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Gender Equality and Green Entrepreneurship in Farms

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ABSTRACT

Gender dynamics in agricultural sustainability, particularly within the framework of Agri-Environmental-Climate-Schemes (AECS), play a critical role in advancing green entrepreneurship. This study explores gender-based differences in the adoption and intensity of AECS practices among Hungarian farms, emphasising the implications for gender equality in sustainable agricultural development. Utilising the Hungarian Farm Accountancy Data Network panel data from 2014 to 2021, we apply Blinder-Oaxaca and Recentered Influence Function decomposition models to dissect disparities in AECS engagement between male- and female-headed farms. Findings indicate that, while male-headed farms receive greater AECS subsidies due to larger economic scales and resource availability, female-headed farms demonstrate comparable levels of AECS intensity when controlled for these factors. These insights highlight the potential for gender-sensitive policies within the European Union's Common Agricultural Policy framework to empower female farmers in green entrepreneurship and sustainable practices. The study's findings contribute to a broader understanding of gender's influence on green entrepreneurship and sustainable development in agriculture, with significant implications for policy frameworks that support inclusive and climate-resilient agricultural practices globally.

1 | Introduction

In the face of escalating global concerns over climate change and the sustainability of agricultural practices, green entrepreneurship in farming has emerged as a crucial mechanism for promoting climate-resilient agriculture and advancing circular economy principles and practices (FAO 2021, 2023; Castillo-Díaz et al. 2023; Islam and Zheng 2024). This form of entrepreneurship involves adopting low-carbon and environmentally sustainable practices, which play a significant role in mitigating the impacts of climate change on agriculture (Stuart, Schewe, and McDermott 2014; Barnes et al. 2019; Peng, Fu, and Zou 2024). The adoption of green farming practices and sustainable behaviours varies across countries and over time due to country-specific conditions and policies (Dessart, Barreiro-Hurlé, and van Bavel 2019; Palm-Forster et al. 2019; Chwialkowska et al. 2024; Sander et al. 2024; O'Donoghue et al. 2024).

However, a critical knowledge gap exists in the literature regarding the role of gender in influencing the adoption and intensity of such practices, particularly within agri-environment-climate scheme (AECS) measures under the European Union's (EU's) Common Agricultural Policy (CAP) framework (Emeka, Asongu, and Ngoungou 2024).

Understanding the interplay between gender dynamics and environmental sustainability within the CAP framework is essential for developing policies that promote both gender equality and environmental sustainability in agricultural development (Pyburn, Slavchevska, and Kruijssen 2023; Shortall and Marangudakis 2024).

The gender dimension of sustainable agricultural practices and investigating gender-based differences in the adoption of green entrepreneurial farming practices represents an interdisciplinary field that bridges sustainability science and human behaviour research (Hechavarria et al. 2012; Lioutas and Charatsari 2018; Soergel et al. 2021; Lakhal et al. 2024). Gender differences significantly impact agricultural innovation and performance (McGuire et al. 2022; Hidrobo et al. 2024). Studies indicate that female farmers may adopt agricultural technologies and sustainable practices at different rates compared to male farmers, often due to distinct behavioural, social, and economic factors (Doss and Morris 2001; Ndiritu, Kassie, and Shiferaw 2014; García-Sánchez, Gallego-Álvarez, and Zafra-Gómez 2021; García-Sánchez and Enciso-Alfaro 2024). These disparities and barriers are frequently attributed to unequal access to resources such as limited access to land, credit, education, and extension services, which are typically skewed in favour of men and can hinder women's engagement with sustainable farming practices (Gülsoy and Ustabaş 2019; Adebayo and Worth 2024). Women farmers often face additional constraints, including traditional gender roles, time poverty due to household responsibilities, and limited decision-making power within households or farms (del Mar Fuentes-Fuentes et al. 2023; Humayra, Uddin, and Pushpo 2024).

