opportunity of accepting or rejecting the product. Following the importance of the CV method, it has been highly used in several studies in agriculture where it has been used to elicit information on farmers' willingness to pay for a product, technology or service. Due to the importance of contingent valuation approach in willingness to pay studies, we adopted this method for our study. The responses expected from the utilization of the double bound contingent valuation are mathematically presented as:

$Yi = (1,1) = (yes, yes)$,
$Yi = (1,0) = (yes, no)$
$Yi = (0,1) = (no, yes)$
$Yi = (0,0) = (no, no)$

The first represents the response to the first bid and the second represents the response to the second bid.

The Tobit, Cragg double hurdle and Heckman selection models were employed in examining the determinants of cassava processors' willingness to pay for cassava peeling machine services as well as the amount processors were willing to pay for these services. The Tobit model has an underlying assumption that the decision on processors' willingness to pay and the amount they are willing to pay are made simultaneously whereas Cragg's model assumes the two decisions are made in two different stages (Mal *et al.*, 2012). Buraimo *et al.* (2010), indicated that it is possible to compare the two models using a standard likelihood ratio test. The hypothesis to be tested are:

H_0: *There is no significant difference between the two models*
H_1: *There is a significant difference between the models*

A rejection of the null hypothesis indicates that there is a difference in the models and the decision on processors' willingness to pay and the amount they are willing to pay are made differently, hence Cragg double hurdle is superior. The null hypothesis is rejected when the likelihood ratio statistic is greater than the chi-square value. According to Greene (2012), the likelihood ratio statistic can be computed as:

$$LR = -2\ [log\ LT - (log\ LP + log\ LTR)] \quad (3)$$

where *LT*, *LP* and *LTR* are log-likelihoods of the Tobit, Probit, and truncated regression models respectively and *LR* is the likelihood ratio statistic. The degree of freedom $(n - k)$ for the hypothesis was identified to be infinity.

To confirm the appropriateness of the Cragg Double Hurdle model, the Heckman Selection model was estimated. As proposed by Heckman (1979), the Heckman model is a two-step estimator model that checks for selection bias and corrects them. Puhani (2000) stated that the first stage of the model is a probit model, whereas the second stage is OLS. The Mill's ratio of the Heckman model serves as the basis of decision for its appropriateness to be employed for a particular study. A significant Mill's ratio indicates the existence of selection bias, in which case the Heckman model is more appropriate (Waithaka *et al.*, 2007). On the contrary, if the Mill's ratio is insignificant, the Cragg Double Hurdle is the preferred model. Therefore, in this study the Heckman model (Appendix 1) revealed insignificant Mill's ratios which necessitated the use of the Cragg Double Hurdle model. The first stage of the Cragg Double Hurdle (probit model) is modelled as:

$$WTPCPM = 1 \ if \ WTPCPM > 0 \ and$$
$$WTPCPM = 0 \ if \ WTPCPM \leq 0 \quad (4)$$
$$WTPCPM = Z_i\alpha + \varepsilon_i \quad (5)$$

where
WTPCPM = a dichotomous variable which assumes a value of 1 if processors are willing to patronize the machine and 0 if they are unwilling to patronize it.
Z = Vector of cassava processors' characteristics
α = Vector of parameters to be estimated
ε_i = Error term

The second stage equation in the Cragg Double Hurdle model (truncated regression) which models the amount cassava processors are willing to pay for the service offered is given as:

$$WTPfee = WTPfeei \ if \ WTPfeei > 0 \ and$$
$$WTPfeei = 0 \ if \ otherwise \quad (7)$$
$$WTPfeei = Xi\beta + Ui \quad (8)$$

where
WTPfeei = observed response on how much cassava processors are willing to pay for the mechanized cassava peeling machine service
X = Vector of cassava processors' characteristics
β = Vector of parameters to be estimated
Ui = Error term

3.2. Data Collection, Sources and Type of Data

Generally, primary cross-sectional data was used in the study and this was collected using structured questionnaires administered on cassava processers. The processors were selected using a multi-stage sampling technique. In the first stage, the Bono East Region of Ghana was purposively selected because it is noted to be one of the major cassava growing and processing regions in the country (Bayitse *et al.*, 2017). Purposive sampling was also used to select Techiman Municipal, Nkoranza North District and the Atebubu-Amantin Municipal as areas for the study in the second stage. These are well known cassava processing areas with communities noted for cassava processing (UNIDO, 2019). Simple random sampling technique was used to select 100 respondents from each district in the third stage, giving a total sample size of 300 respondents. The choice of sampling was driven by the need to focus on well-known cassava processing areas, while stratification in relation to the study ensured representativeness. The subsequent use of simple random sampling within each study area ensured fairness and enhanced the potential generalizability of the findings to the larger population of cassava processors in the study area.

Questionnaires were administered in local dialect and English in order to make communication easy and enhance the quality of the data. Field visit was adopted to obtain information from respondents through face-to-face interview. Primary data was collected using structured questionnaires consisting of closed and open-ended questions. Specific questions were asked to obtain personal information about the cassava processors, characteristics of their processing operation, their perceptions about the cassava peeling machine, willingness to pay for the services of the cassava peeling machine, the amount willing to be paid, associated constraints as well as the cost and returns of commercializing a cassava peeling machine in the Bono East region. The study strategically chose to administer the questionnaire during the peak cassava processing season, which typically starts in the middle of the year. By aligning the questionnaire administration with the period of high cassava processing activities, the study maximized the opportunity to capture accurate and relevant information from the processors. Data was also sourced from journal articles, dissertations and other technical documents that relate to this particular study. This was mainly used in the review of literature concerning various subject matters relating to the study. This also helped in the selection of the variables used in the Cragg double hurdle regression model.

4. RESULTS AND DISCUSSION

4.1. Socioeconomic characteristics of cassava processors

The socioeconomic characteristics of respondents are presented in Tables 1 and 2. The socio-economic characteristics of the cassava processors were analyzed using both descriptive and differential analysis methods. These approaches provided a comprehensive understanding of the data, allowing for the examination of various factors and variables related to the processors' socio-economic situation. By employing descriptive analysis, key features and patterns were identified and summarized. Additionally, differential analysis enabled comparisons and contrasts to be made among different groups or variables, revealing variations and relationships within the data. Together, these analytical techniques offered valuable insights into the socio-economic aspects of the cassava processors under study. The results showed that majority of the cassava processors (90%) are women (Table 1). This is in line with the results of Otunba-Payne (2020) which revealed that the role of women in the cassava value chain is vital and constitutes majority of the people involved in the marketing and processing of cassava into various forms. On average, cassava processors in the Bono East Region have approximately seven and half years of formal education (Table 1). This agrees with a study by Aidoo *et al.* (2016), which stated that most cassava processors have at least basic level of education. The average age of cassava processors in the Bono East region is 45 years (Table 1). The average household size of the processors in the region was found to be five (5) individuals and generally, they had eight and half years of experience in cassava processing (Table 1).

The most common product produced by cassava processors in the Bono East Region is gari. The study found that 98.3% of the processors had gari as the main product of their activity (Table 2). This is mainly due to the fact that there is a higher demand for gari throughout the year as compared to other cassava products (Anning-Dorson, 2023). Although some processors produce one cycle of product per week and others three times in a week, the most common production cycle undertaken in a week is two. The study further revealed that an average quantity of 1,790 kg of cassava is processed per cycle and 3,580 kg of cassava being processed on a weekly basis (Table 1). This is equivalent to 72 bags (50 kg) of cassava being processed on a weekly basis in the study area. The study also revealed that majority of the processors were the owners of the enterprise they operated as 94% of the respondents gave a positive response as being the owners (Table 1).

The results presented in Table 1 also shows that a small portion of cassava processors in the Bono East Region do have access to credit as credit was accessible to 22.7% of cassava processors, out of which few (15.7%) were actually able to receive credit in the last 12-month period. This is an indication that most cassava processors have very limited access to credit, with most of their credit being obtained from informal sources. Majority (34%) of the credit received by cassava processors

Table 1. Socio-economic Characteristics (Descriptive Statistics).

Variable	Description	Min.	Max.	Mean	S.D.
Gender	0=Male; 1=Female	0	1	0.09	0.291
Marital status	1= Married; 0= Single	0	1	0.87	0.333
Own cassava processing enterprise	1= Yes; 0= No	0	1	0.94	0.238
Other occupation aside cassava processing	1= Yes; 0= No	0	1	0.79	0.405
Main source of income	1= Cassava processing; 0= Other occupation	0	1	0.94	0.233
Part of processors' assoc.	1= Yes; 0= No	0	1	0.15	0.358
Access to any credit source	1= Yes; 0= No	0	1	0.23	0.419
Received credit	1= Yes; 0= No	0	1	0.16	0.364
Form of credit received	1= Cash; 0= Input	0	1	0.98	0.146
Willing to pay for the services of cassava peeling machine	1= Yes; 0= No	0	1	0.96	0.188
Age	Age	21	65	45	9.602
Years of education	Years of schooling	0	13	7.49	3.89
Household size	Number of people living with processor	1	10	5	1.40
Household members assisting in processing	Number of people assisting in farm work	0	5	1	0.891
Years of cassava processing	Number of years of operation	3	37	8.5	3.261
Processing cycle per week	Number of times processing is done in a week	1	3	2	0.816
Quantity processed per cycle (kg)	Kilograms of cassava processed per production cycle	50	4700	1790.27	1010.759
Amount received as credit	Monetary value of credit received	150.00	2900.00	1,128	717.717
Amount willing to pay for 50 kg bag of cassava to be mechanically peeled	Amount to be paid	2.00	6.00	4.21	211.4

Source: Field Survey, 2020.

was obtained from friends and families, with the bank accounting for only 21.3% of credit received (Table 2). Almost all credits were received in the form of cash, with only 2% of the credit received being in kind. Manu *et al.* (2016), confirmed that about 76.7% of gari processors do not receive credit for production.

Although most of the cassava processors had their own farms, majority (68%) indicated that the cassava they used came from various cassava farmers in and around their area of operation even though 31.7% combined produce from their farm with supplies from other farmers (Table 2). This is consistent with Adeyemo (2013) who stated that majority of cassava for processing are supplied by small holder farmers. In addition to their cassava processing activities, most of the respondents (80.9%) engaged in farming activities even though majority (94.3%) indicated their main source of income was from the processing of cassava (Table 2). Majority of the processors (85%) were not members of any cassava processors association (Table 2).

However, with the 15% that were members of cassava processors association, some respondents stated that the association is now dysfunctional and ineffective, making their reason for joining not met. This implies that, although cassava processing is predominant in the area, processors do not have a united front with which they can channel their grievances. Cassava processing and gari traders' associations exist mainly to promote the welfare of its members (Aidoo *et al.*, 2016). Majority of cassava processors (64.7%) indicated that the main outlet for the marketing of their products was through retailers (Table 2). This is in line with Odongo and Etany's (2018) findings that among the cassava marketing channels, the producer to retailer channel had the highest gross margins. For this reason, majority of processors prefer to sell directly to retailers. However, the sale of products by a processor was not limited to only retailers. Processors did not discriminate and were willing to sell to any available outlet once the product was ready for the market.

As indicated in Table 1, 96% of cassava processors agreed that they were willing to patronize the cassava peeling machine and 47.92% of them were willing to pay a fee for the service because they believe the technology is an easier and faster way of peeling cassava for processing (Tables 1 and 2). Whilst 46.87% of the respondents indicated that their willingness to pay for the services will help increase their production in a given period, 4.51% were also of the view that patronage of the cassava peeling machine service is a means of mitigating the problems of getting labour to manually peel cas-

Table 2. Socioeconomic Characteristics (Categorical variables).

Variables	Frequency	Percentage
Main cassava processing product		
Gari	295	*98.3*
Cassava dough	3	*1.0*
Flour	2	*0.7*
Major source of cassava for production		
Farmers	204	*68.0*
Farmers & Own farm	95	*31.7*
Own farm	1	*0.3*
Source of credit received		
Relatives and friends	16	*34.0*
Husband	15	*31.9*
Banks	10	*21.3*
Co-operatives	3	*6.4*
Others	3	*6.4*
Main marketing channel		
Retailers	194	*64.7*
Consumers	53	*17.7*
Institution	45	*15.0*
Wholesalers	8	*2.7*
Other occupations		
Farming	190	*80.9*
Trading	38	*16.2*
Food vendor	4	*1.7*
Seamstress	2	*0.8*
Teaching	1	*0.4*
Reason for joining association		
Access to raw materials	32	*71.11*
Financial support	31	*68.89*
Effective in processing	10	*22.22*
Access to labour	2	*4.44*
Reasons for patronizing		
Make peeling easier and faster	138	*47.92*
Increase quantity produced	135	*46.87*
To mitigate the problem of getting labour to manually peel cassava and risk involved	13	*4.51*
Reduce drudgery	1	*0.35*
Reduce cost of manual peeling	1	*0.35*
Reason for non-patronize		
Satisfied with manual peeling	4	*33.33*
Cannot afford the services of the cassava peeling machine	3	*25*
Never heard of cassava peeling machine	2	*16.67*
Does not know the cassava peeling machine operates	2	*16.67*
May add additional cost to production	1	*8.33*

Source: Field Survey, 2020.

sava and risk involved which include some of the cassava roots going waste (Table 1). Amongst the cassava processors who were unwilling to pay for the services, 33.33% attributed their unwillingness to being satisfied with manual peeling and the results it produces. Others also indicated that they do not have the financial power to pay for the services of the cassava peeling machine. Recording 16.67% each, amongst the reasons for the non-patronage was lack of operators for the cassava peeling machine and unawareness of the existence of the cassava peeling technology. Finally, the results show that cassava processors are willing to pay an amount of GH₵ 4.21 for a 50 kg bag of cassava processed (Table 1).

