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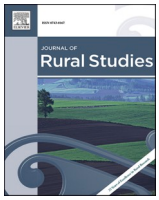

Sowing the seeds of change: unveiling farmer types to promote climate-smart agriculture adoption in Europe

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ABSTRACT

Climate-smart agriculture (CSA) promises to provide a triple win in economic viability, food security and climate change mitigation. This study develops a European farmer typology to enhance the adoption of CSA by combining two research streams, the COM-B behavioural-change theory and segmentation research. Using a survey of 603 farmers from five European countries (Denmark, Lithuania, Netherlands, Slovenia, Spain), the study applies a systematic approach, examining capability, opportunity and motivation factors of the COM-B model. Data analysis resulted into classifying farmers into four types: *environmentalists, constrained, indifferents, and traditionalists*. The farmer typology reveals that all components of the COM-B model were useful to differentiate the four farmer groups. *Environmentalists* express high intention to adopt CSA, motivated both internally, by capabilities and motivation, and externally by the opportunities in the social and food systems environments. *Constrained* farmers share similar intentions but face significant barriers in physical opportunities, such as limited access to markets and credit, policy framework and market willingness to pay. *Indifferents,* despite sharing some commonalities with constrained farmers, they demonstrate low interest in CSA mainly due to lower levels of psychological capabilities and motivation. Finally, the *traditionalists* face the strongest barriers in capability, opportunity and motivation in the transition to CSA. This research contributes to the literature by providing a holistic and systematic approach to segment farmers based on key barriers and drivers in adopting CSA and linking these with four categories of tailored strategy and policy interventions aiming to enhance CSA adoption across diverse farming contexts in Europe.

1. Introduction

Agriculture is involved in major sustainability crises associated with a growing population, climate change and environmental degradation (Chataut et al., 2023; Cullen et al., 2020; Kakkavou et al., 2024). The urgency for the transition to sustainable agriculture is explicit in the EU agricultural policies (e.g., Green Deal, CAP) which promote mainstreaming of sustainable agricultural practices by specifying climate, environmental and biodiversity targets (Braito et al., 2020; Graskemper et al., 2021). Climate-smart agriculture (CSA) has emerged as a promising integrated approach addressing the triple challenges of economic viability, food security and climate change mitigation (Erekalo et al., 2024; Gemtou et al., 2024a, 2024b). CSA is a concept first introduced by the Food and Agriculture Organization (FAO) and aims to sustainably increase agricultural productivity, build resilience to climate change, and reduce greenhouse gas emissions (Erekalo et al., 2025). CSA encompasses a range of traditional and innovative practices and technologies that foster transformation and re-orientation of the agricultural systems to support food security under climate change (Gemtou et al., 2025; Isakhanyan et al., 2024; Lipper et al., 2014; Long et al., 2016; Pedersen et al., 2024). Hence, it does not necessarily require entirely new farming practices, but instead builds on existing ones steering them toward greater sustainability (Erekalo et al., 2025; Gemtou et al., 2025). Over the past decades, concerted efforts in strategy and policy programs

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have rather relied on monetary incentives and one-size-fits-all approach largely failing to convince farmers to adopt CSA and resulting in adoption rates below desired levels (Dessart et al., 2019; Gemtou et al., 2024a; Hoek et al., 2021). Farmers' behavioural change is key to the transition towards sustainable agriculture and as Bartkowski et al. (2022) point out for agricultural strategy and policy to be effective they need to understand the behavioural characteristics of their main target group - farmers.

Recently farmer typologies have emerged as a tool to effectively capture the heterogeneity in farmer adoption of sustainable agriculture (Daloğlu et al., 2014; Kostrowicki, 1977). By grouping farmers, those that belong to the same type hold similar characteristics while different types reflect different behavioural patterns (Graskemper et al., 2021; Upadhaya et al., 2021). This literature recognises that farmer adoption of sustainable practices is guided by a multiplicity of factors, such as age, education, income, farmers' knowledge, subjective norms and technical feasibility (Barnes et al., 2019; Bechini et al., 2020; Hoek et al., 2021; Lähdesmäki and Vesala, 2022; Li et al., 2020; Pagliacci et al., 2020; Pinna, 2017) which result in different responses to environmental, institutional and policy change (Braito et al., 2020; Daxini et al., 2019). A practical application of farmer typologies would be to allow for targeted interventions and group-specific instruments to promote the uptake of CSA. But while past studies tend to agree that farmer types lie in a spectrum between production and conservation types (Barnes et al., 2022; Cullen et al., 2020; Darnhofer et al., 2005), the number of farmer types and their respective profiling characteristics and behaviours are less widely agreed (Emtage et al., 2006; Foguesatto et al., 2019; Graskemper et al., 2021; Nainggolan et al., 2013). Failure to identify recurrent farmer types to date has limited their potential (Bartkowski et al., 2022). This is partly because the behavioural change models that have been employed to build the farmer typologies, such as Theory of Planned Behaviour (TPB) and Technology Adoption models (TAM), fail to encompass all influencing factors affecting adoption of CSA (Cullen et al., 2020; Daxini et al., 2019; Luo et al., 2024) or do not provide a direct link to interventions (Tensi et al., 2022). A closer look at the studies clearly demonstrates that classification has been based primarily on socio-demographic, socio-psychological and farm characteristics while contextual factors related to social, institutional and legal contexts have been systematically overlooked (Daloğlu et al., 2014; Darnhofer et al., 2005; Graskemper et al., 2021). Even more, only few typology studies propose behavioural interventions and policies but these are not guided by the nature of behaviour to be changed (Braito et al., 2020).

A more concerted effort to develop coherent, transferrable, policy-relevant typologies is required for the transition to CSA. In recent years, the COM-B model is acknowledged as a structured framework for exploring behavioural influences and the design of behavioural change interventions (Michie et al., 2011). In this approach, three interrelated components – capability, opportunity and motivation – are used as a "behavioural diagnosis" of key barriers and enablers of behaviour and are linked with relevant types of behavioural and policy interventions (Tensi et al., 2022). While this framework has been extensively applied to health and medical contexts (Michie et al., 2016), its use in agricultural contexts is rare (Farrell et al., 2023; Tensi et al., 2022). In our study, classification of farmers is examined using a variety of sets of characteristics from the COM-B's capability, opportunity, motivation causes of CSA adoption, capturing both personal factors (e.g., socio-psychological) along with contextual factors (e.g., social, institutional and legal). The behavioural characteristics of the resulting farmer typologies are subsequently linked with targeted and effective interventions. On the other side, segmentation research allows for developing a typology that effectively balances key success criteria, such as segment identifiability and actionability. Farmer types in our study derive from the results of a survey administered in five selected European countries reflecting the diversity in environmental and institutional contexts across various parts of Europe. Combining two research streams, the COM-B behavioural-change theory and segmentation research provides an integrated framework to group farmers and to explain why particular groups of farmers behave differently and what levers may help shift their behaviours leading to actionable insights for behavioural change.

This study develops a systematic approach to prioritize relevant typology criteria if the goal is behavioural change. Our application of the COM-B framework addresses four key limitations in past farmer typology studies. Firstly, a holistic and systematic approach to define farmer types accounting both for farmers' capability and motivation (i.e., behavioural and socio-psychological characteristics) and the opportunity (i.e., contextual factors) is currently missing (Baum and Gross, 2017). Secondly, usually farmer characteristics come from one or two categories (e.g., farm characteristics, demographics, socio-psychological) with three or more categories being less common. Bartkowski et al. (2022) suggested that it is crucial for future studies to explore different sets of characteristics to find the minimum number of characteristics that can account for farmer differences. Thirdly, proposed interventions and policies have been unrelated to the behavioural causes restricting effectiveness in changing the intended behaviours. Fourthly, studies tend to focus solely on one country or even region (Daxini et al., 2019; Graskemper et al., 2021; Nainggolan et al., 2013) but to develop a meaningful European farmer typology, more European countries need to be included to consider the diversity in EU contexts and conditions. Bringing together the COM-B model and segmentation research will enable an integrated approach in the characterisation of farmer types and will allow mapping at a wider scale by identifying generalisable behavioural patterns in the transition to CSA.