The mechanisms through which gender influences agricultural innovation are complex (Moreno-Ureba, Bravo-Urquiza, and Reguera-Alvarado 2022; García-Sánchez and Enciso-Alfaro 2024). Social and cultural norms often restrict women's access to technology and information by prioritising male access to agricultural innovation and extension services (Nhamo and Mukonza 2020; Doneys et al. 2022). Additionally, women may exhibit different risk preferences, influencing their willingness to adopt new technologies or engage in green entrepreneurship (Amorelli and García-Sánchez 2023). While some studies suggest that women tend to be more risk-averse, potentially limiting their participation in innovative practices (Akter et al. 2016), others indicate that women are more inclined to adopt sustainable resource management practices that enhance long-term environmental responsibilities and household food security (Njuki et al. 2022; Haque et al. 2024).

Gender can also affect the adoption of sustainable agricultural intensification practices due to differences in farm management styles and priorities (Bazel-Shoham et al. 2024). Women-led farms may focus more on diversification and sustainable resource use, while male-led farms might prioritise productivity and market-oriented outcomes (Gatto, Mozzato, and Defrancesco 2019; Puskur et al. 2023). These divergent approaches influence the types of agricultural and eco-innovations adopted, with women more likely to engage in practices that conserve resources and improve long-term sustainability, such as organic farming or the use of green technologies (Lioutas and Charatsari 2018; García-Sánchez and Enciso-Alfaro 2024).

Green practices in farming are often supported by policy instruments and payments for environmental and nature's services programs, implemented in both developed and developing countries (Wunder, Engel, and Pagiola 2008; Luo, Pan, and Zhang 2024). Policy responses to climate change in agriculture, including payments for environmental services, are delivered through agricultural and environmental measures (Batáry et al. 2015; Börner et al. 2017; Cullen et al. 2021; Wuepper et al. 2024). AECS measures, introduced within the EU's CAP, aim to promote environmentally friendly farming practices (Navarro and López-Bao 2018; Canessa et al. 2024).

Numerous studies have investigated the impacts of AECS on biodiversity (Feehan, Gillmor, and Culleton 2005; Gimona et al. 2023; Neyens, Petrof, and Evens 2023), farm performance (Arata and Sckokai 2016; Diop et al. 2024), employment (Unay-Gailhard and Bojnec 2019), and groundwater quality (Tzemi and Mennig 2022). However, there is limited evidence and a notable gap in the literature addressing the influence of gender on the adoption and intensity of AECS measures, especially within Central and Eastern European (CEE) countries (Unay-Gailhard and Bojnec 2021; Fertő and Bojnec 2024). The distinct socio-economic and historical conditions in this region, such as post-socialist agrarian restructuring, persistent gender inequalities, and rural depopulation, present unique challenges to female farmers' participation in green entrepreneurial activities (Shortall and Marangudakis 2022, 2024).

Hungary presents a unique and pertinent case for examining the interplay between gender-related dynamics and green entrepreneurship in agriculture, as its agricultural sector reflects both the opportunities of EU membership and the constraints of a transitioning economy situated in the CEE region, Hungary's agricultural sector has undergone significant transformations since transitioning to a market economy (Bojnec, Fertő, and Podruzsik 2022). These changes have led to shifts in land ownership patterns, farm management practices, and resource accessibility—all impacting gender dynamics in agriculture. The restructuring has often resulted in women facing additional barriers in accessing land and resources, affecting their participation in sustainable farming practices. Male-headed farms tend to dominate in economic scale and resource access, whereas female-headed farms often prioritise diversification and resource conservation (Bojnec, Fertő, and Podruzsik 2022; García-Sánchez and Enciso-Alfaro 2024).