Table 3 compares the characteristics of processors who are willing to pay (WTP) and those who are unwilling to pay (UWTP) for the services of the cassava peeling machine in the study area. The results of the t-test indicate that there was no significant difference in the characteristics of the two groups for most of the variables. However, the mean difference of some socioeconomic characteristics, namely, main source of income, membership of processors' association, access to, source of and receipt of credit, years of education and quantity processed per week were statistically significant. This indicates that there is a difference in these characteristics between those who were WTP and those who were UWTP for the services of the cassava peeling machine.

4.2. Awareness and Ownership of Cassava Peeling Machine

About a quarter of the respondents (24.67%) indicated they were aware of the cassava peeling machine (Table 4). This means that majority of the sampled cassava processors (75.33%) were not aware of the existence and availability of the cassava peeling machine technology and therefore had no knowledge of it. Out of the processors who were aware of the cassava peeling machine, majority (68.92%) of them got to know of it through other cassava processors, indicating the importance of processors in disseminating information on improved technologies. Amongst the cassava processors who were aware of the cassava peeling machine technology, only one processor owned and used the machine. The implication is that the machine is yet to be patronized by most processors. That is, the traditional peeling of cassava by hand using a knife is still in use by majority. This resonates with the observation made by Alamu *et al.* (2019) who indicated in their study that the level of awareness or knowledge on improved cassava processing equipment among processors is still low. That is, most farmers and cassava processors are only conversant with traditional, rudimentary and laborious tools such as knives rather than improved processing equipment like the cassava peeling machine.

Table 3. Differences in characteristics of consumers who are WTP and those UWTP.

Variables	WTP	UWTP	Mean difference	t-test
Gender	0.09	0.18	0.092	1.0262
Marital status	2.02	1.82	-0.199	-1.2789
Own the processing enterprise	0.94	0.91	-0.032	-0.4385
Other occupation	0.8	0.64	-0.164	-1.3160
Main source of income	0.95	0.82	-0.13	1.71*
Part of processors' association	0.13	0.55	0.41	-1.8165*
Access to any credit source	0.21	0.73	0.52	4.14***
Received credit	0.15	0.36	0.21	1.9296*
Form of credit received	1.02	1.00	-0.023	-0.302
Age	44.48	42.55	2.952	-0.7659
Years of education	8.51	6.77	2.12	1.68*
Household size	4.64	4.27	0.43	-0.8538
Hhd members involved in processing	1.31	1.45	0.274	0.5097
Years of processing	8.426	9.00	1.00	0.5727
Weekly Processing cycles	2.01	1.91	0.25	0.4174
Quantity processed per cycle (kg)	1190.49	1306.25	362.86	1.669*
Credit received	1,088.89	1,480	337.15	1.601
Religion	1.20	1.27	0.072	0.3687
Main cassava product	1.04	1.00	-0.038	0.3375
Major source of cassava	2.63	2.73	0.101	0.3507
Source of credit	2.84	5.25	2.41	2.165**
Main marketing channel	2.97	2.73	-0.255	-1.2633

Source: Field Survey, 2020.

Table 4. Awareness of Cassava Peeling Machine.

	Category	Frequency	Percentage (%)
Awareness	Yes	74	*24.67*
	No	226	*75.33*
Usage (Based on the level of awareness)	Yes	1	*1.35*
	No	73	*98.64*
Ownership	Yes	1	*1.35*
	No	73	*98.64*
Medium of awareness	Other cassava processors	51	*68.92*
	Extension agents	20	*27.03*
	Training (Workshop)	3	*4.05*

Source: Field Survey, 2020.

4.3. Perception of Cassava Processors on Cassava Peeling Machine

Table 5 indicates the perception cassava processors have on the cassava peeling machine and its usage. The perception index of all the statements presented in the table is 2.54, implying that most of the cassava processors had close to a neutral perception on the peeling machine. Given the low level of awareness of the cassava peeling machine among cassava processors (Table 4), it is not surprising that their perception about issues relating to the cassava peeling machine was inconclusive, leading to an indifferent perception. This is in line with Jha *et al.* (2020), that stated that the indecisive and low perception about agriculture technologies is due to low adoption and scaling up of the technologies.

With a mean score of 3.23, cassava processors in the study area held a neutral point of view that the cassava peeling machine is very expensive. This was the only statement that came close to being agreed on by the respondents, with 32.7% of the cassava processors agreeing to the statement. The near agreement to the statement could be because processers compared the cost of the processing machine to cheap ones imported from especially China. This follows Ampah *et al.* (2021) statement that the proliferation of imported processing equipment mainly from China has become a major preference for most processors because of its superior aesthetic quality and being significantly affordable. Also 48% disagreed that the usage of the cassava peeling machine is quite complicated. However, a mean score of 3.03 indicates that the respondents are neutral about

Table 5. Perception of Cassava Processors on Cassava Peeling Machine.

Perception Statement	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree	Mean Score
Cassava peeling machine is very expensive	46 *(15.3%)*	51 *(17%)*	48 *(16%)*	98 *(32.7%)*	57 *(19%)*	3.23
The usage of cassava peeling machine is complicated	2 *(0.7%)*	144 *(48%)*	49 *(16.3%)*	52 *(17.3%)*	53 *(17.7%)*	3.03
Local repairers do not have the capacity and know-how in repairing the cassava peeling machine in case of damage	49 *(16.3%)*	199 *(66.3%)*	50 *(16.7%)*	1 *(0.3%)*	1 *(0.3%)*	3.02
Maintenance of cassava peeling machine is very expensive	0	100 *(33.3%)*	196 *(65.3%)*	2 *(0.7%)*	2 *(0.7%)*	2.69
Revenue from the usage of cassava peeling machine is not enough compared to the cost of operation	50 *(16.7%)*	147 *(49%)*	100 *(33.3%)*	1 *(0.3%)*	2 *(0.7%)*	2.19
Cassava peeling machine does not help reduce postharvest losses	5 *(1.7%)*	247 *(82.3%)*	46 *(15.3%)*	1 *(0.3%)*	1 *(0.3%)*	2.15
There is no difference in the income of cassava peeling machine users and non-users	54 *(18%)*	149 *(49.7%)*	94 *(31.3%)*	1 *(0.3%)*	1 *(0.3%)*	2.15
Cassava peeling machine do not produce the expected outcome	97 *(32.3%)*	148 *(49.3%)*	49 *(16.3%)*	4 *(1.3%)*	1 *(0.3%)*	1.88
Perception Index						2.54

Source: Field Survey, 2020.

the complexity of usage of the technology. In addition, mean scores of 3.02 and 2.69 show that the respondents continued to remain indifferent about the incapability of local repairers to maintain faulty cassava peeling machine and high cost involved in its maintenance respectively. Lips and Burose (2012) opined that the costs of repair and maintenance of agriculture machinery tend to increase with the age of the machine and therefore the findings of the current study call for further studies on maintenance of the peeling machine.

The results also showed that the respondents disagreed to the statement that the cassava peeling machine does not help in the reduction of postharvest losses. The implication is that, cassava processors perceive the use of the cassava peeling machine as a means of reducing postharvest losses since a greater quantity of cassava can be peeled in a day and made ready for further processing. Adeleye *et al.* (2021) and Sugri *et al.* (2021), obtained similar results, stating that post-harvest losses resulting from use of processing machines are minimal. Also, cassava processors disagreed to the statement that there is no difference in the income of cassava peeling machine users and non-users. This means that though the processors are yet to patronize the service, they believed the technology would be beneficial. Finally, cassava processors disagreed to the perception that the revenue generated from the use of the cassava peeling machine is not enough compared to the cost involved in operating the machine, also indicating their confidence in the technology. This finding affirms similar results by Adeleye *et al.* (2021), that utilization of improved processing technologies is beneficial and therefore must be introduced to processors to help increase their incomes and livelihoods.

4.4. Determinants of processors' willingness to pay for cassava peeling machine services

Table 6 presents the results of factors influencing cassava processors' willingness to pay as well as the amount they are willing to pay for the services of a cassava peeling machine. The calculated likelihood ratio statistic is 261.52 and is well above the tabulated value (21.67). This implies that the null hypothesis indicating that there is no significant difference between the models should be rejected. Therefore, Cragg's model, instead of the Tobit model, is preferred and better fits the data used in modelling cassava processors' willingness to pay and the amount they are willing to pay. Also, the insignificance of the Mill's ratio from the Heckman model (Appendix 1) indicates the absence of selection bias, confirming the appropriateness of the Cragg Double Hurdle for the current study.

The results of the probit model in Table 6 show that factors such as level of education, quantity produced per cycle of production and processors' main source of income were significant in the decision to patronize the services of the cassava peeling machine. The results show that level of education is significant at 1% and has a positive coefficient. The results show that the probability that a cassava processor will pay for the services of the cassava peeling machine increases by 42.68% if the processor's educational level increases by one year. The implication is that educated processors are more likely to pay for the services of the cassava peeling machine in the study area. This finding is consistent with similar results reported by Odebode (2008), Abass *et al.* (2016), as well as Ehinmowo and Fatuase (2016) in which educational level was considered to be a major factor influencing the use of improved cassava technologies. Also, the quantity processed per cycle by cassava processors in the study area was significant at 1% and had a positive coefficient. The coefficient of 0.003 implies that the likelihood of a cassava processor to accept to pay for the services of a cassava peeling machine increases by 0.3% if there is a unit (kilogram) increase in the quantity of cassava processed in a cycle. This implies that processors who process relatively larger quantities of cassava are more likely to pay for the services of the cassava peeling machine. This finding is in line with those of Apurba *et al.* (2020), Alemayehu (2014) and Chia *et al.* (2020), that concluded that farmers are willing to pay for improved technologies that will maximize their output. The main source of income of the cassava processor also significantly influences the willingness of cassava processors to pay for the services of the cassava peeling machine, and this was significant at 1% (Table 6). The coefficient of 0.6031 implies that cassava processors who depended more on cassava processing as their source of income will experience a 60.31% increase in the probability that they will be willing to pay for the services of a cassava peeling machine. This is because, they may like to speed up the rate of processing in order to produce more quantities and earn relatively larger income than they use to earn. This finding corroborates with reports from previous studies (Ulimwengu and Sanyal, 2011; Dogan *et al.*, 2020).

4.5. Determinants of the amount processors are willing to pay for cassava peeling machine services

Although most respondents were willing to pay for the services of the cassava peeling machine, the amount they were willing to pay differed among them. The results of the truncated regression in Table 6 presents the factors that influence the amount the processors were willing to pay for the services of the cassava peeling machine in the study area. The results show that factors such as educational level, household size, major source of income, perception about the complicated nature of the cassava peeling machine and membership in cassava processors association significantly influenced the amount the processors were willing to pay for the services of the cassava peeling machine. The study found that the years of formal education received is a significant factor in the decision of the amount they were willing to pay. Years of formal education is significant at 5% and positively influences the amount they were willing to pay.

This means that as the years of education received by a processor increases, the more likely he/she will be willing to pay higher amounts for the services of the cassava peeling machine. Odebode (2008), Abass *et al.* (2016), and Ehinmowo and Fatuase (2016) also found educational level to be a major factor influencing use of improved cassava technology. The results show that household size is significant at 5% and has a negative relationship with the amount they were willing to pay for the services of the cassava peeling machine. This means that cassava processors with larger households will likely be willing to pay a minimum amount for the services of the cassava peeling machine. According to Ulimwengu and Sanyal (2011), larger households are more likely to pay more for technologies that require more labour. However, with the cassava peeling machine requiring less labour, processors with larger households will be willing to pay lower amounts. Having cassava processing as the main source of income had a positive correlation with the amount the processors were willing to pay and the effect was significant at the 1% level. The positive coefficient implies that processors who depended on cassava processing as a major source of their household income will be willing to pay more for the services rendered by the cassava peeling machine. This is due to the fact that respondents with cassava processing as their main source of income view the cassava peeling machine as a necessary equipment in their operation and a means of increasing their output, hence are willing to pay a premium for its services. The perception of cassava processors on the complicated nature of the cassava peeling machine is also significant at 5% and negatively related to the amount they were willing to pay. The implication is that as the perception of the cassava processors increase (approaches agreeing), the less likely they will be willing to pay higher amounts for the services of the machine. Therefore, the amount they will be willing to pay increases as they disagree with the statement that the cassava peeling machine is a complicated equipment to be employed in their business. Membership to any cassava processing association is also significant at 5% and had a corresponding negative coefficient. This means that members of cassava processors' association are willing to pay a minimum amount for the services rendered by the cassava peeling machine. As

Table 6. Factors Influencing Willingness to Pay and Amount Willing to Pay for the Services of Cassava Peeling Machine.