2. Theoretical framework

2.1. Farmer typologies

A small but growing body of literature in European farmers' behaviour recognises that the farmer population is far from homogenous even within the same country or region (Cullen et al., 2020; Darnhofer et al., 2005; Upadhaya et al., 2021). Here, there is no such thing as a "European farmer" but diverse farmer groups with different behavioural characteristics (Bartkowski et al., 2022; Daloğlu et al., 2014). Typology is a systematic or taxonomic concept defined based on the similarities between individuals (Kostrowicki, 1977). Various related terms used in the literature are farmer types, farming groups, farming styles (Bartkowski et al., 2022; Braito et al., 2020). The essence of typologies is that farmer characteristics are internally homogenous while large differences exist between different farmer types (Barnes et al., 2019). Typology studies have been employed to explore behavioural change, such as adoption of practices or participation in policy programmes (Barnes et al., 2019; Braito et al., 2020; Cullen et al., 2020; Daloğlu et al., 2014; Darnhofer et al., 2005; Daxini et al., 2019; Nainggolan et al., 2013), or antecedents of behaviour, such as awareness of climate change. Generally, studies tend to find farmer types that range from conventional to more conservation stances identifying farmer types who are more oriented to food production as a profit-maximisation business as opposed to those guided by environmental concerns (Barnes et al., 2022; Cullen et al., 2020; Darnhofer et al., 2005). What is less clear are the main characteristics of the other farmer types while a widely agreed upon typology is currently missing (Bartkowski et al., 2022).

Past literature reveals the diversity of characteristics selected for farmer classification. Graskemper et al. (2021) identified three farmer types based on farmer demographics and farm characteristics while Cullen et al. (2020) reported four farmer types based on farmer attitudes and self-identity. An examination of previous farmer typologies reveals that classification has been mainly based on socio-demographic, socio-psychological and farm characteristics while contextual factors have been neglected (Daloğlu et al., 2014; Darnhofer et al., 2005; Graskemper et al., 2021). Characteristics, such as age, education, income, farm size along with farmer knowledge, goals, attitudes, perceptions, subjective

norms have been effectively used to derive farmer typologies (Barnes et al., 2022; Braito et al., 2020; Daxini et al., 2019). However, it is becoming increasingly acknowledged that the transition to CSA is a complex and multifaceted process that requires changes at different technological, socio-cultural, organizational, institutional, economic and political levels (Baumgart-Getz et al., 2012; Daxini et al., 2019; Gemtou et al., 2024b; Verburg et al., 2022). In this sense, adoption of CSA depends not only on farmers' behaviour as individual actors but also on the contexts in which they are embedded. Farmers' unique contexts, such as families, society, and institutions shape their behaviour but also the food systems pose certain power imbalances, trade-offs and feedback loops that affect their decisions to adopt CSA (Dessart et al., 2019; Gemtou et al., 2024a; Hoek et al., 2021). These create a multiplicity of dynamics and influences on farmer decision making that ultimately result in their acceptance or not of new practices and behaviours. Despite this, typology studies, with only a few exceptions (Barnes et al., 2022; Braito et al., 2020), have not examined the role of contextual factors as criteria for classification.

A common argument for the classification of farmers is that it provides a means to link commonalities in farmer characteristics with certain behavioural patterns, thus enabling targeted delivery of policies and interventions based on farmer types (Upadhaya et al., 2023). Nevertheless, the lack of recurrent typologies and the variety of contexts, criteria, and methods employed has limited the comparability, transferability and generalisability of results across contexts. Adding to the complexity of the endeavour is the fact that typologies are dynamic in nature and rather fluid meaning that they can change over time subject to policy and institutional changes (Bartkowski et al., 2022). What is currently needed is a more systematic effort to identify a universal typology for the European farmer that will allow more focused and cost-effective interventions for the transition to CSA (Cullen et al., 2020; Upadhaya et al., 2021). As Bartkowski et al. (2022) pointed out to develop such a typology, there is a need to try different sets of characteristics and identify the minimum composite of characteristics that can lead to a coherent and practical farmer classification. To respond to this need, our study will adopt a more integrated and systematic framework to account for the multiplicity of factors affecting adoption of CSA and link farmer types with targeted interventions and policies based on the desired behaviours to be changed.

2.2. The COM-B model

Our study employs Michie et al.'s (2011) COM-B model as a suitable framework to derive a meaningful farmer typology for the transition to CSA. The COM-B model is used to design behavioural change interventions. Behaviour change interventions are coordinated sets of activities designed to change specified behavioural patterns (Tensi et al., 2022). What (Michie et al. (2011) observed in medical and health studies was that causes of unhealthy behaviour were successfully identified. However, when it came to design interventions, little of that knowledge was used, often rendering interventions ineffective. Their COM-B model is a systematic method that integrates an understanding of the nature of the behaviour to be changed and an appropriate system for characterising the types of interventions that can be effective depending on the causes of behaviour. Adopting this framework will enable us to understand the complexity of causes for low CSA adoption in the farming population and link this knowledge with targeted interventions and policies per farmer type.

The COM-B model has been primarily applied to medical and health contexts (Michie et al., 2011, 2016) and environmental contexts (Gainforth et al., 2016; Hedin et al., 2019) but rarely to agricultural contexts (Farrell et al., 2023; Tensi et al., 2022). Specifically, in the field of farmer typologies, there is no previous study employing this model but rather they usually rely on TPB and TAM (Cullen et al., 2020; Daxini et al., 2019). Despite the popularity of the latter models, these provide only an incomplete picture of the causes for adoption of sustainable agriculture while they indicate no direct links with behavioural change interventions, hence limiting their usefulness for a comprehensive farmer typology.

Conversely, the COM-B model consists of three layers linking models of behaviour with interventions. At the core are the three interrelated elements involving capability, opportunity and motivation, used to analyse behavioural causes of the target behaviour. The model proposes that an individual must have sufficient levels of capability, opportunity and motivation in order for a target behaviour to change but when deficits exist, the second layer suggests nine interventions to be used to address one or more deficits. In turn, the outer layer identifies seven types of policy that one can use to deliver the intervention functions (Michie et al., 2016). This model advances the study of behaviour by shifting from a narrow focus on a few individual factors to a broader understanding of behaviour as shaped by multiple levels of influence (e.g., social, institutional), thereby offering a more comprehensive and holistic perspective on human behaviour (Regan et al., 2021). The model as applied to our research can be seen in Fig. 1.

2.2.1. Capability

Capability refers to the farmer's psychological and physical capacity to engage and implement CSA (Michie et al., 2011). It includes all those factors related to having the necessary knowledge and skills. Here our study investigates two factors, farmer's experience and behavioural control. Experience in using CSA practices is said to increase farmer's skills in CSA implementation and foster adoption (Gemtou et al., 2024b). Behavioural control has been extensively studied as part of the theory of planned behaviour and refers to farmer's perception of their ability to carry out a certain behaviour (Ajzen, 1991). In general, the more farmers feel the application of the new practices is under their control, the more likely they will adopt CSA, as opposed to when they perceive lack of capacity or technical difficulties associated with the adoption of CSA (Caffaro et al., 2019; Michels et al., 2020). The above factors tend to lead to different behavioural patterns and hence are expected to be important for our farmer classification.

2.2.2. Motivation

Motivation denotes the brain processes that energise, direct or demotivate behaviour which can be automatic or conscious. Here motivations range from habitual processes and emotional responding to conscious and analytical decision making (Michie et al., 2016). With respect to motivation factors, six characteristics are included in our typology: farmer motives, self-responsibility, perceived financial situation, and CSA practice characteristics associated with perceived ease of use, usefulness and compatibility.

Farmer behaviour is largely driven by motives (Gemtou et al., 2024b). Traditionally, farmers were viewed as profit maximizers, influenced by economic motives, such as increased profits and low production costs (Dessart et al., 2019) but what appears to change is that, after years of agri-environmental interventions, farmer behaviour shows some "shades of green" (Barnes et al., 2022). In many studies, farmers cite other non-economic motives linked to the environmental and social impact of their farming activities, such as environmental preservation, animal welfare, protection of rural communities (Mazurek-Kusiak et al., 2021; Pinna, 2017). What has been consistently shown in previous studies is that adoption of CSA is negatively correlated with economic motives and positively associated with non-economic motives (i.e. environmental and social motives) (Balogh et al., 2021; Lähdesmäki and Vesala, 2022; Mazurek-Kusiak et al., 2021).

Self-responsibility is an aspect of farmers' self-identity and refers to the salient and enduring perceptions of their role as farmers (Cullen et al., 2020). Studies demonstrate a kind of environmental conscience gradually built in farmers with the latter being increasingly concerned about the impact of their activities on the environment, communities and future generations (Pinna, 2017; Schoonhoven and Runhaar, 2018).