Moreover, Hungary's commitment to aligning with EU environmental policies while maintaining agricultural competitiveness creates a dynamic environment for investigating gender roles in green farming innovation. Specific socio-economic conditions, such as rural depopulation and persistent gender disparities in land ownership (Gracia-de-Rentería, Ferrer-Pérez, and Drabik 2023), make Hungary an appropriate case for studying how gender influences the adoption of sustainable agricultural practices. Despite these characteristics, empirical research addressing gender-specific barriers and gender-driven participation and duration in AECS within Hungary is limited and scarce, leaving critical gaps in understanding.

This study aims to fill these gaps by analysing the differences in AECS adoption and intensity between male- and female-headed Hungarian farms using decomposition models. By focusing on structural and behavioural factors, the research provides insights into the interplay between gender equality and environmental sustainability under the CAP framework to provide context-specific insights crucial for developing targeted policies and interventions. Understanding these dynamics is vital for designing gender-sensitive policies that promote both gender equality and environmental sustainability, aligning with broader goals of inclusive agricultural development and climate resilience. By identifying the specific challenges and opportunities faced by female farmers in adopting AECS measures, policymakers can design targeted interventions to address these issues, enhancing the overall effectiveness of environmental policies.

Our research holds broader importance for science, policy, and societal practices concerning gender-based green entrepreneurship in farms. The findings offer valuable insights for policymakers within the EU's CAP, emphasizing the importance of gender-inclusive policies that address the specific challenges faced by women in farming. This study contributes to a deeper understanding of how gender shapes sustainable farming practices and the potential for green entrepreneurship.

We employ the Blinder–Oaxaca (B–O) decomposition panel model econometric approach (Blinder 1973; Oaxaca 1973) to disentangle the factors contributing to gender differences in AECS adoption and intensity. Additionally, we utilise the B–O Recentered Influence Function (RIF) decomposition models to test the robustness of our results.

The remainder of the article is organized as follows: Section 2 reviews the literature on gender equality, drivers of gender empowerment, and green entrepreneurship in farms. Section 3 describes the data and methodology used. Section 4 presents the empirical results. Section 5 discusses the findings. Finally, Section 6 concludes with policy implications and suggestions for future research.

2 | Literature Review and Hypotheses Development

2.1 | Related Literature

The intersection of gender equality and green entrepreneurship has gained increasing attention, particularly in the context of sustainable climate-smart agricultural development, women's empowerment in agriculture, innovations and food security literature (Shortall, Budge, and Adesugba 2020; Aziz et al. 2022; Pandey and Pandey 2023; Quisumbing et al. 2023; Perelli et al. 2024). Gender equality, defined as equal access to resources, opportunities, and decision-making power, has far-reaching implications for agricultural practices, especially in rural areas where women play a pivotal but often overlooked role (UN Women 2020; Bryan et al. 2023; UN Women and UN DESA 2023). Understanding how gender influences green entrepreneurship in agriculture is critical to fostering sustainable farming development and addressing environmental challenges, including climate change.

The first stream in literature focuses on gender equality and agricultural development (Shortall, Budge, and Adesugba 2020). Recent studies have increasingly recognised that gender equality and inclusion are not only a matter of social justice but also a driver of economic, corporate and environmental sustainability (Eastin 2018; FAO 2021, 2023; Sieweke, Bostandzic, and Smolinski 2023; Lakhal et al. 2024). Women in agriculture face unique challenges, such as limited access to land, credit, and agricultural technologies, which can affect their ability to engage in entrepreneurial activities (Nhamo and Mukonza 2020; Saluja, Singh, and Kumar 2023). Despite these barriers, women's contributions to agriculture are essential for household food security, community resilience, and environmental stewardship (UN Women 2022). Research has shown that empowering women in agriculture leads to increased productivity and sustainability, making gender equality a key factor in achieving green growth (Doss et al. 2020).

The behavioural differences between male and female farmers have been extensively studied, with findings suggesting that women are often more risk-averse and tend to prioritise long-term sustainability over short-term profits (Akter et al. 2020). This is particularly relevant for the adoption of sustainable agricultural practices, such as AECS measures, where women's focus on environmental stewardship may lead to higher levels of participation in green farming practices (Gatto, Mozzato, and Defrancesco 2019). These behavioural factors are crucial for understanding how gender influences the farmers' adoption of AECS and other green entrepreneurship activities (Cammarata et al. 2024).