Variables	Probit		Truncated regression		Tobit	
	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.
Age	-0.007	0.019	-0.01	0.022	0.021**	0.0097
Gender	-0.4993	0.436	0.005	0.698	-0.277	0.212
Years of education	0.4268	0.136	0.082**	0.036	0.146**	0.067
Household size	0.0803***	0.094	-0.477**	0.225	0.012	0.046
Other occupation	0.1539	0.318	-0.046	0.086	-0.227	0.157
Main cassava product	-1.329	0.408	0.781	136.356	0.299	0.217
Own processing enterprise	0.1347	0.518	0.536	0.700	-0.222	0.256
Years of processing	0.0449	0.056	0.027	0.020	-0.047	0.029
Member of processing assoc.	0.0402	0.422	-1.176**	0.482	0.034	0.204
Processing cycle per week	0.0821	0.151	0.059	0.268	-0.085	0.074
Quantity processed per cycle	0.0003***	0.0001	0.00009	0.0002	-0.0002***	0.00006
Access to credit	0.2748	0.350	0.094	0.096	0.124	0.172
Main marketing channel	-0.118	0.191	-0.074	0.052	-0.151	0.095
Awareness of cassava peeling machine	-0.0985	0.293	0.213	0.569	-0.033	0.142
Main source of income	0.6031***	0.542	1.273*	0.680	-0.236	0.276
Perc. cassava peeling machine is expensive	0.4782	0.285	-0.734	0.488	-0.005	0.141
Perc. cassava peeling machine is complicated	-0.390	0.326	-1.048**	0.529	-0.075	0.161
Perc. cassava peeling machine does not produce expected results			0.897	0.357	-0.316	0.542
Perc. revenue not enough compared to cost			0.345	0.555	-1.88**	0.756
_cons	6.782	1.42	-1.044	136.375	2.811	0.707
Log likelihood			-191.73		-399.47	

***significant at 1%, **significant at 5% and *significant at 10%.
Source: Field Survey, 2020.

a processor becomes a member of a cassava processors' association, the lesser the amount the individual will be willing to pay. This may be because members of various agriculture related associations do enjoy subsidies on various technologies, hence creating an impression of paying a relatively lesser amount for the services of the cassava peeling machine.

5. CONCLUSION AND POLICY IMPLICATIONS

The introduction of the cassava peeling machine has been a major step in the quest to quickly process the highly perishable cassava tubers into various forms in order to reduce postharvest losses. Despite the efficiency of the cassava peeling machine compared to manual peeling, the inability of cassava processors in the country to own this machine due to financial constraint is a bottleneck to patronizing this technology. This study therefore assessed the willingness of cassava processors to pay for the services of the cassava peeling machine in Ghana. The results showed that cassava processors were indifferent with their perception on the cassava peeling machine. However, they perceived the cassava peeling machine to be one that can produce the expected peeling outcome, reduce postharvest losses, provide enough revenue over its associated cost and also cause a difference in the income of its users.

The study revealed that a greater majority of the cassava processors are willing to patronize the services of the cassava peeling machine. This concludes that regardless of their inability to purchase the cassava peeling machine due to the high cost involved, they are willing to pay in order to enjoy its service. The processors attributed the reasons for their willingness to pay for the services of the machine to the machine's ability to make peeling easier and faster and increase the quantity of cassava they can process in a given time period. On the contrary, respondents who were unwilling to pay for the services of the cassava peeling machine gave some reasons for their decision. Among the reasons are their satisfaction with manual peeling, the inability to afford the services of the cassava peeling machine, and their unawareness of the cassava peeling machine and its operation.

Cassava processors in the Bono East Region of Ghana are willing to pay GH₵ 4.21 (US$ 0.70) for mechanically peeling a 50 kg bag of cassava. With an initial bid of GH₵ 4.00 and a follow-up second bid, the study revealed that most of the respondents are willing to pay for the initial bid but rejected the idea of paying a second bid which was higher than the initial bid. Only a handful of respondents were willing to pay beyond the initial bid for the services of the cassava peeling machine. The study further revealed that factors such as years of formal education, quantity produced per processing cycle and having cassava processing as the main source of income were significant in determining the willingness to pay for the services of the machine by the processors. All the factors had a positive correlation with the decision to pay for the services of the cassava peeling machine. This shows that an increase in any of these factors causes an increase in the likelihood of a cassava processor willing to patronize or pay for the services of the cassava peeling machine. Moreover, the amount processors were willing to pay for the services of the cassava peeling machine is influenced by factors such as years of formal education, household size, having cassava processing as the main source of income, perception about complicated nature of the cassava peeling machine and membership in cassava processors association. These factors are essential and need critical consideration in the quest to promote the use of the cassava peeling machine in cassava processing operations.

Based on the results and findings of the study, it is recommended that cassava processors should be educated or exposed to key information about the cassava peeling machine, more importantly with regards to how the technology operates. Also, since cassava processors have expressed their willingness to pay for the services of the cassava peeling machine, government agencies, non-governmental organizations and private business individuals are encouraged to consider installing cassava peeling machines in various cassava processing areas to help provide services to cassava processors at a fee. For instance, government can do this by collaborating with the private sector in especially the one district one factory (1D1F) policy initiative of the Government of Ghana. To this end, government needs to create awareness of the benefits of the cassava peeling machine vis-à-vis manual peeling using its available communication apparatus. While providing trainings for uneducated cassava processors, this sensitization should also target the educated especially unemployed graduates to help enhance patronage of the technology thereby ensuring the profitability of provision of mechanized peeling service. The government of Ghana can therefore take advantage of provision of mechanized cassava peeling services to help create jobs to absorb her numerous unemployed graduates into the cassava processing business. This can be of great benefit to the graduates as well as benefit investors.

From the foregoing, this paper recommends that further studies should be conducted on the profitability of provision of a cassava peeling machine service on commercial basis. This will serve as a basis for potential investors to consider adopting and investing in the technology as one of their businesses. Also, there is the need for studies aimed at examining different business models and service delivery mechanisms for cassava peeling machine services. To this end, the viability and efficacy of various service models, such as equipment leasing, service contracts, or shared facilities, may be examined in this regard. Considering these models' scalability, viability, and profitability might help in the creation of marketable service offerings.

The conduct of the current study was not without limitations. Firstly, most of the cassava processors had no idea about the existence of the cassava peeling machine and how it operates. With no model of the cassava peeling machine available during the conduct of the study, most of the questions regarding the cassava peeling machine were asked hypothetically. This could influence the appropriateness of responses given by the respondent cassava processors. Also, the quantity to be processed by the cassava peeling machine was represented by the quantity of cassava processed by the respondents who were willing to pay for the services of the cassava peeling machine. There is a possibility that respondents who said they were willing may not use it when it is made available and others who said otherwise may show interest afterwards.

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APPENDIX 1

Table A.1. Heckman Model of the Willingness to Pay for the Services of the Cassava Peeling Machine.

	Coef.	Std. Err.	z	P> |z|
Stage 1 – Probit model				
Age	.0184254	.0084702	2.18	0.030**
Gender	-.2501002	.1933508	-1.29	0.196
Years of education	.1239456	.0605088	2.05	0.041**
Household size	.0131408	.0456568	0.29	0.773
Other occupation	-.1673135	.1407322	-1.19	0.234
Main cassava product	.2536415	.1932808	1.31	0.189
Own processing enterprise	-.0226198	.2512374	-0.09	0.928
Years of processing	-.0374449	.0248322	-1.51	0.132
Part of processors association	-.0126055	.2732142	-0.05	0.963
Processing cycle per week	-.0762469	.0682352	-1.12	0.264
Quantity processed per cycle	-.000192	.0000547	-3.51	0.000***
Access to credit	.0725256	.1532634	0.47	0.636
Main marketing channel	-.144712	.083567	-1.73	0.083*
Aware of Cassava Peeling Machine	-.0054748	.1291074	-0.04	0.966
Main source of income	-.0841386	.3533063	-0.24	0.812
_cons	2.486503	.8195061	3.03	0.002
Stage 2 – OLS				
Age	-.0015817	.0203527	-0.08	0.938
Gender	.037526	.6126515	0.06	0.951
Household size	.3949053	.193601	2.04	0.041**
Main cassava product	1.271333	1.689649	0.75	0.452
Own processing enterprise	.6237963	.5949846	1.05	0.294
Processing cycle per week	.1475169	.2358521	0.63	0.532
Quantity processed per cycle	.0000558	.0001873	0.30	0.766
Main source of income	1.442092	.5711969	2.52	0.012**
Aware of Cassava Peeling	-.0583095	.4326904	-0.13	0.893
Part of processors association	-1.070105	.3786763	-2.83	0.005***
_cons	-2.761597	.	.	.
Mills				
Lambda	.5381038	1.243518	0.43	0.665
Rho	0.59566			
Sigma	.90336745			
Number of observations = 300 Wald chi^2 (15) = 28.1 Prob > chi^2 = 0.0207				

***significant at 1%, **significant at 5% and *significant at 10%.

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Review article

Animal welfare in the Common Agricultural Policy evolution

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Abstract. Animal welfare assumes a certain relevance within a farm context in the European Union through the Common Agricultural Policy (CAP). In the face of a wide range of animal welfare legislation enacted in Europe since the 1970s, also following ambitious public and private debates sometimes supported by scientific research, "animal welfare" has been part of the CAP since 1999. This paper outlines the evolutionary path of the animal welfare issue within the CAP, underlining the role it plays in a context of interrelations with other central and recurrent strategic themes in European policies. Indeed, the role of animal welfare within the CAP has been increasingly valorized and addressed to animal-oriented protection while intersecting with different strategic objectives over the course of time, which currently relate particularly to the environment and climate with the aim of supporting the ecological transition highlighting the practical implications for involved farmers and stakeholders. The new provisions of the CAP will take effect from 2023 until 2027, whereas currently Regulation (EU) 2020/2220 covers the delay concerning the Commission's legislative proposals on the CAP after 2020. The paper drafts the regulatory progression of the virtuous path that the new CAP has consolidated over time for the improvement of animal welfare in the livestock sector, which is also linked to the future development of innovative technologies for a strategic approach including digital methods at farm and/or animal level.

Keywords: animal welfare, livestock, Common Agricultural Policy, regulation, European Union.
JEL codes: Q18.

HIGHLIGHTS

- The CAP has raised the relevance of animal welfare within the European Union.
- Animal welfare is an emerging issue and is reaching a normative status.
- Animal welfare became a prerequisite for access to certain sectoral benefits.

1. INTRODUCTION

Animal welfare (AW) is nowadays of great interest. "The Brambell Report" has represented a milestone since 1965 and contains the fundamental recommendations for animal rights known as "The Five Freedoms" (Brambell, 1965).

Thus, it initiated a long journey involving different views on AW, variously based on the animal's biological functioning (health, growth, reproduction, etc.), on its affective states (pain, suffering, etc.) and on its ability to live a relatively natural life. Building on each of these visions, based on useful scientific research, the science of AW assessment has elaborated a considerable amount of knowledge to improve AW (Fraser, 2004). These studies have also favoured livestock farming systems, which have benefited over time from the development of mechanisms geared towards actively improving the close links between AW, as well as economic and environmental sustainability (Halachmi *et al.*, 2019).

In the context of a growing and qualified multidisciplinary debate about AW in Europe, the European Union institutions have drafted legislative measures to improve farm animal welfare focusing on the development of the livestock sector.

In favour of livestock farms, the EU has carried out actions focusing on AW through the Common Agricultural Policy (CAP). The CAP has been steered towards AW since 1999; this interest was drummed up by the 2003 Mid-Term Reform ("Fischler Reform"), it continued with greater recognition in the "2014-2020 CAP" and will certainly do so in the near future with the "2023-2027 CAP". This programming has aimed at encouraging support for improving AW on livestock farms.

The various regulatory acts promulgated over time have given AW an increasingly important role. It has become an indispensable prerequisite in various commitments that the legislation has made available for both the farmer and the breeder. In the context of CAP policies, the AW requisite has also contributed to the stimulation of modernization and support processes of the entire agro-zootechnical sector through innovative tools, as in the case of one of the "precision" approaches that serve the purpose of qualitative and quantitative enhancement (Singh *et al.*, 2021).

The approach adopted in this paper is "sectoral" as it covers the CAP's regulatory measures of rural development with reference to AW. Given the growing innovative vision for the sector from stakeholders, a proactive form of support has emerged for strengthening sustainability in livestock production, Therefore, among various perspectives, digital technologies play a strategic role in revolutionizing the production system. Digitalization may also help to improve the resource utilization efficiency and sustainability in livestock farms (Pirlo, 2020).