Fig. 1. BCW and COM-B model.

Farmers with heightened perceptions of self-responsibility tend to feel personally responsible to change their current practices and hence, are more likely to shift to more sustainable ones (compared to conventional farmers) (Hyland et al., 2016; Renault et al., 2021).

Farmers' transition to CSA also depends on the characteristics of the practice or technology. These characteristics are: 1) whether the CSA practice will be useful in enhancing farm productivity, reducing workload and simplifying farm operations, 2) how complex or difficult it is to use, 3) how compatible the practice is with the existing farmer values, goals and operations (Gemtou et al., 2024b; Mohr and Kühl, 2021). Accounting for these characteristics has clear benefits in predicting farmer's behaviour and can explain why farmers do not adopt CSA practices even when they will be profitable for their operations (Adrian et al., 2005).

2.2.3. *Opportunity*

Opportunity involves all those contextual factors external to the individual, which enable or hinder the desired behaviour. Factors can be social associated with social actors and interactions (Michie et al., 2016) or physical, afforded by the environment. Here the model accounts for the multidimensionality of the factors embedded in the unique contexts of farmers that can influence adoption of CSA. Farmer behaviour is determined by the social environment and the interactions with social actors like peers and family, as well as the food systems in which they operate, which create power dynamics and trade-offs affecting their decision making (Braito et al., 2020; Hoek et al., 2021). This is what Gemtou et al. (2024b) refer to as systemic factors which pose barriers or drivers in the transition to CSA.

Social factors emerge quite strongly in the literature suggesting that wider social networks influence adoption of CSA (Barnes et al., 2022; Happel et al., 2022; Siepmann and Nicholas, 2018; Zhang et al., 2023). More specifically, Barnes et al. (2022) found that that the perspectives of other farmers influence the uptake of ecological practices while Cullen et al. (2020) identified a large neighbourhood effect on adoption of agri-environmental schemes. Farmers who feel that important social referents, such as other farmers, family and citizens, expect them to apply CSA practices are more likely to adopt them to avoid any criticism or social exclusion for not meeting their expectations (Daxini et al., 2019; Läpple and Kelley, 2015). Other studies further stress the importance of social factors, such as number of social networks (Blasch et al., 2022) and public image (Balogh et al., 2021) in the adoption of sustainable agricultural practices.

Six physical opportunity factors will be considered for our segmentation study due to their importance for our context. First, the role of extension and advisory services is well established (Blasch et al., 2022; Knuth et al., 2018). These services may take the form of training courses, field visits and demonstrations as well as advice from formal instruments such as advisors. Ayoub (2023) suggests field visits and demonstrations as key capacity building enablers for farmers allowing for peer-to-peer observation, tacit knowledge transfer and learning which, in turn, increase the uptake of new practices (Blasch et al., 2022). Similarly, advisors play a key role in adoption and diffusion providing farmers with access to relevant and reliable information (Knuth et al., 2018; Long et al., 2016).

Previous studies further indicate that easy access to markets and access to credit encourage uptake of CSA, the former by enabling closeness between farmers and buyers and higher profitability (Home et al., 2019; Pinna, 2017) and the latter by reducing investment risks and opening up investment opportunities in CSA (Schoonhoven and Runhaar, 2018). Market willingness to pay a price premium serves also as a

key driver to adoption (Kociszewski et al., 2020; Verburg et al., 2022). Farmers' adoption of CSA cannot happen if there is no market for these products either because buyers are unaware of the potential benefits or they are unwilling to pay for the higher production costs.

Existing policies and regulations shape the transition to CSA (Balogh et al., 2020; Tamirat et al., 2018). A favourable policy framework fosters adoption of CSA while a negative policy environment serves as a disincentive for adoption. Although a positive relationship may seem intuitive, not all policy instruments are viewed in a positive light (Linares Quero et al., 2022) while farmers frequently cite bureaucracy and lack of adequate compensations as main barriers for the adoption of new policies and regulations (Maurizio et al., 2022; Pinna, 2017).

Finally, the notion of fairness in the supply chain, although important for the sustainability of the food systems, is less explored in the literature. This is mainly due to the difficulty of operationalizing and measuring the concept of fairness (Hendrickson and James Jr, 2016). Fairness perceptions are formed based on expectations and the position of participants in the value chain (Hoang et al., 2021). It is widely accepted that power imbalances (e.g., bargaining power, market power) and information asymmetries give rise to fairness issues in the value chain, such as unfair prices and unequal welfare distribution among different parts of the supply chains which affects adoption of sustainable agriculture practices (Barling et al., 2022). Barnes et al. (2022) identified trust and long-term relationships between farmers and supply chain actors as key drivers in the adoption of ecological practices. Taking this one step further, Hoang et al. (2021) identified various conditions and practices that increase fairness in the value chain such as legal, economic, environmental and social. It can be concluded that fairness and contribution of supply chain actors to the transition to sustainable agriculture positively affect adoption of CSA practices.

In conclusion, the set of characteristics we will employ for our farmer typology draws on capability, motivation and opportunity factors. This approach responds to the need for more studies adopting a holistic approach in testing various categories of characteristics (both individual and contextual) to identify the minimum set of characteristics that can produce discernible and reproducible farmer behaviours that can generalise to the wider European farmer population but also match them with tailored interventions and policies (Bartkowski et al., 2022).

3. Methods

3.1. Data collection

A survey was administered to farmers across five European countries (Denmark, Lithuania, Netherlands, Slovenia, Spain) to account for the diversity of environmental and institutional conditions in Europe ensuring representation from the northern, southern, western and eastern countries. The purpose of the survey was to classify farmers into types with respect to their intention to adopt CSA employing the COM-B framework. When designing the survey, a literature review and expert consultations with researchers and agriculture specialists were used to identify important characteristics for farmer classification. The survey consisted of three sections. The first section involved a definition of CSA giving some examples of relevant practices to ensure that respondents across countries had a consistent understanding of what CSA is, and that farmers understood CSA in the same way as researchers do. Two additional questions aimed to capture farmers' awareness of CSA practices and past experience with CSA. The second section contained questions about farmer and farm characteristics which were subsequently used to stratify results. These variables were mainly categorical. The third section asked participants to evaluate statements related to certain variables associated with capability, motivation and opportunity factors from the COM-B model. The variables assessed in the survey can be seen in the Appendix while responses were recorded on 7-point Likert scales. The initial survey was prepared in English which was subsequently translated into the five local languages. The survey took on average 15 min to complete.

Data collection lasted from January 2023 to March 2023 while data were collected online (via Qualtrics survey tool). Data collection was done by national organisations in the five participating countries in their local language. For the purpose of this research a farmer was defined as an individual actively engaged in managing or co-managing an agricultural holding producing crops or livestock. The same definition was used across the five countries. Questions such as those examining farmer experience with CSA, farming experience, farm size, production system, were used as screening questions that could eliminate some people who were not farmers. No restrictions to farm sizes were used so that smallholders, medium and large farm owners could participate in the survey. The survey was initially pilot tested with five farmers within each of the five countries to test appropriateness of questions for the local contexts while iterations were made (e.g., improvements in wording) before the final survey was distributed to participants. The national organisations distributed the survey link via agricultural and institutional networks, farmer associations. Farmer participants were invited via emails, social media, newsletters or phone calls. A total of 603 responses were collected. After gathering the responses, data cleaning and coding was performed to form the final dataset for analysis.

3.2. Finite mixture model as analytical approach

In previous studies farmer typologies have been derived using qualitative (Braito et al., 2020; Darnhofer et al., 2005) and quantitative approaches (Barnes et al., 2022; Daxini et al., 2019; Nainggolan et al., 2013; Upadhaya et al., 2021) with the majority of the studies favouring quantitative methods. The challenge with quantitative methods is the criteria for segment choice selection especially with respect to assuring that the correct number of segments has been identified (Hair et al., 2006).

To address these limitations in our study we used the concomitant finite-mixture model to estimate segment membership and the explanatory variables behind membership. This approach has been previously used in a number of farmer and consumer studies (Daxini et al., 2019; Kornelis et al., 2010). The finite-mixture model is a model based approach used to identify the underlying structure of data in order to predict the probability that each observation belongs to a specific segment (Daxini et al., 2019). The finite-mixture model is based on the assumption that there is an underlying latent categorical variable that divides into discrete segments based on certain measured items (Barnes et al., 2022). Finite-mixture models are based on robust estimation algorithms to decide on the correct number of segments and hence, unlike other analytical approaches, the choice of segmentation criteria is less arbitrary. Moreover, finite-mixture models can deal with variables measured with different scale types (Barnes et al., 2013). In our model, farmer types were identified based on a set of core variables involving capability, motivation, opportunity factors (see Fig. 1) under the assumption that segment membership depends on a set of background variables (farm and farmer characteristics), which are called concomitant variables. Hence, this methodological approach is well suited to analyse the possible relations between background characteristics and our core variables with respect to farmer adoption of CSA.