The second stream in literature focuses on gender equality and green entrepreneurship in farms. Green entrepreneurship refers to the implementation of environmentally sustainable practices within a business framework. In agriculture, this includes the adoption of sustainable technologies, practices, and innovations that mitigate environmental degradation and contribute to climate resilience (Hechavarria et al. 2019; Praveen et al. 2024). While green entrepreneurship has been widely studied, the role of gender in shaping these entrepreneurial activities is less understood (García-Sánchez and Enciso-Alfaro 2024). Recent literature highlights that woman are often at the forefront of adopting sustainable practices due to their closer connection to natural resource management and their focus on household and community well-being (del Mar Fuentes-Fuentes et al. 2023).

The influence of gender on green entrepreneurship is evident in the differences in farm management styles. Women-led farms tend to be more diversified and oriented toward sustainable practices, such as organic farming and agroforestry, which contribute to environmental sustainability (Lioutas and Charatsari 2018). In contrast, male-headed farms are often more focused on productivity and market-driven outcomes, which may not always align with long-term sustainability goals (Barnes et al. 2019). This divergence suggests that gender plays a critical role in shaping the entrepreneurial orientation of farms, particularly in the adoption of AECS measures, which require long-term commitment to environmental goals.

The third stream in literature focuses on gender equality and AECS adoption. A growing body of research has examined the relationship between gender equality and the adoption of AECS measures. Studies conducted in various European countries have found that women farmers are more likely to adopt environmental schemes that align with sustainable agricultural practices (Tourtelier, Gorman, and Tracy 2023; Fertő and Bojnec 2024). For example, Unay-Gailhard and Bojnec (2021) found that female farmers in Slovenia exhibited a higher intensity of participation in AECS programs compared to male farmers, suggesting that women are more engaged in environmentally friendly farming practices.

Additionally, recent literature has emphasised the importance of opportunity costs and economic incentives in influencing AECS adoption (Schaub et al. 2023). For women, who often manage smaller farms with fewer resources, the opportunity costs of adopting green practices can be lower, especially when such practices align with their existing farming strategies and long-term goals (Nhamo and Mukonza 2020). This suggests that women's adoption of AECS may be driven by both economic and behavioural factors, including their focus on environmental sustainability and community well-being (Eastin 2018).

Finally, it is important to develop theoretical framework on gender equality, green entrepreneurship and AECS adoption. To understand how gender equality affects green entrepreneurship in farming, we draw on several theoretical perspectives.

First, the *resource-based view* suggests that access to critical resources—land, capital, labour, and knowledge—determines the ability of farms to engage in green entrepreneurship and sustainable resource management (Barney 1991; Samarakoon and Parinduri 2015; de Rosa et al. 2021; Malesu and Syrovátka 2024; Grigorescu and Andrei 2024; Villanthenkodath and Pal 2024). Gender disparities in access to these resources can hinder women's ability to adopt AECS measures, but when women have equal access, they may engage more actively in sustainable farming practices and in entrepreneurship for sustainable development (Doss et al. 2020; Altwaijri, Omri, and Alfehaid 2024).

Second, *behavioural economics* offers a lens for understanding how gender differences in risk preferences and decision-making affect AECS adoption. Studies have shown that women tend to be more risk-averse than men, which may lead them to adopt low-risk, sustainable practices that ensure long-term environmental benefits (Akter et al. 2020; O'Donoghue et al. 2024). This helps explain why women farmers may have a higher intensity of AECS participation compared to men.