Before further deepening the discussion on the CAP regulatory measures, this paper traces the main events that have characterized the evolving socio-normative debate on AW breeding in Europe as a complementary and preparatory contribution to the evolutionary path on the norms which are dealt with.

Therefore, the contribution aims at identifying the AW role in the succession of CAP programming periods. Over the course of time, this role has become strategic, so much so, as to reveal simultaneously the EU's growing orientation towards this important issue. All this has occurred in the context of the aid provided for the agricultural sectors.

The special focus attached to the CAP evolution, which is aimed at intercepting the European policy decisions trend and trajectory, may help those farmers who can steer their decisions and make strategically informed management choices, thus taking into account the support possibilities that would most likely be offered to them. Specifically, the higher the awareness of the policy measures on livestock is, the higher the chances are that they might decide to apply for support, and benefit from it.

The paper, therefore, makes an important contribution to those who, through their behaviour and choices, exert influence over the guidelines and principles of good practice with regard to the welfare of farm animals. Indeed, the availability of institutional information can be useful to breeders, stakeholders and academics, each one for their expertise.

2. BACKGROUND

Animal welfare perception and concept have changed over time, philosophical, religious, deontologic currents have driven this evolution as well as later scientific movement (Bentham, 2013; Broom, 2011). Public interest in AW began in 1824 in England with the establishment of the Royal Society for the Prevention of Cruelty to Animals (MIPAAF, 2007-2013; Pickett *et al.*, 2014), a very active body established for the protection of animals. This body probably contributed to the adoption of the Cruelty to Animal Act in 1876, and Animal Protection Act in 1911.

In 1924, the Office International des Epizooties (OIE) (Bayvel, 2012), an intergovernmental organization based in Paris, was instituted through the establishment of an International Agreement to ensure maximum transparency regarding animal health status and the control of animal diseases. It is still responsible for improving veterinary public health worldwide, and is globally known as The World Organization for Animals.

The AW in livestock farms became of public interest in Europe for the first time in 1964, when an activist for animal rights and welfare, Ruth Harrison, published the book "Animal Machines", describing "intensive livestock and poultry farming practices of the time". The book aroused so much opposition among British public opinion that the British Government (Fernandes *et al.*, 2021) proceeded with the appointment of a Committee that would look into the welfare of farm animals. The Committee dealt with the general concept of farm AW and tried to trace its possible determinants in intensive farming systems with reference to all major species except dairy cows, as there were few intensively raised cows at the time (McCulloch, 2013; Farm Animal Welfare Council, 2009). In December 1965, in the concluding stages of that assignment, the Committee published "The Brambell Report" (Report of the Technical Committee to Enquire into the Welfare of Animals Kept under Intensive Livestock Husbandry Systems), which was very popular among breeders. Thus, in 1967 the British government went so far as to establish the Farm Animal Welfare Advisory Committee (FAWAC) (McCulloch, 2013) with a view to monitoring initiatives tending to achieve significant AW improvements on intensive livestock farms, on the basis of and in compliance with the Brambell's Five Freedoms (Elischer, 2019). To sum up, the report stated that animals should have the freedom "to stand up, lie down, turn around, groom themselves and stretch their limbs". (McKenna, 2017).

The mention of the feelings and suffering of animals, in that period welfare was still connected with stress conditions. A different perspective emerged from an American ethologist, Donald Griffin who wrote about animals' subjective experiences in his book "The Question of Animal Awareness" (Duncan, 2019).

However, the Brambell Report seems to have influenced and raised awareness among social and political groups even though there is no explicit link with European Acts (Ruschen 2008; Veissier *et al.,* 2008). During the International Transport, the Council of Europe drafted the Convention for the Protection of Animals, which was adopted by the Committee of Ministers of the Council of Europe in 1968. It was the first European institution that proposed measures that would ensure AW (Council of Europe, 1968).

In the 1970s, the AW topic, already widespread in Britain, entered the European debate. When the United Kingdom became part of the Economic Community in 1973, AW ripened into an issue that was addressed at the European level. A first important act occurred with the "European Convention for the Protection of Animals kept for Farming Purposes" (ETS No. 087) (Council of Europe, 1976) of the European Economic Community, approved in June 19th, 1978 (article 1, Council Decision - 78/923/EEC). The European Convention for the Protection of Animals kept for Farming Purposes (the Convention) began its operation on 10/09/1978, specifically in relation to the protection of animals in intensive stock-farming systems (Council of Europe, 1976). Its purposes consisted of the keeping, care and housing of animals, and in particular those in modern intensive stock-farming systems. The countries that have signed the convention commit themselves to conforming to specific standards regarding the space and the environment of farming premises, feed, animal health and the organization of inspections of the technical installations in the case of modern intensive stock-farming systems (Council of Europe, 1976). The Convention may have played an important role in the redefinition of "The Five Freedoms" and, thus, in the British government's transformation of FAWAC. In fact, ten years later, in 1979 (Farm Animal Welfare Council, 2009), again with reference to the development in the field of scientific research, the British government replaced the previously mentioned FAWAC with FAWC (Farm Animal Welfare Council) (McCulloch, 2013). It shifted from Committee to Council (independent body) and became responsible for monitoring the welfare of farm animals in the countryside, in the market, slaughterhouses, as well as in transport (LIDA, 1978). It called attention to the fact that the animal is in "harmony with its own living environment" (Hughes, 1976) with sufficient space, adequate facilities and the company of its fellow humans (Elischer, 2019). It remained operational until October 1st, 2019 when it took the name AWC (Animal Welfare Committee) (Farm Animal Council, 2009).

Peter Singer, an Australian philosopher, stated that as long as animal livestock systems ensure a good quality life and a painless death eventually their use is less objectionable (Villanueva, 2016). Conversely, Tom Regan, Emeritus Professor of Philosophy at North Carolina State University, affirmed that killing is the biggest harm we can do to another individual (Duncan, 2019).

Later, Council Decision 92/583/EEC of 14th December 1992 in the conclusion of the Protocol of amendment to the European Convention for the Protection of Animals kept for Farming Purposes further enhanced the strength of the Strasbourg Convention (ETS No. 087). A relevant element of this Council Decision concerns the important human role for AW in intensive livestock farming (Boivin *et al*., 2003).

With its entry into force, the Treaty of Amsterdam in 1999, which officially recognized animals as sentient beings in its Protocol (No. 33), recommended that the EU should direct its policies towards AW, and that each Member State should implement relative measures, in the agriculture or internal market field, etc.

At a later stage, the Treaty on the Functioning of the European Union (TFEU) reserved an appreciable role to AW; article 13 emphasizes that "the Union and the Member States shall pay full regard to the welfare requirements of animals as sentient beings".

Also, the Council Directive 98/58/EC of July 20th, 1998, concerning the protection of animals kept for farming purposes, is an important EU legislative act, which still continues to be its cornerstone. It incorporated the principles of five freedoms of The Brambell Report. It empowered Member States to implement the envisaged rules through their own "competent authority" in connection with the European Commission (European Commission, 2006). This Directive still refers internally to the European Convention (ETS No. 087) signed by the Member States of the Council of Europe (Council Decision of June 19th, 1978 concerning the conclusions of the European Convention for the Protection of Animals kept for Farming Purposes), which indicated a set of common provisions to protect animals on farms. According to this Council Directive, Member States shall guarantee that the owners or keepers implement adequate measures for AW and that those who take care of animals do not cause any unnecessary pain, suffering or injury. In addition, it recommends that the availability of shelter, nutrition and care, appropriate to the physiological and ethological needs of the animals, must be ensured (Greiveldinger *et al.*, 2013).

Until Council Directive 98/58/EC, the literature discussion on AW appeared anchored to scientific vision, while it started successively to gain ethological, cognitive scientific and neuroscientific perspectives (Leone, 2020). Studies in the past approached the biological functioning and affective state frameworks separately, whereas recently, affective states are studied in their bijective interaction in order to manage AW improvement (Hemsworth *et al.*, 2014).

3. THE COMMON AGRICULTURAL POLICY TOWARDS ANIMAL WELFARE IN LIVESTOCK PRODUCTION

3.1. The past and current CAP. The Animal Welfare evolution.

The discourse on EU legislation traced here below addresses aspects concerning AW, not only as an end in itself, but also as an element that has proved to be necessary among the minimum requirements that farmers in the Member States must comply with in relation to the various commitments in order to benefit from the EU CAP. Figure 1 displays the succession of CAP Regulations. The first European regulatory measure that incorporated AW into the CAP was the Council Regulation (EC) 1257/1999 in support of rural development from the European Agricultural Guidance and Guarantee Fund (EAGGF). The inclusion in this Regulation was a choice dictated by the 1997 Treaty of Amsterdam exhortation to European institutions. This regulation was part of the 2000-2006 CAP programming.

It emerges that the Commission's Agenda 2000 for a stronger and wider Europe on EU structural action in the 2000-2006 programming period was also of great importance since it had the ambition to conceive production methods respectful of the environment and AW.

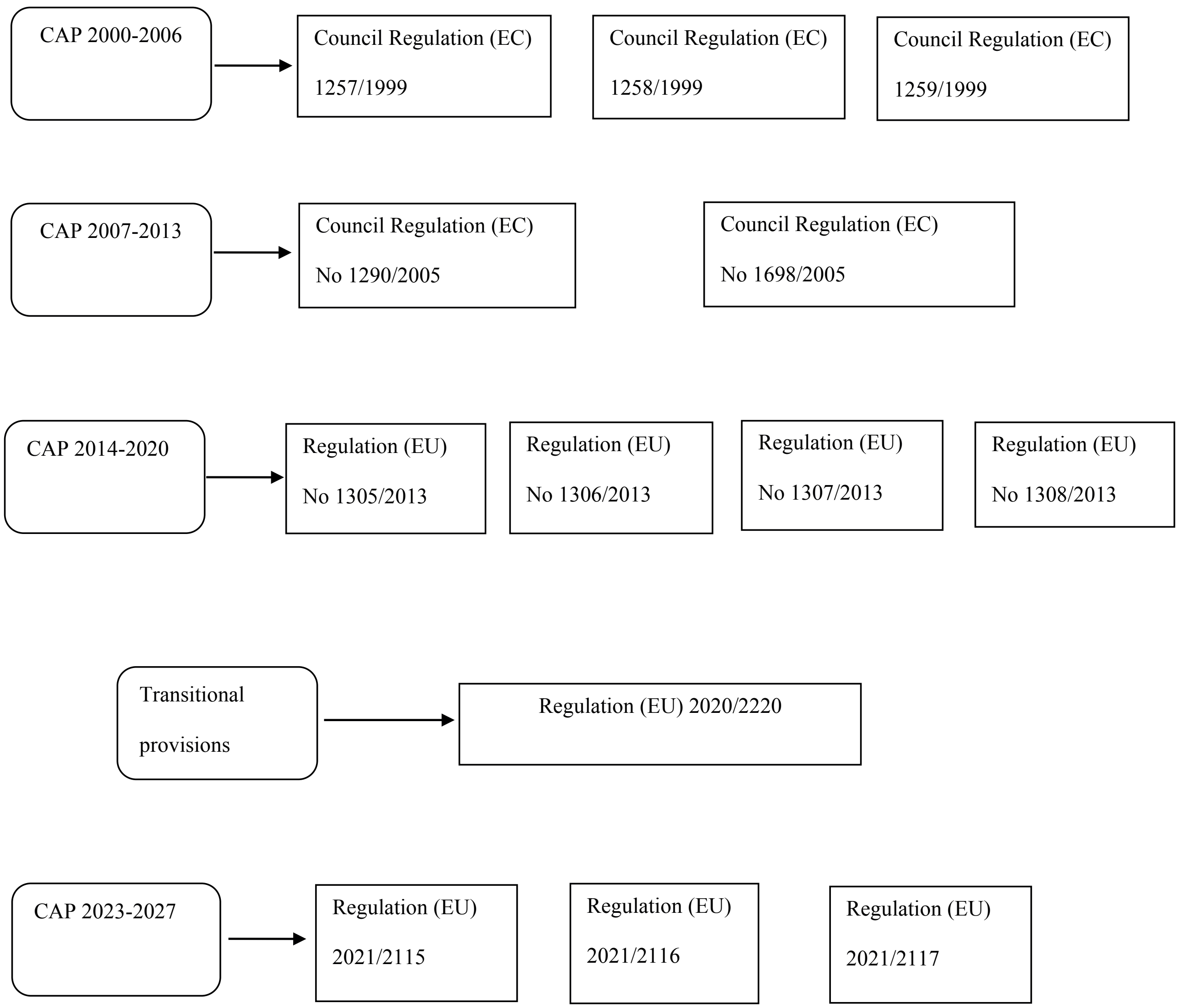
Therefore, AW became a prerequisite for access to certain sectoral benefits. Specifically, it maintains that farms shall receive support for investment depending on the respect of minimum standards, which include not only environment and hygiene, but also AW, next to the demonstration of economic viability and adequate occupational skill, as well as competence on the farmer's part (article 5). As for the financial support of rural development measures, Council Regulation (EC) 1258/1999 established the European Agricultural Guidance and Guarantee Fund (EAGGF).