3.3. Results

3.3.1. Principal component analysis

As a first step, we conducted an exploratory factor analysis using Principal Component Analysis (PCA) on multiple-item questions related to farming motives (eleven items, see Appendix), extension and advisory services (seven items), and information use (eight items). The aim of the PCA was to determine whether the items could be grouped into underlying constructs, thereby reducing the complexity of the analysis (Hair et al., 2006). The criterion for extracting constructs was based on the eigenvalue-greater-than-one rule, meaning that only components with

eigenvalues exceeding one were retained. The analyses were performed using the correlation matrix of the variables, and no factor rotation was applied. The final variable items were also assessed for internal consistency and reliability using Cronbach's alpha and results can be seen in the Appendix along with the scales used per variable. All variables had a Cronbach's alpha above 0.77 and a value of 0.60 was considered as acceptable (Daxini et al., 2019).

3.3.2. Number of segments

Our finite-mixture model analysis commenced with a comprehensive model incorporating all core variables from Fig. 1, while the farm and farmer related background variables were used as concomitant variables to further explore whether the socio-demographic profile of farmers and farm characteristics have discriminating power up and beyond the core variables of the classification base.

An exploratory approach was used to identify the optimal number of segments and a number of statistical information criteria were evaluated to assess the best model fit. The finite-mixture model was estimated using one to ten segments. The statistical information criteria examined were the Consistent Akaike (CAIC), Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC), with smaller values indicating better fit (Nylund et al., 2007). Entropy R^2 values (ranging from 0 to 1) were also examined with higher values indicating a better model fit and goodness of segment separation (Daxini et al., 2019). As can be seen in Table 1, the CAIC, BIC, and AIC indicated a four-, seven-, and ten-segments solution, respectively without providing an agreement about the number of segments. It is however known in literature that the AIC tends to overestimate the optimal number of segments (Nylund et al., 2007). In Fig. 2, we graphically depict the values of the Information Criteria. It shows that the largest drop could be found between one and two segments, and that both the CAIC and BIC showed relatively small value changes between four and seven segments. Given that all ten models had an excellent model fit in terms of the entropy R^2 (all values are above 0.88), we opted for the four-segment model as this model was more parsimonious, than the seven-, or ten-segment model.

3.3.3. Finite-mixture model analysis

Subsequently, we investigated the discriminating power of the core and background variables by means of Wald tests. The results are given in Table 2 for the four-segment model (four-segment model A). As it appears on Table 2 all core variables helped to identify the four segments (p-values are <0.01). Conversely, not all background variables had discriminating power. We therefore estimated a four-segment model in which the nonsignificant (according to the Wald test) background variables were no longer used to predict segment membership (four-segment model B). The non-concomitant variables were not further used to predict segment membership.

3.3.4. Profiling the four segments

The fixture-model analysis based on four segments of farmers demonstrates that all segments are substantial in size. The first segment of environmentalists has a segment membership probability of around 21 %, this means that about 21 % of the sample is estimated to be in this segment. Accordingly, constrained have a probability of 32 %, indifferents 34 % and traditionalists 13 %. Table 3 presents the sizes of the four segments and their mean importance ratings and percentages of the core variables. Again, Wald tests were used to see if these patterns are significantly different among the segments.

3.3.4.1. Segment 1: environmentalists (21 %). The environmentalists indicate the highest intention to adopt CSA among all four segments which arises from the fact that they have the highest scores in capability and opportunity among all groups and equally high scores in motivation with the constrained farmers. In particular, 75 % of this segment has previous experience with CSA and they score high in behavioural control meaning that they feel they have the control, ability and resources to implement CSA. Farmers that belong to this segment have high motivation demonstrating a high level of agreement with faming goals that promote environmentally-friendly production, animal welfare, public health, and employment in rural areas. However, they are also driven by economic motives. They have a sense of responsibility about the environmental, social and economic impact of their farming activities. With respect to practice related characteristics, they present high scores in perceptions of usefulness, ease of use and compatibility. Members of this segment also report having high social opportunity, being heavily influenced by social norms, and agree that adopting CSA is socially accepted. Although extension and advisory services are viewed favourably, this group presents the highest scores in perceptions of unfairness in the value chain. Notably, physical opportunity is the highest among all farmer types since they feel enabled by the food systems in which they operate having the most favourable views about access to market, access to credit, market willingness to pay, as well as policy framework. Overall, this segment indicates a conservation stance which is also enabled by the internal capability and motivation but also externally by opportunities in the social environment and the food systems conditions. The environmentalists group has been consistently found in previous farmer typologies with corresponding names such as conservationists (Upadhaya et al., 2023), enabled ecologists (Barnes et al., 2022), and committed organic (Darnhofer et al., 2005).

3.3.4.2. Segment 2: constrained (32 %). The constrained have the second highest intention to adopt CSA. Compared to the environmentalists, they demonstrate lower but still significant physical and psychological capabilities. 44 % of farmers in this segment have previous experience with CSA practices and they hold a good sense of behavioural control. Their motivation is similar to the previous segment. They demonstrate the highest levels of agreement with economic farming motives but their farming operations are also driven by non-economic motives. They also have a high sense of self-responsibility (second highest scores after environmentalists). This farmer segment shows high levels of agreement with statement that the CSA practices/technologies are useful, easy to use and compatible with current farming operations and goals. They agree that adoption of CSA is socially acceptable, but to a lesser extent than environmentalists. Although they perceive the value chain as unfavourable, they have the lowest perceptions of unfairness implying that they are more satisfied with the contribution of other actors in sustainable food systems compared to the other three segments. What seems to be constraining in this segment is the food systems conditions depicted in the low physical opportunities. Farmers here present the second lowest scores in aspects, such as access to market and credit, policy framework and market willingness to pay, indicating the generally unfavourable environment for them. Hence, this segment shows attitudes amenable to adoption of CSA but are impeded by the low physical opportunities and the conditions in the food systems.

Table 1
Fit statistics for segment membership.

Number of segments extracted	CAIC	BIC	AIC	Entropy R^2
1	32627.38	32594.38	32449.12	1.00
2	31124.19	31031.19	30621.81	0.89
3	30777.71	30624.71	29951.22	0.90
4	**30741.06** [a]	30528.06	29590.45	0.90
5	30774.58	30501.58	29299.86	0.91
6	30803.47	30470.47	29004.63	0.92
7	30819.57	**30426.57** [a]	28696.62	0.92
8	30950.75	30497.75	28503.68	0.93
9	31068.28	30555.28	28297.10	0.93
10	31273.46	30700.46	**28178.16** [a]	0.95

Where: [a] is the lowest value of the information criterion.

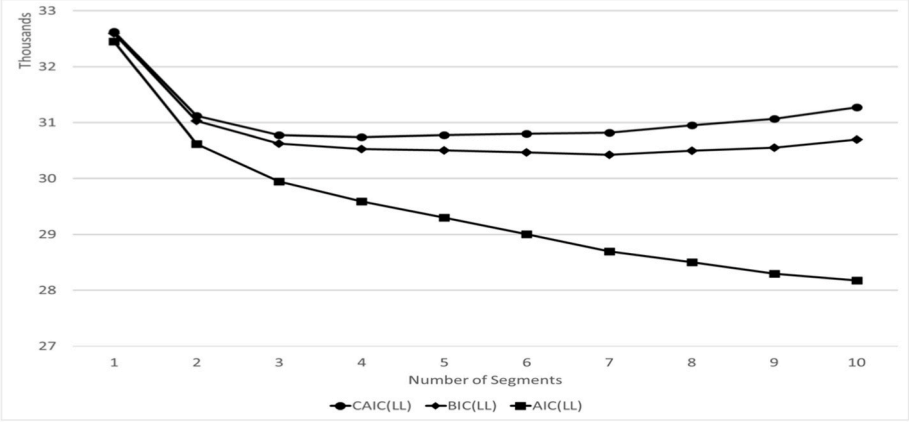

Fig. 2. Graphical depiction of the Information Criteria.