Finally, *social capital theory* posits that networks and relationships play a crucial role in shaping entrepreneurial behaviour, community development and agricultural diversification (Coleman 1988; Sakamoto 2024; Chen and Barcus 2024; Addai et al. 2024). The role of social networks can also be important for environmental innovation and environmental policy (Waheed et al. 2024; Zhang 2024). Women, who often have stronger ties to their communities, may leverage social capital to promote green entrepreneurial activities that benefit both their farms and the broader community. This focus on community well-being may drive women's participation in AECS programs, which are designed to promote sustainable agricultural practices.

2.2 | Hypotheses Development

Previous studies have provided insights into the relationship between gender equality, women entrepreneurship in farm businesses and sustainable agricultural practices (Shortall, Budge, and Adesugba 2020; Pandey and Pandey 2023; Perelli et al. 2024), but remains a significant gap in understanding how gender affects the intensity of AECS adoption (Fertő and Bojnec 2024). Most studies focus on general gender differences in farm entrepreneurship, farming performance in agricultural productivity and eco-efficiency (Adinolfi et al. 2020; Puskur et al. 2023; Czyżewski, Prędki, and Brelik 2024) or participation in environmental schemes (Schaub et al. 2023; Wuepper et al. 2024; Canessa et al. 2024) but fail to explore the specific factors that influence the intensity of AECS participation. This study addresses this gap by investigating both the adoption and intensity of AECS measures in Hungarian farms, with a particular focus on gender-driven differences.

Based on the existing literature and theoretical framework, we hypothesize that *gender equality positively influences the adoption and intensity of AECS participation*. Specifically, we propose that *female farmers are more likely to adopt AECS measures and participate at a higher intensity compared to male farmers*, due to their stronger focus on environmental sustainability and long-term resource management.

A body of literature was developed on mainstreaming and implementing gender equality, and women's empowerment (OECD 2015; Bohnet 2016; Goldin 2021; Peterman et al. 2023; Lecoutere, Achandi, et al. 2023; Beloskar, Haldar, and Gupta 2024). One of the main focuses is on within-job gender pay inequality or the gender wage gap with its extent, trends and explanations (Blau and Kahn 2017). Gender inequality can be also related to work-family balance relationships (Anthopoulou 2010; Field et al. 2021), gender-dominated occupations (Bridges, Wulff, and Bamberry 2023) and opportunities for women in the green economy, biodiversity conservation and environmental sectors (Nhamo and Mukonza 2020; Lima and Cunha 2024; Czyżewski, Prędki, and Brelik 2024).

In women's empowerment and gender equality studies in agriculture and rural areas main geographical focus has been on African (Akpan 2015; Uduji, Okolo-Obasi, and Asongu 2019; Asongu and Odhiambo 2021; Osinubi and Simatele 2024) and South Asian countries (Abrar-ul-haq, Jali, and Islam 2017; Akter et al. 2017; Akram 2018; Ahmed et al. 2023; Haque et al. 2024). Less attention in empirical analysis of gender equality and gender critical issues for policy and practices has been on countries from other regions (Oedl-Wieser 2015; Černič Istenič 2015; Shortall and Marangudakis 2022, 2024). However, this does not mean that there are no such possible research and policy problems at different levels of agricultural sustainability (Coleman and Sandfort 2014; Nowak and Różańska-Boczula 2024; Czyżewski, Prędki, and Brelik 2024), with similarities and differences in challenges and drivers that women face in agriculture (Balezentis et al. 2021) and in charge of a farm (Annes, Wright, and Larkins 2021; Czyżewski, Prędki, and Brelik 2024).

Women-led green entrepreneurship in farming and rural areas can develop in different economic activities (Duflo 2012; Henry, Coleman, and Lewis 2023), which require women empowerment and women's entrepreneurship policy in agriculture and in rural areas (O'Brien, Hanlon, and Apostolopoulos 2024; Fertő and Bojnec 2024). Gender can affect differences in the adoption of agricultural technologies, agricultural innovations, sustainable agricultural intensification practices and farm performance (Gülsoy and Ustabaş 2019; Doss and Morris 2001; Ndiritu, Kassie, and Shiferaw 2014; del Mar Fuentes-Fuentes et al. 2023).