Council Regulation (EC) 1783/2003 amended Regulation (EC) 1257/1999. It extensively dealt with AW providing various aids therein. The CAP began thus to become a fulcrum for AW protection. Council Regulation (EC) 1782/2003 "conditioned" financial aid based on strict standards and rules. So, farms had to comply with the "Cross-compliance" principle. This made all payments to farms subordinated to compliance with two types of standards, on the one hand, the statutory management requirements (SMRs), and on the other, maintenance of land in good agricultural and environmental conditions. A special Annex (III) to Council Regulation (EC) 1782/2003 listed all the criteria including AW.

This Regulation originated in response to certain needs urged by the Agenda 2000 document (Schmida and Sinabell, 2007), including the promotion of sustainable and market-oriented agriculture, decoupling farm support from production and making aid conditional on compliance on minimum This implied that the farmers could receive an income support on condition that they fulfilled food safety, environmental, animal health and welfare standards in accordance with the cross-compliance principle (Hoffstadt, 2008; Denis Cvitković *et al.*, 2020). Cross-compliance required the payment of "decoupled" premiums to farmers no longer to quantity, but to "environmental" quality (MIPAAF 2007-2013).

Concurrently, the CAP medium-term reform aimed to give even greater attention to AW. On the one hand, it tended to promote sustainable and market-ori-

Figure 1. CAP Programming scheme.



ented agriculture through specific actions and, on the other, strengthened rural development, in particular where measures included the promotion of food quality. To pursue a sustainable agriculture, the vision was to complete the shift of support from product to producer by applying a decoupled system of payments per farm conditional upon cross-compliance to environmental issues, taking into account next to historical references, AW and food quality criteria (European Commission, 2002).

Subsequently, regarding the 2007-2013 programming period, Council Regulation (EC) 1290/2005 divided the EAGGF (traditionally the only fund financing the CAP) into two separate funds, namely the European Agricultural Guarantee Fund (EAGF) and the European Agricultural Fund for Rural Development (EAFRD). Council Regulation (EC) 1698/2005, in support of rural development by the EAFRD, provided specific payments for AW for a maximum period of five years. This was in order to benefit from rural development support, such as measures to improve the quality of agricultural production and products, as well as to improve the environment and rural space. With regard to AW, it is worth noting, that the Regulations demanded a stronger pledge to farmers. In fact, payments covered only those commitments going beyond the relevant mandatory standards established pursuant to article 4 of/and Annex III to Regulation (EC) 1782/2003 and other relevant mandatory requirements established by national legislation and identified in the programme.

Therefore, in line with the earlier legislation, Council Regulation (EC) 1698/2005 required farmers to go beyond good agricultural practices and the various "cross-compliance" obligations imposed by Council Regulation (EC) 1782/2003 as an integral part of the mid-term report to obtain those payments.

Commission Regulation (EC) 1974/2006, which laid down detailed rules for the application of Council Regulation (EC) 1698/2005 in support of rural development by the EAFRD, confirmed the great importance devoted to the AW requirement by dedicating detailed and specific punctuations. Additionally, it again brought to the surface the link with the cross-compliance obligations. In fact, it established that in order to receive funds (article 27, paragraph 7) farmers had to implement AW practices upgrading the established standards. The provision in this case not only listed, but also detailed specific practices and thus served as a guideline for farmers as regards the actions they needed to take concerning AW.

Council Regulation (EC) 73/2009 repealed the above-mentioned Regulation (EC) 1783/2003 and established common rules for direct support schemes under the CAP.

With reference to AW, it announced that Member States could grant specific support to farmers who complied with SMRs listed in Annex II, Point C, and to those who practised enhanced AW standards (article 68). Thus, each Member State became responsible for the General Conditions laid down in Council Directive 98/58/EC on the protection of animals in breeding.

The need to strengthen the competitiveness of the agricultural sector to promote innovation and sustainable agriculture, and foster growth and employment in rural areas, underpinned the reform of the subsequent CAP programming period from 2014 to 2020, which was finalized through the new specific European Union legislative Acts.

Regulation (EU) 1305/2013 repealed the above-mentioned Council Regulation (EC) 1698/2005 and largely outlined the new CAP 2014-2020 objectives regarding the support for rural development by the EAFRD. This was the first CAP reform to fall under the ordinary legislative procedure (introduced by the Treaty of Lisbon, where the Council co-legislates with the European Parliament). It still provided for enhanced support through actions contributing to the achievement of the Union's rural development priorities (defined as "measures"), including those in favour of AW (article 33) for those farmers who undertook the initiative to adopt farming methods that went beyond mandatory requirements (Recital 27). The goal of the AW payment was to compensate farmers for all or part of the additional costs and income foregone resulting from the commitment made and, in certain cases, for covering transaction costs to the value of up to 20% of the premium paid for the AW commitments. In addition, AW was included, albeit indirectly, among "agro-environment-climate payments" in the case of local breeds in danger of being lost to farmers (Annex II).

Subsequently, par Commission Delegated Regulation (EU) 807/2014 of 11th March 2014, on support for rural development by EAFRD, supplemented Regulation (EU) 1305/2013, and it still dedicated the whole of article 10 to AW. Whilst on the one hand these rules constituted limitations for farmers in their choice of intervention to implement in favour of animals, on the other, they eliminated the risk of vagueness in the identification of the eligible payment hence the uncertainty of the relative payment. Furthermore, these specifications clarified the vision of the European Union's policy aimed at protecting AW.

Also, AW found space in Regulation (EU) 1306/2013 on the financing, management and monitoring of the CAP. It still confirmed the importance of the cross-compliance system application which contributed to the development of sustainable agriculture, and to incorporating basic standards in several sectors including AW. As regards the implementation of rules, reference should be made to Commission Implementing Regulation (EU) 809/2014 of 17th July 2014. It concerned the integrated administration and control system, rural development measures and cross-compliance.

Regulation (EU) 652/2014 established provisions for the management of expenditure from the general budget of the European Union. It still included support for AW improvement and training programmes, identifying the priorities for intervention, based on the identified risks for animal health and welfare.

Therefore, Regulation (EU) 2017/2393 amended Regulations (EU) 1305/2013 and, with reference to AW, it added some specifications to the provisions of article 33(1), still in force. Thus, AW payments were to be granted to farmers who undertook, on a voluntary basis, to carry out operations consisting of one or more animal welfare commitment and who were active farmers within the meaning of article 9 of Regulation (EU) 1307/2013, as applicable in the Member State concerned.

Regulation (EU) 1308/2013, establishing a common market organization in agricultural products, enclosed the disposition on AW both from a business point of view in support of farmers, and in strict reference to animal protection. In the first case, it still took into account the importance of optimising production costs and returns on investments in response to environmental and animal welfare standards, and stabilising producer prices; also, in the case of export of products of the beef and veal sector, the granting and the payment rules of the refund had to comply with AW standard. Indeed, in the second case, reference was made to the use of sound animal welfare practices and production techniques and sought ways to restrict the use of animal-health and improve animal health and welfare.

4. DRIVING ANIMAL WELFARE TOWARDS THE FUTURE CAP 2023-2027

During the lively debate on the CAP reform 2023-2027, one question came up in the literature: Is the process of the CAP reform in line with the aim of fully integrating farm AW into EU agricultural policy? (Leone, 2020).

While the preparatory discussion process for the new CAP unfolded, the European Union continued to repeatedly innovate the previous regulations put in place for the 2014-2020 period. In fact, the protracted negotiations on the Multiannual Financial Framework made it necessary to provide for a transitional period in order to extend the current rules and speed up the transition towards the future CAP. Since the delay of the legislative procedure regarding CAP beyond 2020 continued, the temporary Regulation (EU) 2020/2220 extended the current CAP regulatory framework to 31 December 2022. With regard to AW, the temporary Regulation completed the changes to Regulation (EU) 1305/2013, already initiated earlier by changes to Regulation (EU) 2017/2393, article 33, but in this case amending paragraph 2. The changes, in favour of the farmer, related to the length in years of the commitment period, made for rural development programmes involving the improvement of AW: Member States could determine a period of longer than three years in their rural development programmes based on the nature of the commitments and the AW benefits sought. Furthermore, (as part of the amendments to Regulation 1305/2013), Regulation (EU) 2020/2220 introduced article 58a, specifically, "Resources for the recovery of the Union agricultural sector and rural areas". It still allocates additional resources to Member States from previous commitments made for rural development programmes; also, part of these resources concerns measures referring to AW.

CAP transitional regulation has been ensuring continuity in legal and financial support, thus avoiding interruption in payments, at a time when Member States were focusing on preparing their national CAP strategic plans (European Commission, 2018; European Council, 2021).

After the intense debate in the years following 2020, the main outlines of the CAP 2023-2027 reform came to the surface.

Each of the three new drafted regulations that form the basis of the post-2020 CAP reform, contains references to AW.

With the new Regulation (EU) 2021/2115, the main changes on AW on the one hand, consist of a more pronounced flexibility recognized to Member States in detailing definitions and conditions in their CAP Strategic Plans (the needs of their farming communities in cooperation with local authorities and relevant stakeholders); on the other, there is an explicit connection with the elected environmental and climatic requirements, which are necessary for accessing the benefits provided in favour of farmers. It is also relevant to consider the close links in animal husbandry between AW, animal health and food-borne diseases This aims at stimulating EU actions and supporting farmers and EU countries in their fight against antimicrobial resistance.

In addition, Member States, as part of CAP Strategic Plans, will have to define a list of practices beneficial to AW. One example is the provision of farm advisory services during the farm cycle development (article 15). Therefore, Regulation (EU) 2021/2115 recognizes considerable support for the modernisation of farming techniques in order to make the agricultural sector more effective, more competitive and more environmentally friendly. Also, digitalisation, technological innovation and research prove relevant in a situation where one needs to rise to the challenges like those faced by farmers on issues such as AW alongside food sustainability, nutrition security, energy efficiency and many more. Investing in technological development, digitalisation and innovation is crucial to the improvement of farmers' market reward.

Regulation (EU) 2021/2115 corroborated the provisions of Regulation (EC) 1783/2003 regarding compliance with minimum requirements related to SMRs. AW is among the SMRs areas as well as Climate and Environment, Public Health and Plant Health. Member States, in accordance with the cross-compliance rules referred to in article 12 of Regulation (EU) 2021/2115, shall provide for administrative penalties for farmers and other beneficiaries receiving direct payments if they do not comply with the SMRs. The new direct payments also had different methods of determination compared to previous programming. Benefits to improve AW, albeit indirect, may come from strengthening the socio-economic fabric of rural areas as dictated by the "overall objectives" in Regulation (EU) 2021/2115; this provision involved a social dimension aimed at ensuring adequate working conditions for agricultural workers. It is an aspect introduced for the first time by CAP, and is likely to contribute to the implementation of the 2030 Agenda for Sustainable Development.

Certainly, the EU's growing interest in AW is now obvious in the Regulation (EU) 2021/2115, not least because of its juxtaposition with the new set of climate-environmental goals, the so-called "eco-schemes" for the climate, environment and AW (article 31) – that also regards the distribution of financial allocations (article 93).

Regulation (EU) 2021/2116, on the financing, management and monitoring of the CAP, repealed Regulation (EU) 1306/2013. It reiterated the importance of cross-compliance as a mechanism to ensure that payments foster a high degree of sustainability and a level playing field for farmers within Member States and within the Union, also concerning animal welfare. It introduced "information measures" to help explain, implement and develop the CAP and raise public awareness of its content and objectives, but also of its interaction with the climate, environment and animal welfare. Thus, it aimed at enlightening citizens on the agriculture and food knots.

The connection between sustainability and AW was also explicit in Regulation (EU) 2021/2117, which established that the "sustainability standard" also includes animal health and AW objectives. Therefore, it aimed to boost the previous PAC measures by underlining the importance of extending the list of objectives set out in article 157 of Regulation (EU) 1308/2013, which also indicated the protection of animal health and AW.

In regard to the effectiveness of the support for AW within the various CAP programmes, criticism and doubts have emerged in the literature (Leone, 2020).

5. DISCUSSION AND CONCLUDING REMARKS

Over the last decades, AW has increasingly become an emerging issue to address raising awareness in the community and over time reaching its normative status (Leone, 2020).

Over the past 30 years, the EU has developed a considerable regulatory framework (Supplementary figure 1) where AW improvement has found increasing and qualifying spaces. Within the CAP, the role of livestock AW has evolved. The succession of laws, and, particularly that of CAP programming, has constituted a response to the changing needs for AW protection. This dynamism has evolved reflecting different versions of AW shaped into different rules and supports at each historical stage of regulation.