Table 2
Wald tests for the four-segment model.

Core variables	Four-segment model A		Four-segment model B	
	Wald	p-value	Wald	p-value
Stated Intention	244.67	≪0.001	183.72	≪0.001
Physical Capability				
Experience in CSA	36.57	≪0.001	36.99	≪0.001
Psychological Capability				
Perceived behavioural control	275.58	≪0.001	190.13	≪0.001
Motivation				
Economic farming motives	128.08	≪0.001	118.89	≪0.001
Non-economic farming motives	121.76	≪0.001	115.05	≪0.001
Self-responsibility	160.56	≪0.001	150.35	≪0.001
Perceived ease of use	550.96	≪0.001	546.14	≪0.001
Perceived usefulness	378.13	≪0.001	381.51	≪0.001
Perceived compatibility	393.90	≪0.001	389.69	≪0.001
Social Opportunity				
Descriptive norm	176.15	≪0.001	188.85	≪0.001
Injunctive norm	272.78	≪0.001	264.94	≪0.001
Extension and advisory services	57.57	≪0.001	66.07	≪0.001
Perceived unfairness in the value chain	19.82	<0.001	18.50	<0.001
Physical Opportunity				
Access to market	96.18	≪0.001	85.56	≪0.001
Access to credit	119.13	≪0.001	112.80	≪0.001
Market willingness to pay	138.47	≪0.001	145.46	≪0.001
Policy framework	117.02	≪0.001	108.87	≪0.001
Background variables				
Financial situation	34.34	≪0.001	29.02	≪0.001
Country of residence	69.19	≪0.001	117.62	≪0.001
Information source_mass media	26.50	≪0.001	34.12	≪0.001
Information source_ farm-related	8.88	0.03	18.35	<0.001
Education	12.15	0.06	18.01	<0.001
Farm size	15.85	0.09		
Cooperative	6.63	0.09		
Production type	12.22	0.20		
Farming experience	10.91	0.28		
Year of birth	4.04	0.67		
Income	2.78	0.84		
Information source_social media	4.72	0.19		
Information source_family & friends	0.83	0.84		

3.3.4.3. Segment 3: indifferents (34 %). Indifferents are the biggest farmer segment with a size of 34 %. Although stated intention to adopt CSA is above the mid-point (but still the second lowest), these farmers indicate the lowest motivation along with traditionalists. They demonstrate the lowest agreement with statements about the usefulness, ease of use and compatibility of the practices/technologies. Notably, they have the lowest scores in both economic and non-economic motives and the second lowest levels of agreement with statements that they are responsible about the environmental and socioeconomic impacts of their farming activities. While they share similar physical capability to the constrained group, they have lower psychological capability. In the social and physical opportunities, they face similar circumstances to the constrained group. They tend to agree that adopting CSA is socially acceptable, however, they view the conditions in the food systems quite negatively. In this segment, all institutional factors, including market willingness to pay, access to market, access to credit, policies and regulations score low indicating low cooperation in the supply chain and unfavourable conditions. Overall, this segment appears disengaged with both low motivation and psychological capability along with unfavourable opportunities in the social, institutional and regulatory framework.

3.3.4.4. Segment 4: traditionalists (13 %). The traditionalists are a minority (13 %) and they have the lowest intention to adopt CSA serving as the group with the highest deficits in capabilities, motivation and opportunities. This is mainly explained by the fact that they have low behavioural control and perceive the food system as unfavourable for a transition to CSA. More specifically, although they appear to have somewhat positive attitudes about the usefulness, ease of use and compatibility of the practices, they indicate the lowest scores of all segments in the behavioural control variable. With respect to experience with CSA only 26 % of farmers have experience. They demonstrate the lowest scores in non-economic motives and sense of self-responsibility about the impacts of the farming activities. In this farmer segment, CSA adoption seems socially marginalised since they have the lowest probability to agree with statements that CSA is what people in their surroundings do or approve. They show the lowest scores in extension and advisory services along with physical opportunities including access to market, access to credit, market willingness to pay and policy framework. This farmer type resembles the "unengaged" (Barnes et al., 2022), committed conventional (Darnhofer et al., 2005) and traditionalists (Daloğlu et al., 2014; Daxini et al., 2019) in previous literature.

3.3.5. Background variables

We then proceeded with further profiling of the farmer segments identified based on the background variables. As appeared in Table 2, the variables financial situation, country of residence, education and information sources – mass media and farm-related information sources – have a significant discriminating power over farmer segment membership and thus, are used for further profiling.

Table 4 presents the percentual distribution of the active covariates over the segments. When comparing these percentages with the segment sizes, one can check if specific background characteristics are over-represented in one of the segments. This may further help to identify the farmer segments.

With respect to financial situation, results indicate that

Table 3
Mean scores of the core variables per segment.

Farmer types	Environmentalists	Constrained	Indifferents	Traditionalists
Segment Size	21 %(0.02)	32 %(0.02)	34 %(0.02)	13 %(0.01)
Stated intention	6.12(0.1)^{c}	5.11(0.09)^{b}	4.95(0.07)^{b}	3.41(0.19)^{a}
Physical Capability				
Experience in CSA	75 %(0.04)^{c}	44 %(0.04)^{b}	46 %(0.04)^{b}	26 %(0.05)^{a}
Psychological Capability				
Perceived behavioural control	5.84(0.1)^{d}	4.8(0.08)^{c}	4.55(0.07)^{b}	3.36(0.18)^{a}
Motivation				
Economic farming motives	5.93(0.07)^{b}	5.95(0.05)^{b}	5.22(0.06)^{a}	5.38(0.14)^{a}
Non-economic farming motives	6.2(0.06)^{b}	6.13(0.05)^{b}	5.47(0.06)^{a}	5.49(0.14)^{a}
Self-responsibility	6.17(0.06)^{b}	6.09(0.05)^{b}	5.29(0.07)^{a}	5.18(0.14)^{a}
Perceived ease of use	5.97(0.09)^{b}	6.3(0.05)^{b}	4.32(0.08)^{a}	4.65(0.23)^{a}
Perceived usefulness	5.96(0.11)^{c}	6.37(0.05)^{d}	4.35(0.09)^{a}	4.91(0.24)^{b}
Perceived compatibility	6.3(0.07)^{b}	6.32(0.05)^{b}	4.75(0.08)^{a}	5(0.21)^{a}
Social Opportunity				
Descriptive norm	4.88(0.13)^{c}	3.64(0.11)^{b}	3.78(0.09)^{b}	2.26(0.14)^{a}
Injunctive norm	5.58(0.09)^{c}	4.59(0.08)^{b}	4.41(0.07)^{b}	2.72(0.16)^{a}
Extension and advisory services	5.21(0.09)^{c}	4.46(0.1)^{b}	4.57(0.09)^{b}	3.76(0.18)^{a}
Perceived unfairness in the value chain	5.59(0.11)^{b}	4.97(0.1)^{a}	5.35(0.08)^{a,b}	5(0.21)^{a}
Physical Opportunity				
Access to market	4.33(0.12)^{c}	3.44(0.1)^{b}	3.5(0.08)^{b}	2.53(0.15)^{a}
Access to credit	4.3(0.15)^{c}	3.57(0.11)^{b}	3.35(0.09)^{b}	2.11(0.16)^{a}
Market willingness to pay	3.6(0.16)^{c}	2.82(0.11)^{b}	2.95(0.09)^{b}	1.63(0.11)^{a}
Policy framework	4.38(0.18)^{c}	3.24(0.13)^{b}	3.54(0.09)^{b}	2.07(0.15)^{a}

Note: The alphabetical order of the superscripts represents the ascending order of the significantly different means following Wald test (all p values < 0.05).

Table 4
Distribution of concomitant background variables over the segments (in percentages).