The green on-farming entrepreneurial and innovation activities can be measured in different ways (Kasztelan and Nowak 2024), often with the voluntary participation of farms in AECS (Unay-Gailhard and Bojnec 2016; Defrancesco, Gatto, and Mozzato 2018; Fertő and Bojnec 2024).

Agricultural and environmental policies can play a key role in shaping more sustainable the pro-environment-climate behaviour and green entrepreneurship of farmers (Recanati et al. 2019; Matthews 2020; Ricciolini et al. 2024). The role of behavioural factors and opportunity costs in farmers' adoption and adoption intensity in voluntary AECS can be important for sustainability of environmentally friendly practices (Gholamrezai, Aliabadi, and Altaei 2021; Czyżewski and Kryszak 2023; Schaub et al. 2023; Dai et al. 2024). Therefore, it is important to understand the motivation factors as possible drivers encouraging farmers to adopt and intensify participation in AECS.

Economic farm size often represents a measure of farm's economics of scale. A few studies in literature argue that farm size is positively associated with AECS continuation (Hynes and Garvey 2009; Murphy et al. 2014; Defrancesco, Gatto, and Mozzato 2018; Gatto, Mozzato, and Defrancesco 2019). According to this stream of literature, it is expected that economic farm size increases the adoption and adoption intensity of AECS. However, it remains an open question how farm size can be associated with the gender gap in the adoption and adoption intensity of AECS, and the results can be ambiguous.

Demographic and human capital characteristics have been investigated in the literature such as age and gender of a head/manager of farms. It is argued that younger farmers are more likely to participate in AECS than older farmers (Hynes and Garvey 2009). It is expected that with youth inclusion in rural transformation younger farmers are more engaged in green entrepreneurship on farms with a greater adoption and adoption intensity of AECS (Arslan et al. 2021). Therefore, it can be expected association between age and the gender gap in the adoption and adoption intensity of AECS.

Several studies also confirmed that female farmers are positively associated with the adoption and sustained participation in AECS (Gatto, Mozzato, and Defrancesco 2019; Unay-Gailhard and Bojnec 2021; Fertő and Bojnec 2024). Specifically, we propose that female farmers are more likely to adopt AECS measures and participate at a higher intensity compared to male farmers, due to their stronger focus on environmental sustainability and long-term resource management. While a positive association with adoption and adoption intensity of AECS is expected, the results on the gender gap might be ambiguous.

Employment of family labour may provide opportunities for green jobs (Unay-Gailhard and Bojnec 2019). The agricultural diversity and AECS payments can represent more stable source of farm income (Harkness, Areal, and Bihop 2021; Bojnec, Fertő, and Podruzsik 2022). Therefore, the higher share of employed family labour may generate more adoption and adoption intensity of AECS, but it is unclear a sign of association between the share of unpaid family labour and the gender gap in the adoption and adoption intensity of AECS.

The share of market-driven income can be in trade-offs with the subsidy-driven income from adoption of AECS in complexity of economics and sustainable development (Guerrero and Castañeda 2024). Therefore, greater opportunities for market-driven income may reduce efforts toward green entrepreneurship in farms with adoption and adoption intensity of AECS (Bougherara et al. 2021; Bjørnåvold et al. 2022). Greater dependence on subsidies versus market income can increase the likelihood of participation in AECS (Cullen et al. 2021). The share of market income can be associated with the gender gap in the adoption and adoption intensity of AECS.

The share of off-farm income represents farmer's employment and income diversification strategy (El Benni and Schmid 2022), which may vary by different farm sizes (Unay-Gailhard and Bojnec 2015; Tacconi et al. 2023). Rural transformation can have an impact on gender inclusiveness, off-farm and rural income in developing and developed countries, important for rural well-being and transforming role of the gender in sustainable agricultural and rural development (Rola-Rubzen et al. 2023, 2024; Al Abbasi et al. 2024; Appelt et al. 2024). While it is expected a positive association of off-farm income with adoption and adoption intensity of AECS, the results on the gender gap might be ambiguous.