This analysis in particular showed that AW enters the CAP with a concrete approach, constituting from the outset a requirement for access to some rural development support payments in the case of farm investments.

AW appeared in the late 1990s as a requirement for accessing certain payments provided by the EAGGF.

Thus, AW became an integral part of the policy-making process. Subsequently, the role of welfare became stronger and so entered fully into the CAP with the Fischler Reform (2003) increasingly through rural development measures and those oriented towards the quality of livestock production. The novelties introduced by the Fischler Reform still represent the main tool for improving AW (Macrì and Scornaienghi, 2017). This regulatory context tended, at the level of the agricultural phase, to encourage the interrelation of improving AW next to food safety, environmental and climate sustainability, etc. Annex I shows the specific interrelations between AW and the mentionat topic over time. The vision that emerged showed that the current livestock agricultural production structure provides peculiarities that aim to be in balance with the environment (grazing) and climatic conditions (change), so as to contribute to the preservation of the territory and valorisation of the products obtained to increase market penetration. The novelties that came with the introduction of single farm payments decoupled from certain production activities, have made it possible to achieve the goals set: good agricultural and environmental conditions (MIPAAF, 2007-2013). Sustainability is now enshrined as a fundamental principle and the granting of direct payments to producers will depend on cross-compliance with AW. Cross-compliance delineated agro-environmental and AW commitments in relation to the calculation of the corresponding payments.

This is confirmed and reinforced in the 2014-2020 programming where the greening system became one of the components of the Direct Payment Scheme in 2015. It was an obligation for farmers receiving the basic payment to comply with climate and environmental practices. Failure to comply with the obligations under the greening system resulted in reductions and/or penalties for non-compliance. This, to some extent, constituted a constraint for farmers.

This "green" context favoured by the CAP 2014-2020 also included the reinforcement of targeted intervention measures in favour of AW, to which a specific payment section was dedicated only for covering those commitments that went beyond the relevant mandatory minimum requirements dictated by the conditionality. To this end, payments may have represented a benefit for farmers for the implementation of practices with a view to improving the living conditions of livestock.

The coming CAP 2023-2027 will substitute the greening system with the eco-schemes, which comprehend payments in addition to the basic support for active farmers who make commitments to observe beneficial agricultural practices that go beyond the minimum requirements established by the Union law. One eco-scheme is specifically dedicated to AW.

CAP 2023-2027 aims particularly at contributing to the development of sustainable agriculture in order to be more compatible with society's expectations, through compliance with standards that include the AW topic alongside the environment, climate change, good agricultural land conditions, food safety, public health, animal health, and plant health. Despite already being present in the past, these interconnections are nowadays reinforced in the new CAP 2023-2027. This also includes the ecological transition of the agricultural sector through the increase in funds planned to provide support to it. This consolidation certainly depends on the political context around the new CAP, whose directions originate from The European Green Deal and the Farm to Fork Strategy. In essence, the new CAP should steer to semi-intensive animal husbandry, or rather extensive animal husbandry, considering the latter a farming system more in line with the sustainability principles, due to the multiple implications of an eco-environmental character and the safeguarding of animal health. The fact that AW is linked to these factors contributes to returning to the market a genuine, natural and healthy image on the one hand, and the achievement of European policy objectives on the other.

The path of this analysis shows a great variety of CAP strategic measures aimed at improving the living conditions of livestock farming in an overall view, which combines AW values with the food quality and safety ones.

With regard to the new CAP, within the "overall" general regulations on AW, the strategic choices are influenced by the need to leave ample margins for manoeuver to the Member States, given the different characteristics of each territory. So, the EU creates the general framework then all nations define the specific policy orientation. In addition, there is another level, i.e. the local context. In fact, the application or non-application of CAP measures depend on the choices of the actors involved in the livestock environment to which AW improvements should be addressed. In fact, for the farmer, the best policy measures in favour of animals remain those that take into account the structural conditions in which animals live.

In relation to livestock management, in CAP 2023/2027 purposes also emerge. One of the cross-cutting objectives, consisting of modernising agriculture in rural areas by fostering innovation and digitalization, is in compliance with Horizon Europe, the Framework Programme for Research and Innovation 2021-2027 (Regulation (EU) 2021/695) leading to fostering the adoption of innovations in the farming sector. In this context, EU regulations show how important it is to ensure the sustainable development of rural areas in order to apply knowledge transfer and innovation in agriculture and rural areas in harmony with the promotion of innovative agricultural technologies, and sustainable management, including AW. In the CAP, digitisation and innovation aim to improve competitiveness, environmental sustainability and the development of rural areas. In this direction "precision livestock farming" technology may facilitate the identification and implementation of environmentally-friendly and efficient AW practices - (next to the providing of technical and economic data) (Morrone *et al.*, 2022), but the relative adoption still remains a breeder choice.

In fact, the ability to adapt to the advent of cutting-edge technological innovations, as tools to improve animal health and welfare, remains a challenge for most farmers due to management and organizational issues. Finally, the political and regulatory framework drafted to address the process of modernizing livestock farming may also be of great support for competitiveness. Indeed, investments in modernization and innovation with the intention of implementing new practices and technologies may constitute an opportunity to enhance the farmers' market reward.

With reference to the regulatory discourse analyzed, the criticism and doubts that emerged in the literature (Leone, 2020) concerning the effectiveness of the CAP in supporting AW, may give rise to new insights and be the starting point for verification, but only when the concrete action of the new CAP becomes operational, as well as when the degree of implementation by farmers is available.

Finally, at present, based on the regulatory framework already outlined, it is certainly possible to assert that an increasing evolution of the role assigned to AW within the CAP has already emerged. The evolution has shifted from initially being an inclusion of the minimum AW support models to being, mainly in the near future, a complementary and indispensable element among the main requirements for the implementation of measures related to economic, social and environmental sustainability of all production processes in the livestock sector.

In conclusion, it is crucial for farmers to be aware of the existence of AW support measures, so that they know what support possibilities are available to them. In this way, they can gain access to the support that may benefit them. That will help them steer the strategic decision-making process as efficiently as possible regarding the way they manage and run their farm. Academic research may help to deepen and spread the knowledge and insights in favour of all stakeholders along the agricultural supply-chain.

Once farmers know about the supporting scenario available to them, it may be interesting to verify through future research, firstly, how many of them practically decide to apply for the contributions. Secondly, it would be interesting to investigate whether farmers perceive AW measures as a constraint or an economic benefit. Thirdly, it would be interesting to explore and find out if these policies succeed in involving livestock farmers by triggering a new philosophy attentive to sustainability in a threefold sense: the economic, environmental and AW aspects.

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Short communication

The 7th Census of Italian agriculture: characteristics, structures and dynamics of generational renewal

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Abstract. The 7th General Census of Italian Agriculture offers an opportunity to assess the current state and key trends within Italian agriculture. One pressing issue that it highlights is the aging workforce in this sector. Encouraging youth entrepreneurship is a primary goal endorsed by both national and European policies. It aims to ensure a seamless generational transition while promoting a more innovative and dynamic agricultural sector. Agriculture faces a set of critical challenges in the years ahead, including efficiency enhancement, resilience building, digitalization, and sustainability practices. These necessitate the integration of fresh, well-qualified entrepreneurial talent, making generational turnover not only highly desirable but also essential. This article employs data from the latest Census to delve into the age distribution of farm managers, placing a particular emphasis on the younger demographic and the farms they oversee. The study aims to scrutinize the primary shifts in the demographic makeup of agricultural holdings, with a specific focus on contrasting young and elderly farmers. The outcomes of this analysis bring to the forefront an intriguing generational shift marked by well-educated agricultural entrepreneurs who exhibit a proclivity for innovation and the adoption of digital technologies. This cohort of farmers is actively diversifying their agricultural pursuits, with a strong commitment to environmental sustainability and the market. Nonetheless, despite these commendable efforts, they continue to grapple with establishing a firm position in the sector.

Keywords: agricultural Census data, generational renewal, young farmers, ageing farmers, farm structures, Common Agricultural Policy.
JEL codes: Q10, Q12.

HIGHLIGHTS

- Data from the 7th Agricultural Census 2020 confirm a lack of dynamism in terms of generational turnover in Italian agriculture.
- Young farmers lead larger farms on average and are oriented towards multifunctional agriculture that is more sustainable and respectful of the environment.
- Innovation is one of the elements that qualifies farms with young managers.

1. INTRODUCTION

Italy is among the countries of the European Union (EU) that records the highest rates of aging in agricultural entrepreneurship (Eurostat, 2018; Dwyer *et al.*, 2021) and associates this phenomenon with the abandonment of agricultural activities, particularly in more marginal areas (Zanetti *et al.*, 2019).

As emphasized by the European Commission through its initiative "Long-term vision for rural areas: for stronger, connected, resilient, prosperous EU rural areas" (European Commission, 2021), fostering the relocation or retention of young individuals in rural areas is essential for sustaining the vitality of both the sector and the territories. This is due to their greater inclination towards innovation and entrepreneurial growth, whether in agriculture or other economic activities (de Guzman *et al.*, 2020; Dax, Copus, 2022).

Murtagh *et al.* (2023) argue that rejuvenating the farming profession involves addressing the age imbalance within the sector and making farms more appealing and sustainable as a livelihood.

As indicated by various studies (Ascione *et al.*, 2014; Zagata, Sutherland, 2015; Suess-Reyes, Fuetsch, 2016; Van der Ploeg *et al.*, 2017; Coopmans *et al.*, 2021; Korthals Altes, 2023), the entry and continuity of young individuals in the management of agricultural businesses tend to be impeded by a combination of factors related to the structural and organizational characteristics of the sector (e.g., limited access to land, credit constraints, etc.), which are further influenced by social, economic, environmental and institutional factors. It appears that despite efforts made by rural development policies to promote generational turnover, the desired effects have not been realized (Zagata, Sutherland, 2015; Licciardo *et al.*, 2022; Sutherland, 2023).

There is not a single universally accepted definition of young farmers (Cersosimo, Ferrara, 2013). Precisely defining the age range is crucial to establish the scope of our current analysis. Both national and EU regulations generally categorize farm managers as young up to the age of 35 or 40, especially concerning the establishment of new agricultural holdings and accessing subsidies and support systems. For instance, within the framework of the Common Agricultural Policy (CAP), individuals who have not yet reached the age of 40 are considered young farmers as an eligibility requirement for the Young Farmer Payment.

In this article, we have chosen to adopt the age range defined by the CAP, with the threshold of 40 years distinguishing young from older agricultural entrepreneurs[1]. The data utilized in this analysis originate from an extensive study conducted by ISTAT on the 2020 Census, focusing specifically on this age group. These data shed light on the entrepreneurial behaviour of young farmers compared to the entire population, revealing their innovative tendencies[2].

The analysis presented here does not aim to offer a comprehensive overview of the role played by young farmers in the Italian primary sector. This limitation arises from both the absence of available structural data at the time of writing this article and the impossibility of conducting historical comparisons. Nonetheless, the inclusion of information on young farmers in the 2020 Census provides valuable insights for examining various aspects of young farmers and their businesses. This data can help better orient support policies by implementing appropriate actions and tools to encourage and sustain their activities over time.

The subsequent analysis serves as an initial step toward characterizing the profile of a young farmer, which is essential for comprehending the pressing issue, widely debated at European level, regarding generational turnover in agriculture and the likely trajectories of the sector's evolution. In this regard, our study focuses on two key aspects. Firstly, it delves into the primary changes occurring within the demographic structure of farm managers by comparing young and older farmers. Secondly, it explores the novel insights provided by the census survey. Furthermore, we examine the presence of young individuals in the agricultural sector and contrast it with the over-40 demographic, particularly at a regional level.

2. A GENERAL OVERVIEW

The 7th edition of the Agricultural Census, which is the final one before the commencement of the permanent and sample Census, offers data on Italian agriculture up to the year 2020. These data provide an extensive statistical overview of the agricultural sector at the national, regional, and local levels. Simultaneously, they contribute to enhancing the existing information resources on various structural aspects (e.g., standard production, utilized agricultural area, livestock, tenant profiles, etc.), while also capturing emerging trends related to farm management, such as innovation and digitalization.

In contrast to the 2010 Agricultural Census, where data regarding age groups pertained to only a few aspects of farmers and farms, the current edition allows

[1] Article 4(6) Regulation (EU) 2115/2021.

[2] The related document is available at www.istat.it

Table 1. Number of farms and Utilized Agricultural Area (UAA) categorised per farmer age (young and not-young).