Segment size	Environmentalists	Constrained	Indifferents	Traditionalists	Total
	21 %	32 %	34 %	13 %	100 %
Financial situation					
1–2.5	7 %	46 %	19 %	28 %	100 %
3–3.5	16 %	40 %	34 %	11 %	100 %
4–4.5	11 %	28 %	49 %	11 %	100 %
5–5	26 %	31 %	34 %	10 %	100 %
5.5–7	42 %	18 %	34 %	6 %	100 %
Country of residence					
DK	37 %	7 %	56 %	0 %	100 %
NL	10 %	3 %	82 %	6 %	100 %
LT	16 %	60 %	9 %	15 %	100 %
ES	25 %	21 %	35 %	20 %	100 %
SI	19 %	12 %	40 %	29 %	100 %
Information source_mass media					
1–3	7 %	22 %	43 %	28 %	100 %
4–4	8 %	26 %	57 %	9 %	100 %
5–5	23 %	32 %	33 %	12 %	100 %
6–7	33 %	42 %	18 %	7 %	100 %
Information source_farm-related					
1–4.2	5 %	42 %	26 %	27 %	100 %
4.4–4.8	14 %	36 %	38 %	12 %	100 %
5–5.2	19 %	34 %	36 %	10 %	100 %
5.4–5.8	30 %	26 %	35 %	8 %	100 %
6–7	35 %	23 %	35 %	8 %	100 %
Education					
secondary school or lower	13 %	32 %	37 %	18 %	100 %
degree in agriculture	16 %	29 %	42 %	14 %	100 %
bachelor or higher	26 %	34 %	28 %	12 %	100 %

traditionalists and constrained farmer segments have a more unfavourable financial situation while environmentalists and indifferents have more financial resources. Environmentalists mainly come from Denmark and Spain while traditionalists from Spain and Slovenia. Indifferents come from Denmark, Netherlands and Slovenia while constrained from Lithuania. Educational levels for environmentalists are higher and the same holds for constrained farmers. Traditionalists have lower educational levels while indifferents tend to have vocational training. With regards to information sources, environmentalists tend to be well informed using both mass media and farm-related sources. This is in contrast with traditionalists who do not use information sources to get informed about CSA. Indifferents tend to not use mass media but rely more frequently on farm-related sources while for the constrained segment mass media are mainly used as opposed to farm-related sources.

4. Discussion

4.1. Applicability of the COM-B model for deriving a farmer typology

The aim of this study was to develop a European farmer typology to

enhance the adoption of CSA by combining two research streams: behavioural change through the lens of the COM-B model along with segmentation research. By collecting data from farmers from five European countries, our typology reveals that there are four farmer types when it comes to adoption of CSA, categorised based on capability, motivation and opportunity along with farmer characteristics. While our farmer typology presents some commonalities with previous studies (Bartkowski et al., 2022; Daxini et al., 2019), it is unique in that it is the first study to adopt a systematic approach in the characterisation of the farmer groups, considering the complexity of farmer decision making that happens on different personal, social, institutional and policy levels and linking these behavioural causes with targeted behavioural and policy interventions for CSA adoption.

Integrating the COM-B model into the segmentation analysis has proven informative and suitable to identify facilitating and impeding factors in the decision to adopt CSA in each of the four farmer types ensuring a holistic understanding of underlying behavioural causes. Characteristics associated with farmers' capability, opportunity, and motivation all significantly predicted our farmers' typology. A closer look at the farmer types reveals that components of the COM-B model differentiate the environmentalists from the other three farmer types. This segment appears to be the pioneers in the transition to CSA as they feel enabled both internally, by capabilities and motivation, and externally by the opportunities in the social and food systems environments. The constrained and indifferents farmer types, despite sharing commonalities, they mainly differ in their psychological capabilities and motivation with the former type facing fewer deficits as compared to the latter. Finally, the traditionalists differ from the other groups in all components of the COM-B model. These farmers face the strongest barriers in capability, opportunity and motivation factors and the transition to CSA appears less likely compared to the other farmer types. Based on the COM-B model, we have investigated farmer types using decision making factors that go beyond current knowledge which has mainly focused on the intra- and interpersonal aspects associated with the physical and psychological capability, and motivation of the COM-B model (Cullen et al., 2020; Dessart et al., 2019; Kropf et al., 2020), such as in the TPB and TAM. Our study addresses this gap by investigating the contexts in which farmers operate (e.g. social, institutional, legal) and showing that social and physical opportunity factors provide a useful way to categorise farmer behaviours in CSA adoption. Except for environmentalists, constrained, indifferents and traditionalists face many barriers in the food systems in their transition to CSA. Market unwillingness to pay for CSA products, unfairness in the value chain, low access to markets for agricultural products, low access to credit along with unfavourable and bureaucratic policy framework are key challenges that need to be resolved to foster behavioural shifts to CSA. This is consistent with recent reports where farmers report difficulties with market and policy instruments (Linares Quero et al., 2022). Our study not only advances our understanding of the farmer adoption behaviour but also enables the design of behavioural interventions and policies tailored to the characteristics of each farmer type and targeted to specific causes of behaviour, as will be elaborated further in section 4.

4.2. Capability

Capability is manifested in farmers' experience with CSA (physical capability) and farmers' sense of behavioural control (psychological capability). As in previous studies, environmental farmer profiles usually consist of educated individuals with a high level of experience with CSA who tend to stay well informed about agriculture through the use of various information sources (Barnes et al., 2019; Daxini et al., 2019). This gives them confidence that they have the ability and resources to adopt sustainable practices. The constrained and indifferent farmers have significantly lower experience but quite high sense of behavioural control rendering them prone to adopt CSA, if other barriers in social and physical opportunities are overcome. In the traditionalists group, farmers tend to feel constrained by lack of technical and management skills and lack of financial resources to implement CSA. Our findings are in line with previous research showing that lower experience and behavioural control are linked with lower intentions to adopt CSA (Michels et al., 2020; Tey and Brindal, 2012).

4.3. Motivation

With respect to motivation factors, previous literature has consistently highlighted the importance of farming motives and self-responsibility in the transition to CSA (Kociszewski et al., 2020; Pinna, 2017). A surprising finding of our study is that farmers across all types are driven simultaneously by economic and non-economic motives along with a high sense of self-responsibility. The environmentalists and constrained groups demonstrate significantly higher scores as compared to indifferents and traditionalists. However, the co-existence of economic and non-economic motives contradicts typical outcomes of previous literature that tend to categorise farmers based on varying farming goals. For instance, in Upadhaya et al.'s (2021) typology, conservationists are driven by ecological and not financial motives as opposed to productivists who have economic rather than ecological farming goals. Despite this, our finding is not entirely new and echoes Cullen et al.'s (2020) study where both environmentalist and productivist farmer types were affected by the economic benefits in their decision to participate in agri-environmental schemes. It can be inferred that an ecological outlook can be developed even when economic motives are salient (Barnes et al., 2022). Amidst the sustainability crises, farmers begin to understand that environmentally friendly production is the only viable solution and may gradually shift to more ecological behaviours.

Farmers tend to evaluate the extent to which practices will enhance farm productivity, simplify farm operations, are user-friendly and compatible with current farming operations and goals, as extensively investigated in the TAM model (Davis et al., 1989; Kernecker et al., 2020). Our findings here suggest that all farmer groups appreciate the benefits of CSA implementation (all scores above mid-point) with the environmentalists and constrained groups being more appreciative of the practices compared to the other two groups. This result may indicate that farming communities are aware of the economic, environmental and social benefits of the CSA practices and that they are quite mature with respect to user friendliness to meet the needs of their targeted farmers.

4.4. Opportunity

The opportunity component in our study involves both social opportunities and physical opportunities. The social influence emerges quite strongly within the literature, identifying wider social networks and neighbourhood effects affecting CSA adoption (Cullen et al., 2020). Our findings reveal that the majority of the farmer types (except for traditionalists) feel that the transition to CSA is socially desirable (injunctive norm) while at the same time only the environmentalists believe that CSA is widely adopted in their farming communities (descriptive norm). This is in line with reports that awareness raising campaigns and changing social norms develop more ecological identities while adoption rates remain below desired levels (Barnes et al., 2022). Additionally, extension and advisory services are well received by almost all types as they are considered key knowledge transfer and support CAP mechanisms (Linares Quero et al., 2022). Fairness in the value chain is a relatively new concept and unexplored in the literature. Our study is the first to examine this factor demonstrating that all farmer types feel that they contribute more to a sustainable future compared to other value chain actors like industry, policy and consumers. It is implied that farmers experience unfair value chains as they perceive that power imbalances and information asymmetries result in unequal value distributions (Barling et al., 2022).

While previous farmer typology studies have partially investigated

decision making factors associated with capability, motivation and social opportunity, the physical opportunity component has been neglected (Braito et al., 2020; Darnhofer et al., 2005; Daxini et al., 2019). Our study is the first to show that the physical opportunity component serves as a useful way to categorise farmer behaviours in adoption of CSA. While environmentalists hold a positive outlook about the food systems and appear empowered by good relationships with the supply chain, good access to markets, access to loans/credit, and the policy framework, the rest of the farmer types face strong barriers in the food systems impeding their transition to CSA. This is in line with findings reporting key barriers such as limited availability of financial instruments, financial support (e.g., subsidies, tax reductions), where compensation does not cover investment costs, as well as complex and bureaucratic procedures associated with policy instruments (Gemtou et al., 2024b; Linares Quero et al., 2022). What seems to be the biggest barrier to adoption is the market unwillingness to pay for CSA products. Market demand creates feedback loops from buyers to farmers about the practices they should use and hence, low market demand signals that consumers do not see the added value of CSA products (Kociszewski et al., 2020). Therefore, trust and building long term relationships between farmers and buyers are key determinants for the transition to CSA (Barnes et al., 2022).

5. Implications for strategy, communication and policy

The key strength of the COM-B model is that it provides a systematic way of linking interventions and policies with the barriers and drivers. In particular, the model suggests nine intervention functions and seven policy categories (Michie et al., 2011, 2016). The starting point is the target behaviour that needs to be changed, depending on the key barriers in capability, opportunity and motivation each of the four farmer types faces, and with this in mind tailored mechanisms of action are proposed leading to more effective strategies in fostering behavioural shifts to CSA. Suggested interventions for the four farmer types are seen in Fig. 3.

5.1. Policies

The first category of interventions corresponds to the motivation, social and physical opportunity. Our findings suggest that all four farmer types are driven by both economic and non-economic motives simultaneously. Policies that are considered a win-win (i.e. simultaneously promote economic gains and environmental benefits) may be equally attractive to all types stressing the environmental benefits (e.g., reduction of GHG emissions, water and soil conservation) along with financial benefits associated with investing in CSA. The new CAP promotes a mix of mandatory and voluntary schemes (e.g., eco-schemes) to foster sustainability in the agricultural sector (Dessart et al., 2019). Our results suggest that voluntary schemes may be more effective for the environmentalists and constrained while mandatory schemes for the indifferents and traditionalists due to their differences in the farming goals and sense of self-responsibility for the transition to sustainable agriculture.

Except for environmentalists, the other three farmer types view the policy and institutional framework as unfavourable. Based on the results, it is expected that monetary instruments (e.g., direct payments, subsidies) will be more effective for traditionalists and constrained types since they lack financial resources and income compared to the other types. Moreover, more flexible policy instruments (e.g., adjustment of policy instruments in local contexts and needs) both in implementation and monitoring will be more beneficial for traditionalists who face big hurdles arising from increased costs, lack of market access and complex procedures and are expected to increase their uptake of CSA (Brown et al., 2021).

Policy instruments that increase fairness in the value chain may influence environmentalists and indifferents more than constrained and traditionalists. Interventions that promote fair trade, fair contractual agreements, certifications, transparency in the value chain and fair prices for farmers may be more effective in increasing the uptake of CSA from the former types which hold the highest perceptions of unfairness (Hendrickson and James Jr, 2016). Conversely, interventions that facilitate access to market such as direct marketing, public procurement and community seeds exchange will be more attractive for constrained, indifferents, and traditionalists as opposed to environmentalists.

5.2. Social norms, social signalling and opinion leaders

The second category targets the social opportunity aspect of the COM-B model. An insight from our findings is that social norms play a key role in the adoption of CSA especially for environmentalists and somewhat for the constrained and indifferents. Although environmentalists, constrained and indifferent types perceived that adopting CSA is socially desirable, the latter two types do not believe that this is what their farming communities actually do. In recent years, the effectiveness of green nudges in creating subtle changes in farmers behaviour has been acknowledged (Bonan et al., 2020). Accordingly, a nudge which communicates to farmers that the norm in their farming community is the implementation of CSA practices will likely increase adoption. Another option here, is to persuade important social referents in a farming community to adopt CSA. Opinion leaders have been shown to have increased influence on others and are trustworthy information sources (Dessart et al., 2019). According to our results,

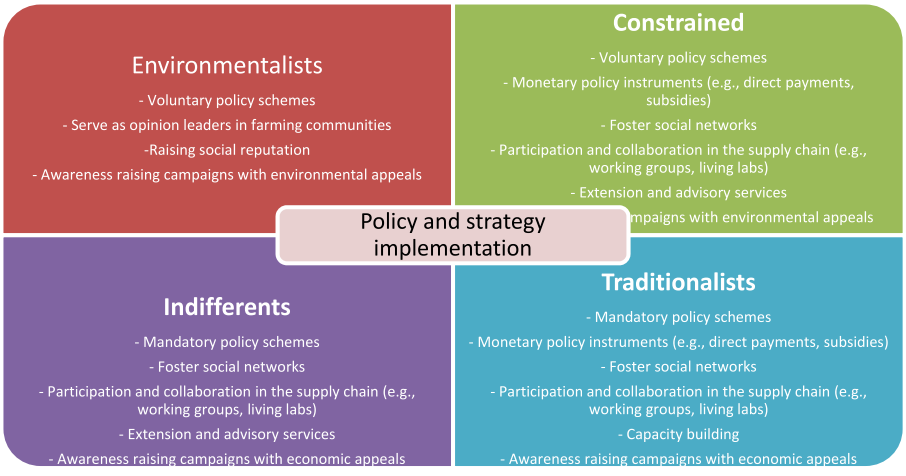

Fig. 3. Strategy and policy recommendations per farmer type.

environmentalists could serve as opinion leaders since they are the early adopters, both environmentally-conscious and business-oriented, they lead profitable businesses and they seem to have a strong position in the value chain. Recruiting these opinion leaders in local farming communities will likely influence the rest of the farming communities and foster the transition to CSA. Finally, social signalling plays a key role and hence farmers should be rewarded and acknowledged for their contribution to sustainable agriculture, e.g. with certification programmes or advertisements that publicly praise them.

5.3. Collaboration in the value chain

The third category of interventions corresponds to the social and physical opportunity. Findings of this study is that for the majority of farmer types, except for environmentalists, the supply chain acts as a barrier to adoption of CSA. Although these farmer types are prone to consider CSA practices, they find lack of access to market, access to credit, low market willingness to pay and unfair distribution of value as limiting factors. Participatory approaches to decision making and collaboration in the supply chain should be enabled for a fair transition to CSA (Gemtou et al., 2024b; Isakhanyan et al., 2024). Thus, establishing working groups, platforms that allow close communication of stakeholders or participation in policy design and advocacy can facilitate mutual understanding of various perspectives, increase transparency and power balance in the value chain as well as inclusion of more vulnerable farmers groups. Recently, the concept of living labs has emerged which act as open innovation platforms bringing together stakeholders across the value chain to co-create innovative and sustainable solutions to agriculture (Barnes et al., 2022). These strategies increase the sense of fairness and create strong community support fostering CSA adoption.

5.4. Communication and capacity building

The final category can influence deficits in both capability and motivation. Awareness raising campaigns are crucial to inform not only farmer decision making but also increase awareness and participation of all value chain stakeholders. Our farmer types appear to use different means to get informed. Environmentalists use both mass media and farm-related sources, constrained farmers use mass media, indifferents farm-related sources while traditionalists none of them. These sources of information should be leveraged depending on the farmer type of the intervention to effectively reach the respective farmers. Moreover, framing of messages in communication such that the more environmentally-conscious types receive an appeal in terms of binding moral values (e.g., duty, social norms) and the more economic-oriented types receive an appeal in economic terms (e.g., cost efficiency) will differentially impact our farmer types. Addressing the wider public by offering the opportunity for farm visits to the general public or farmers visiting schools to talk about their CSA practices will boost public awareness and will likely affect post-farm gate stakeholder involvement in the transition to sustainable agriculture (e.g., increased willingness to pay for sustainable products).

Extension and advisory services are a promising means to promote CSA among the types of environmentalists, constrained and indifferent farmers. Services such as advisors, trainings, farm visits, field demonstrations, provide exposure to information that reduces uncertainty with respect to the use of innovative CSA practices and technologies as well as equip farmers with the necessary knowledge, skills and capacity to overcome barriers for adoption (Gemtou et al., 2024b). Strengthening the role of advisors, both public and private, to become the main point of contact as well as tailoring the advisory services to farmer needs will likely increase adoption among these types. On farm demonstrations and peer-to-peer learning will be important instruments to support those farmers in the transition to CSA, providing first-hand experience about the benefits of introducing CSA practices in farming communities. Capacity building is especially important for traditionalists who lack the education and behavioural control to adopt CSA. However, making extension and advisory services attractive to traditionalists may be challenging since this type appears to value or use less the services. This type is hard to approach since they do not consult any information sources like mass media or farm-related sources but rather rely on passed-on knowledge of farming. Hence, more concerted effort is needed to attract and train this type of farmers.