	Young farm manager (≤40)				Not-young farm manager (>40)				Total		
	Farms		UAA		Farms		UAA		Farms	UAA	
	No.	% of the regional total	hectares	average	No.	% of the regional total	hectares	average	No.	hectares	average
North	30,452	*10.1*	586,459	19	269,654	*89.9*	3,713,599	14	300,106	4,300,059	14
Center	16,041	*9.0*	288,078	18	162,931	*91.0*	1,716,085	11	178,972	2,004,162	11
South	58,393	*9.0*	1,044,349	18	593,057	*91.0*	4,704,470	8	651,450	5,748,819	9
ITALY	104,886	*9.3*	1,918,886	18	1,025,642	*90.7*	10,134,154	10	1,130,528	12,053,040	11

Note: Common land agricultural units are excluded.
Source: our elaborations on ISTAT Census data.

for a more comprehensive understanding of the characteristics of the new generation of farmers. This is achieved by comparing data from their farms with those managed by older farmers. For instance, it enables us to assess their inclination towards innovation, sustainable production systems, participation in associations, and adoption of digital technologies. However, it is important to note that ISTAT has yet to release data concerning the structural issues (e.g., economic size of holdings, farming types, etc.) of businesses operated by young farmers. Therefore, this analysis does not provide information on these aspects.

Without delving extensively into certain nationwide trends that have already been addressed by other authors – such as a notable decrease in the number of farms, a slight reduction in land area, and an increase in the average farm size (Cardillo *et al*. 2022; Giacomini, 2022; Henke, Sardone, 2022; Manzi *et al*., 2022) – the authors wish to draw attention to the generational imbalance within the agricultural workforce. As highlighted by VV. AA. (2022), the age composition of farm managers primarily consists of individuals aged 60 and over (57.6%), with a notably limited presence of those in the younger age group (from 30 to 44 years: 11.2%) and a minimal representation of very young individuals (under 29: 2.2%)[3].

The ongoing aging of national agricultural entrepreneurship is certainly not a recent development (Corsi *et al*., 2005; Tarangioli, Trisorio, 2010; Cersosimo, 2012; Cersosimo, Ferrara, 2013; Carbone, Corsi, 2014; Ascione *et al*., 2014). Nevertheless, the expanded information fields in the latest Census allow for a broader exploration of young farmers compared to their older counterparts. This enables us to create a more comprehensive profile of their structural characteristics and delve deeper into the evolutionary paths of their farms. Additionally, we can consider potential regional variations in this phenomenon.

2.1. The outcomes of Census data collection on Italian agricultural entrepreneurship

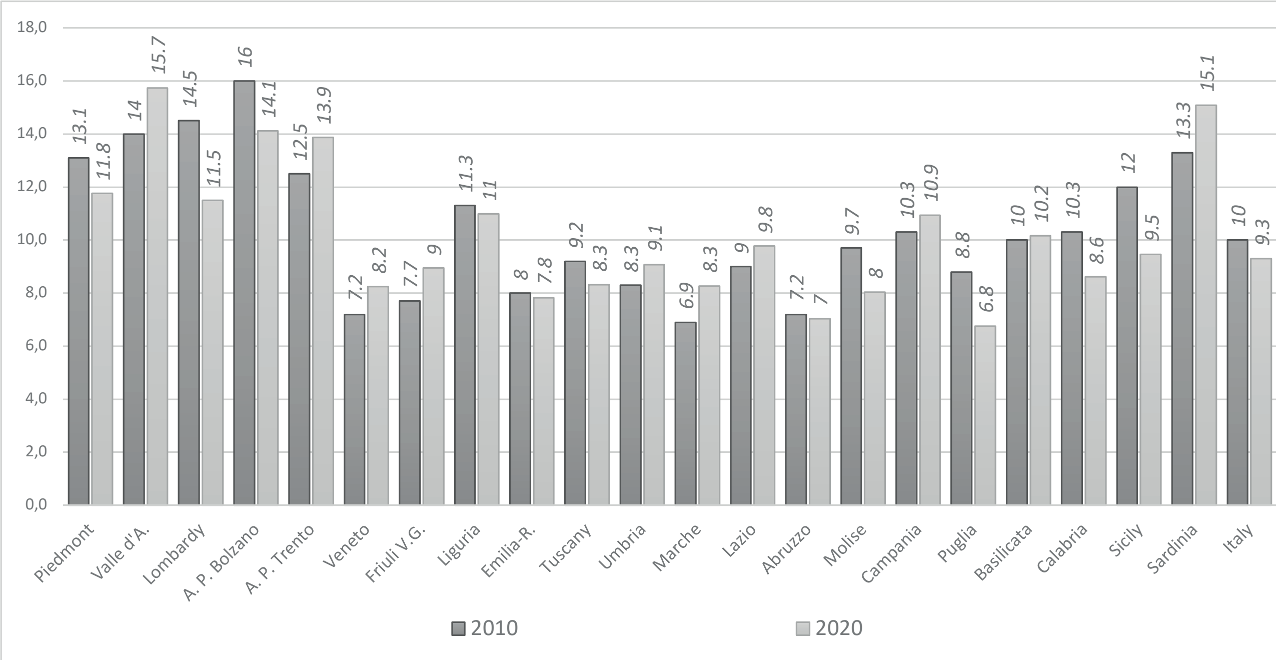
The analysis of data regarding the method of entering the agricultural business reveals that 64.6% of young farmer inherit family-run operations, reaffirming the predominantly familial nature of national agricultural holdings: only 27.9% of young farmer initiate and manage entirely new ventures. As of 2020, there are a total of 104,886 young farmers (aged ≤40), constituting 9.3% of the overall figure. This represents a decrease of 2% compared to a decade ago when the proportion of young individuals stood at 11.3%.

The highest percentage of young farmers reside in the northern regions of the country. At regional level, Valle d'Aosta (15.7%), Sardinia (15.1%), and the two Autonomous Provinces of Trento and Bolzano (14.1% and 13.9%, respectively) have the highest proportions of young individuals within the total farming population (see Table 1). From a comparative standpoint, this situation mirrors that observed in the 2010 Census, particularly concerning the "younger" regions (refer to Figure 1).

The distinct presence of two demographic groups, the young and the elderly, in the 2020 Census, offers the opportunity to assess the extent to which farms managed by young individuals (aged ≤ 40) are poised to replace the elderly component (aged ≥ 60). In Figure 2, we provide a regional map of Italy that categorizes regions into four groups, ranging from those facing the most significant challenges in terms of generational renewal to those unaffected by this phenomenon. This

[3] The study on the age of the farmers was conducted using the age groups and data released by ISTAT in August 2022 (www.istat.it).

Figure 1. Incidence of farmers ≤40 in the last two Censuses (% values).



Source: our elaborations on ISTAT Census data.

analysis adopts the same approach previously outlined by Matthews (2018) in a study focusing on the topic of young agricultural holders within the EU.

Despite variations in results and substantial differences among regions within the same group, territorial analysis offers valuable insights for a deeper understanding of the generational renewal phenomenon in Italy. One initial finding highlights the presence of more critical situations, where the issue of generational renewal significantly surpasses national averages. These situations are represented by nine regions positioned in the upper-left quadrant of the graph. Notably, some economically significant regions such as Emilia-Romagna, Tuscany, Veneto and Friuli Venezia Giulia fall within this category. These regions boast a strong agricultural and agri-food sector but simultaneously, they exhibit a higher percentage of elderly farmers compared to the national average and a lower percentage of young farmers. For some of these areas, obstacles preventing young farmers from entering agricultural activities may be linked to limited land access and the existence of a more integrated and competitive agriculture where older operators lack incentives to relinquish their farm management roles.

On the other hand, regions where a concerning gap between the new and old generation of farmers is observed are Puglia and Abruzzo, where the majority of farmers are over 60 years old. In these circumstances, it is likely that young individuals may not engage in agriculture due to economic reasons, but they may also not be trapped in it due to a lack of alternative employment opportunities (Carbone, Corsi, 2004). Consequently, it is primarily the older farmers who perform the role of preserving the territory, based on a more extensive and less profitable form of agriculture.

On the contrary, the bottom-right quadrant highlights a group of regions with a demographic structure that is much more favourable to generational turnover in the primary sector. These geographic areas exhibit a balanced demographic ratio above the national average, consequently showing a greater inclination toward generational renewal. The regions falling within this quadrant encompass territories spanning both extremes of the Italian Peninsula. On one side, Basilicata, Sardinia, Campania, regions where agriculture may also represent a "necessary" choice due to the limited availability of alternative employment opportunities. On the other side, Piedmont, Liguria, Lombardy, Valle d'Aosta, and the two Autonomous Provinces[4], regions distinguished

[4] In the case of Alto Adige, it is essential to consider the importance of the "Maso Chiuso" institution (Geschlossen Höf), which imposes limitations on property subdivision, both in cases of inheritance and through sales. This institution plays a crucial role in preventing land fragmentation and facilitating the preservation of agricultural activities in mountainous regions.

Figure 2. Distribution of regions based on the level of generational renewal (% values).

Notes: (1) The regions have been categorized into four groups based on how they compare to the Italian average in terms of the proportion of younger (X-axis) and older farmers (X-axis) and the share of older farmers (Y-axis). (2) PIE (Piedmont); VDA (Valle d'Aosta); LOM (Lombardy); BOZ (A.P. Bolzano); TRE (A.P. Trento); VEN (Veneto); FVG (Friuli V.G.); LIG (Liguria); E-R (Emilia-R.); TUS (Tuscany); UMB (Umbria); MAR (Marche); LAZ (Lazio); ABR (Abruzzo); MOL (Molise); CAM (Campania); PUG (Puglia); BAL (Basilicata); CAL (Calabria); SIC (Sicily); SAR (Sardinia).
Source: our elaborations on ISTAT Census data.

by a more competitive and integrated agricultural sector within the local economic framework, rendering it increasingly appealing to younger individuals. In these regions, a lower percentage of elderly farmers compared to the national average is accompanied by a higher percentage of young farmers. Sicily, Lazio and Molise stand out as extreme cases. While, for the first two regions located in the upper-right quadrant, the presence of young farmers, though limited in an aging context, hints at the possibility of generational renewal, this prospect appears remote in Molise. Indeed, Molise is characterized by a lower percentage of young farmers but also by a lower percentage of elderly farmers compared to the Italian average.

Furthermore, a significant contrast, as highlighted by Figure 2, emerges between Sardinia, Valle d'Aosta and the Autonomous Province of Bolzano on one side, and Abruzzo and Puglia on the other. This disparity may result from various factors influencing generational turnover.

Examining the data from the latest Agricultural Census allows us to highlight the changes that have occurred in the past decade, particularly regarding access to agricultural activities. In farms with young farmers, there is a higher incidence of start-ups compared to not-young farms (27.9% vs. 17.6%), which, conversely, have a higher percentage of takeovers.

In the farms located in Central Italy, the percentage of young farmers initiating new businesses exceeds the national average by more than 10 percentage points. In farms managed by individuals over 40 years old, respondents reported inheriting the farm from a family member in 75% of cases. In contrast, for young farmers, family successions decreased to 64.6% (see Table 2). Again, the regions in Central Italy deviate from this pattern, where the opportunities for succession reduce even further to 55.3%.

Table 2. Type of access to the management of the farm (% values).

	Young farm manager				Not-young farm manager			
	From family members	From third parties	From none (start-up)	Total	From family members	From third parties	From none (start-up)	Total
North	*60.0*	*5.2*	*34.8*	*100*	*74.7*	*5.3*	*20.0*	*100*
Centre	*55.3*	*4.7*	*40.0*	*100*	*71.9*	*4.5*	*23.6*	*100*
South	*63.6*	*5.6*	*30.8*	*100*	*76.3*	*5.8*	*17.9*	*100*
ITALY	*64.6*	*7.5*	*27.9*	*100*	*75.0*	*7.3*	*17.6*	*100*

Notes:
(1) This classification only includes the following types of legal entities: individual farmers, family-run farms, and farming partnerships.
(2) ISTAT categorizes the source from which the farm is acquired as follows: from a family member, from a relative, from third parties, from nobody (i.e., a new farm). In the table, the first two items are combined.
Source: our elaborations on ISTAT Census data.

It is worth noting that in recent years, in addition to the conventional practice of family succession (Cassidy, McGrath, 2014; Sroka *et al*., 2019; Bertoni *et al*., 2023), there has been a gradual emergence of a modest generational turnover effect, supported by European and national policies (Ascione *et al*., 2014; Licciardo *et al*., 2022). Young farmers collectively manage 1,919 million hectares of UAA, which account for roughly 16% of the entire national UAA. The average farm size for businesses operated by a holder under the age of 40 is 18.3 hectares, significantly exceeding the overall average of 10.7 hectares for all farms. Consequently, young farmers are overseeing notably larger farms in comparison to the surveyed population as a whole, as indicated by a study conducted by Licciardo *et al*. in 2023. Notably, in the regions of Valle d'Aosta and Sardinia, young farmers are managing farms that surpass both the regional and national averages, with sizes of 44 and 42 hectares, respectively[5]. These data should be interpreted while considering two significant aspects. Firstly, despite a national average decline of 2.5%, Valle d'Aosta stands out as one of the eight regions where the UAA is actually increasing. Apart a few specific geographical exceptions, notably the two Autonomous Provinces and Lombardy, the number of farms has, on average, decreased by 22.6%. The most significant declines have been observed in the southern regions (-33%) and the islands (-32.4%). The reduction in the number of farms has facilitated the concentration of the UAA, and in this context, the data demonstrate that younger farmers, as in the case of Sardinia, have particularly benefited from this trend.

Another noteworthy finding drawn from the Census data is that in farms managed by young individuals, approximately 61% of the UAA is rented, a percentage that declines to 38% for those over 40 years of age. Conversely, in young-run farms, ownership stakes decrease to 27.4%, while they rise to 52.4% in farms operated by individuals no longer young. These data would confirm a problem to land access (as highlighted by Brun *et al*., 2014; Mausch *et al*., 2021), especially for start-up farms, primarily due to the exorbitant costs associated with land purchase (as discussed by Rossier, 2010; Keiko Yamaguchi *et al*., 2020), coupled with the reluctance of older farmers to retire.

2.2. The new generation of agricultural entrepreneurs

Young farmers exhibit a notably higher level of education compared to the average for farmers, both at the national and regional levels. Approximately 50% have successfully attained a high school diploma, in stark contrast to the 22.1% among individuals over the age of 40. Furthermore, 19.3% hold a university degree, a percentage that drops significantly to 8.7% for farm managers who are not classified as young. Among the top five regions boasting the highest percentage of young farm managers with university degrees, only one is situated in the south of the country: Umbria (26.5%), Tuscany (25.9%), Marche (22.6%), Lombardy (22.2%) and Basilicata (21.8%).

The increased professionalization of young farmers, as assessed by their level of education, has a positive impact on various aspects of farm activities. Over the three years leading up to the Census survey, 24.4% of young farmers introduced innovations, compared to just 9.7% among entrepreneurs over the age of 40. Moreover, when it comes to digitalization, farmers under 40 exhibit

[5] In Valle d'Aosta, the 392 farms led by young managers make up 15.7% of the regional total (or 28.8% in terms of UAA). Meanwhile, in Sardinia, there are 7,073 young farms, accounting for 15.1% of the regional total (or 2.5% in terms of UAA).

a level that is more than double that of their older counterparts, with figures standing at 33.6% versus 14%.

A significant 71.4% of farms managed by young individuals prioritize the marketing of their products. This inclination appears to be bolstered by their interest in associationism, a collaborative tool that attracts young farmers. Indeed, 46.8% of farmers under 40 are members of associations, compared to 40.1% of older individuals. Additionally, 21.5% are part of a producer organization, and 2.2% (in contrast to 0.7% among those aged 40 and above) are affiliated with a business network[6].

Based on the analysis of Census data, it becomes evident that young farmers play a significant role in embracing the multifunctional agriculture model, which encompasses activities like agritourism, processing and direct sales, rural preschools. This model is progressively reshaping the Italian primary sector, as indicated by studies such as Henke (2004) and Henke, Povellato (2012). Furthermore, young farmers are enthusiastic advocates of the agroecological approach. They exhibit a heightened commitment to environmental concerns, exemplified by their adoption of organic production systems. Indeed, the percentage of young farmers (14.6%) engaged in organic farming surpasses that of older farmers (5.9%), more than doubling the participation rate[7]. Furthermore, there is a higher prevalence of productive diversification, involving the inclusion of at least one additional income-generating activity alongside agriculture. In this regard, 11.6% of farms managed by young individuals engage in diversification by incorporating at least one profitable activity related to agriculture. This percentage declines to 5.2% when considering farms operated by individuals who are not categorized as young, as highlighted by Korthals Altes (2023) «*Greener production methods involve more than a few updates, which can be performed as a simple fix by a farmer who is a few years before retirement but needs a different practice of farming. Therefore, the issue of rejuvenating farming is more than just a change of generations; it is also a change of practices*».

Farmers who engage in production diversification are most prevalent in both the north and south of the country, accounting for shares of 50% and 27%, respectively. In the central region, the percentage of young farmers involved in diversification stands at 23% (see Table 3). Across all three geographical areas, both young and older farmers exhibit a balanced inclination toward diversification.

Table 3. Number of farms engaged in supplementary activities, categorized by young and non-young farm managers.

	Young farm manager		Not young farm manager	
	No.	% Distribution	No.	% Distribution
North	6,140	*50.0*	29,926	*50.9*
Central	2,758	*23.0*	12,508	*23.6*
South	3,307	*27.0*	13,487	*25.5*
ITALY	12,205	*100.0*	52,921	*100.0*

Note: Common land agricultural units are excluded.
Source: our elaborations on ISTAT Census data.

However, the territorial disparities become even more pronounced when examining regional data. In 12 regions, the percentage of farmers engaged in other income-generating activities exceeds the national average, with the highest value recorded in the Autonomous Province of Bolzano (30.3%). Conversely, in certain regions of the south, including Calabria, Sicily and Puglia, this figure does not even reach 5%. A closer look at the specifics of the primary connected activities (refer to Figure 3) reveals that young farmers almost always outnumber those older by more than double. The main type of connected activity is agritourism, with a 4% share of farms run by young managers (2% in the case of not-young ones).

This is followed by subcontracting activities present on 1.8% of young farms, such as the production of renewable energy, the transformation of animal and vegetable products.

3. FINAL REMARKS

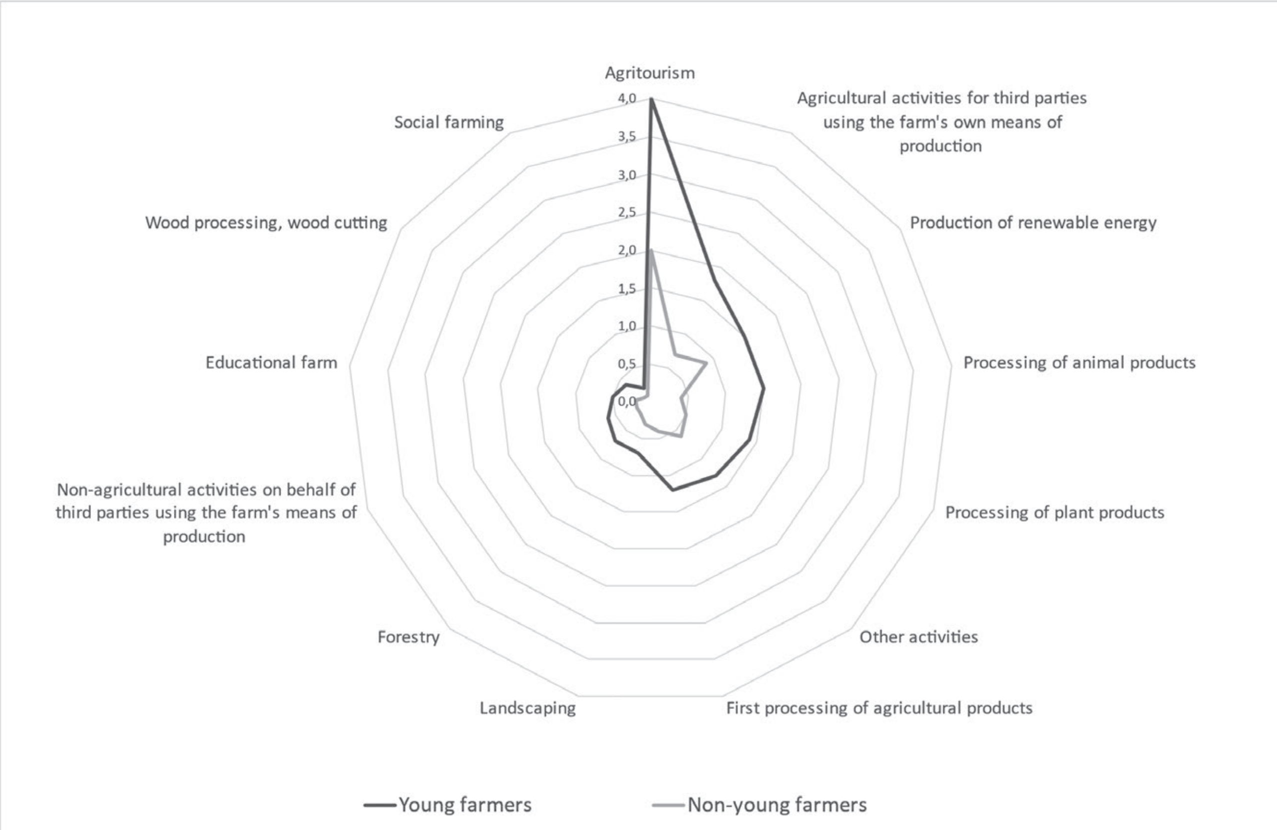
The statistical survey highlights the presence of specific entrepreneurial requirements that need to be investigated. The objective is to facilitate the development of suitable interventions for supporting new start-ups and to establish effective methods for providing this support. The data collected in the 7th Census of 2020 enable us to define an updated picture of youth entrepreneurship as the new CAP is launched. Within the CAP, one of the nine strategic objectives involves facilitating generational turnover, and the Census data help inform this effort.

Despite public policy efforts to promote and support young individuals in entering farm management, data analysis reveals a limited presence of young farmers and the continued predominance of older ones. Once

[6] When examining specific categories of associations (producer organizations, business networks and other entities), it consistently emerges that farmers under the age of 40 exhibit higher participation rates. At regional level, the most notable percentages of youth engagement in associations are observed in the northeast regions (64%), followed by the northwest (54%) and central regions (51%).

[7] In the context of livestock farms engaged in organic breeding practices, the participation rate stands at 2.3%, in contrast to the 0.7% figure seen among farms managed by individuals who are not considered young.

Figure 3. Prevailing type of associated activities among farms managed by both young and older managers (% values).



Note: The Census encompasses a total of 21 business categories, with the most substantial shares displayed in the graph.
Source: our elaborations on ISTAT Census data.

again, these circumstances can be attributed to sociocultural factors and the persistence of entry barriers linked to the structural and organizational aspects of the sector, which have been extensively studied by numerous authors. However, there are regional exceptions that, while not contradicting the overall trend, show a higher concentration of young farmers, surpassing the national average. This suggests the potential existence of facilitating factors for their establishment.

To fully comprehend these enabling factors, further analysis will be necessary in the future, using data from the new permanent Census of Agriculture and incorporating information gathered through qualitative surveys such as sample surveys and technical tables.

The available data at the moment do not provide an in-depth analysis of the structural attributes of businesses managed by young individuals. Instead, they primarily focus on the entrepreneurial choices made by these individuals in terms of innovation and their market approach. In our perspective, what stands out most within the young farming demographic is their heightened commitment to green and digital transitions. This inclination is facilitated by the adoption of innovations within the farming sector and their continuous professional development. Young farmers, indeed, demonstrate a stronger inclination toward sustainability, organic farming and animal welfare. It is important to highlight that fostering innovation and entrepreneurship can also play a pivotal role in fostering more virtuous development cycles in rural areas. On the contrary, a scarcity of young individuals may impede the modernization and balanced development of these regions.

In our opinion, the analysis at the territorial level offers valuable insights for a deeper understanding of both internal and external factors that can either facilitate or impede the entry of young individuals into the agricultural sector. Despite the complexities inherent in demographic analysis, notable disparities are evident, as exemplified by the stark differences between regions like Sardinia, Valle d'Aosta and the Autonomous Province of Bolzano compared to Abruzzo and Puglia. These disparities shed light on specific determinants influencing generational turnover. One such determinant is the variation in the size distribution of agricultural holdings. For instance, the prevalence of medium-small-sized farms may be associated with a higher percentage of older farmers, particularly in areas where agriculture is less productive. Consequently, the presence of young individuals in these regions remains limited.

Furthermore, it is essential to recognize that in certain regions of the country, social and cultural attitudes regarding access to the job market play a significant role. In regions with limited employment prospects young individuals may be inclined to pursue opportunities in the agricultural sector. In these cases, the presence of youth in agriculture is more a consequence of a lack of alternative professional avenues rather than a deliberate choice driven by personal interest or economic convenience. Conversely, in regions where other economic sectors are highly competitive, young individuals may be less inclined to embark on careers in agriculture. This is particularly evident in some central Italian regions and along the Adriatic coast, where the strong competition in sectors like tourism and manufacturing diminishes the appeal of agriculture for young individuals. A similar scenario exists in various parts of northern Italy, although in specific regions characterized by more integrated and competitive agriculture, this trend may not hold true, and the presence of young farmers can be substantial.

However, it is believed that while the Census data can outline the profile of a young farmer and their business, they contribute only partially to understanding the territorial distribution of entrepreneurship and its evolution between censuses. They fall short of providing a comprehensive understanding of demographic dynamics associated with settlement and abandonment. For a more comprehensive picture, additional information from the Farm Accountancy Data Network (FADN), which collects technical and economic data (income, income support, etc.) from a sample of holdings, is essential. This data supplements the young agricultural holder's profile by including economic and income-related information derived from various variables.

On the other hand, analysing the structure and dynamics of young farms and comparing them with businesses in other sectors can be achieved by using structural statistics from businesses registered in the Business Register of the Chambers of Commerce (Infocamere-Movimprese). This administrative source records the registrations and cancellations of business activities, making it the primary resource for such analyses.

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