6. Limitations and future work

Our study comes with a number of limitations which should be addressed in future studies. The application of the COM-B model, although valuable, proved resource intensive and difficult in practice. The model's comprehensiveness required the design of a long survey instrument leading to a high number of incomplete responses possibly due to participants' fatigue. Additionally, the automatic motivation element was under-represented. The framework was examined through a quantitative methodology which is subject to social desirability bias and currently there is a lack of pre-tested, validated survey instruments to examine the different facets of the model. Therefore, qualitative methods may be needed to derive farmer typologies using the COM-B model or a considerable effort to design a standard survey instrument associated with the COM-B model should be made. The farmer population appears to be highly environmentally-conscious and be motivated both by economic and non-economic motives. Other studies have also found shades of green in farmers perspectives and behaviours (Barnes et al., 2022). However, a more representative to the European farmer population sample is needed to replicate our results and farmer typology. Finally, our study provides a static snapshot of the European farmer. However, farmer types are rather fluid and change over time (Bartkowski et al., 2022). Hence, longitudinal studies are required to capture the size of farmer types and type of change in time.

7. Conclusions

The agricultural sector is now undergoing a heightened state of global emergency to reverse climate change impacts and environmental degradation. Despite significant expense of agricultural support programs in the EU, efforts to encourage farmers in the transition to CSA have only been partially successful. Our study suggests that the European population is far from homogenous and farmers are likely to respond differently to communication, outreach and policy strategies. Nevertheless, previous attempts to produce recurring farmer types have been rather unsuccessful in using a holistic and systematic approach. Our study addresses this gap by providing a more universal European farmer typology based on a wide set of both personal and contextual factors and administered in 5 EU countries, thus accounting for the variety of biophysical, environmental and institutional conditions in the EU. To the best of our knowledge, this is the first time the COM-model has been applied to farmer typology studies. Our typology reveals that there are four farmer types when it comes to adoption of CSA, categorised based on capability, motivation and opportunity factors along with farmer characteristics, namely environmentalists, constrained, indifferent and traditionalists. The research has demonstrated that the COM-B model is useful for the holistic identification of barriers and drivers facing the four farmer types in their transition to CSA. These unique behavioural causes can be used to match them with targeted behaviour change interventions that are likely to be effective for each farmer type. In conclusion, although there is certainly a trade-off between specificity and complexity of implementing group-specific instruments, only by accounting for behavioural patterns and characteristics of the farmer population will the interventions foster CSA adoption.

Declaration of generative AI in scientific writing

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CRediT authorship contribution statement

Marilena Gemtou: Conceptualization, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. **Marcel Kornelis:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Gohar Isakhanyan:** Methodology, Supervision, Writing – review & editing. **Søren Marcus Pedersen:** Conceptualization, Methodology, Writing – review & editing. **Spyros Fountas:** Funding acquisition, Project administration, Writing – review & editing. **Liselotte Puggaard:** Data curation, Methodology, Writing – review & editing. **Jon Bienzobas Adrian:** Data curation, Methodology, Writing – review & editing. **Alexia Izco Zabalza:** Data curation, Methodology, Writing – review & editing.

Appendix

Introduction of the survey

This questionnaire concerns new practices or technologies that farmers can use to.

- increase farm productivity in such a way that it is also better for the environment and animal welfare.
- increase farm income in such a way that it is also better for environment and animal welfare.
- increase resilience of crops, animals and the food system to a climate change.
- reduce greenhouse gas emissions that harm the climate.

These practices and technologies are also called climate-smart agriculture practices and technologies.

Some examples of these practices are: organic farming, integrated pest management, crop diversification, variable rate application of fertilizers, precision irrigation, intercropping, manure management to reduce greenhouse gas emissions, carbon soil farming and reduced tillage.

Some examples of these technologies are: Robotic systems, drones, satellite images analysis, Smart farming sensors, Big data, Internet of Things (IoT), smart sprayers (for irrigation).

Have you heard of the term climate-smart agriculture practice or technology? [Yes, I have/No, I have not]

Have you used a climate-smart agriculture practice or technology in the last five years? [Yes, I have/No, I have not/I don't know]

Variables used in the survey

Variables	Items	Sources	Cronbach's alpha
Stated intention	I plan to adopt a climate-smart practice/technology in the coming year I intend to use a climate-smart practice/technology over the next five years I will regularly try to apply a climate-smart practice/technology in the near future	Despotović et al. (2019)	0.91
Economic farming motive	It is important to me that running my farm business: [has low production costs, produces the highest quality products, has a low labour need, results in high yields, results in a high income, is good for the employment in my rural area]	Kallas et al. (2010)	0.78
Non-economic farming motive	It is important to me that running my farm business: [produces in an environmentally friendly way, produces with care for animal welfare, produces fairly priced products, produces with care for public health, maintains the tradition of my family]	Kallas et al. (2010)	0.81
Self-responsibility	As a farmer it is my responsibility to contribute to: [better environment, better animal welfare, better public health, more jobs for people in my local area, fair priced products]	Pradhananga and Davenport (2019)	0.83
Behavioural control	I have the ability to implement a climate-smart agriculture practice/technology; If it were entirely up to me, I am confident that I will adopt a climate-smart agriculture practice/technology; I have resources, time and willingness to apply a climate-smart agriculture practice/technology on my farming activities	Dilotsotlhe and Duh (2021)	0.79
Technologies perceived usefulness	If I am going to adopt the climate-smart agriculture practice/technology, I think that it will: [lower production costs, increase productivity, reduce workload; be useful for farm operations]	Adrian et al. (2005)	0.91
Perceived ease of use	If I am going to adopt the climate-smart agriculture practice/technology, I think that it will: [be easy to learn; be easy to control; be easy to understand how it is used]	(Adrian et al., 2005; Caffaro et al., 2020)	0.92
Perceived compatibility	If I am going to adopt the climate-smart agriculture practice/technology, I think that it will: [suit in the way I like to work, be consistent with the goals I find relevant]	Sharifzadeh et al. (2017)	0.81
Descriptive norm	1. Farmers similar to me mostly use a climate-smart agriculture practice/technology 2. Many farmers in my surroundings apply a climate-smart agriculture practice/technology	Despotović et al. (2019)	0.88
Injunctive norm	1. People, who are important to me, would approve the use of a climate-smart practice/technology 2. People, whose opinion I value, think that I should apply a climate-smart agriculture practice/technology	Despotović et al. (2019)	0.78
Perceived fairness	Farmers do more for a better environment, animal welfare, public health, and fair trade, than the following groups [supermarkets, food industry (such as dairy companies, fruit and vegetable processors, and meat industries), consumers, governments]	Kumar et al. (1995)	0.89
Market prices/ willingness to pay	1. It is easy to find business buyers (for instance, wholesalers, retailers) who are willing to pay fair prices for climate-smart agricultural production; 2. Consumers are willing to pay fair prices for climate-smart agricultural production		0.77

(*continued on next page*)

(*continued*)

Variables	Items	Sources	Cronbach's alpha
Extension and advisory services	To what extent did you make use of the following sources for your agricultural training or advice in the last five years? [farmer trainings, farm visits, field demonstrations, field/farmers days, workshops/ open discussions, advisory services, other]	Mariano et al. (2012)	0.88
Access to market	It is easy for me to: [access the input markets for my agricultural production, sell my products on the internet, reach a physical marketplace to sell my products]		0.70
Access to credit	Getting access to a loan to support my financial needs is easy; The bureaucracy surrounding receiving a loan is transparent		0.79
Policies and regulations	1. Governmental financial support (schemes, tax reduction, subsidies) to climate-smart agriculture is adequate; 2. Existing policies and regulations to support adoption of climate-smart agriculture are adequate		0.79
Information use	Suppose that you have a question about farming business. To what extent are you going to use the following sources of information? [agricultural advisor, trade events and fares on agriculture, training courses, farmer associations, other farmers, other source]	Caffaro et al. (2020)	0.81
Financial situation	1.My financial resources are sufficient; 2. I can get by with the income of my household]		0.82
Country of residence	Where do you currently live? [Denmark, Spain, Netherlands, Lithuania, Slovenia]		
Education	Was is your highest education level? [secondary school or lower, degree in agriculture, bachelor or higher]		

Data availability

Data will be made available on request.

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