The number of products offered by a farm indicates diversification of farms output with a shift from employing economies of scale towards employing economies of scope (Akter et al. 2016). This might indicate farm's flexibility which can be in trade-offs between market-driven and subsidy-driven sources of incomes. In addition, farm output trade can have social impacts onto the sustainable development goals (Schaafsma et al. 2023). Therefore, the result between the number of products per farm and the gender gap in the adoption and adoption intensity of AECS can be ambiguous.

The number of parcels operated by a farm shows possible effects of land fragmentation on efficiency and green entrepreneurship in farms (Bradfield et al. 2021). In addition, agricultural land parcel size can have impacts on cultivation costs (Valtiala et al. 2023). It can be expected that the number of parcels that a farm cultivates is associated with the gender gap in the adoption and adoption intensity of AECS.

Finally, farm types of farming can have mixed impacts on the gender gap in the adoption and adoption intensity of ACES

(Murphy et al. 2014) and sustainable development in agriculture (Galbreath and Tisch 2022).

3 | Data and Methods

3.1 | Data

Measuring sustainability at farm level can be critical issue regarding data and indicators used (Uehleke, Petrick, and Huttel 2019; Robling et al. 2023). We use the Hungarian Farm Accountancy Data Network (FADN) panel datasets between 2014 and 2021, which offers a robust and detailed foundation for analysing gender dynamics in the adoption of AECS measures. This comprehensive dataset includes farm-level demographic, economic, and operational variables, such as the gender of the farm head, economic size, income diversification, and land use, enabling a nuanced exploration of gendered differences in AECS participation and intensity. Spanning 2014–2021, its longitudinal nature allows for tracking changes over time, particularly in response to evolving policies and socio-economic conditions. Uniquely suited to the study's focus, the FADN is an informative source to monitors the implementation of the CAP measures, directly linking AECS engagement to broader policy objectives. Hungary's post-socialist agricultural context, marked by gender disparities in land ownership, availability and access to resources, provides a relevant backdrop for examining the interplay between gender dynamics and AECS sustainability. By capturing diverse farm types and sizes, FADN facilitates a detailed understanding of structural and behavioural drivers of gendered outcomes, offering critical insights for evidence-based, gender-sensitive policy development.

FADN provides farm-level data based on national surveys for agricultural holdings above the size threshold that can be considered commercial (European Commission 2024b). The farm-level data are provided according to regional farm location, economic size of farm, and its type of farming. FADN data were used for monitoring and evaluation of different CAP measures such as the economic sustainability of Italian farms (Coppola et al. 2022). Due to dynamics in challenging issues in data collection for sustainable farming, there is a need for converting FADN into Farm Sustainability Data Network (European Commission 2024a; European Commission et al. 2024).

To investigate gender-related differences in AECS adoption and intensity, the FADN variables were selected based on theoretical and empirical findings from prior research. These variables are grouped into categories to capture factors that influence both the likelihood of AECS adoption and the level of engagement intensity:

Demographic variables: The age of the farm head is included as it has been shown to influence openness to innovation, with younger farmers typically more inclined toward adopting environmentally sustainable practices (Hynes and Garvey 2009).

Farm economic size: Farm size, expressed in economic terms, is a crucial determinant of agricultural sustainability, as larger farms often have greater resources to implement AECS practices (Murphy et al. 2014; Ren et al. 2019).

Labour composition: The share of family labour, as opposed to hired labour, is relevant in this context because family-managed farms may approach risk and sustainability with a long-term focus, potentially enhancing engagement in green practices (Unay-Gailhard and Bojnec 2019).

Income sources: Income diversity is represented by the share of income from market activities and off-farm sources. Farms with higher market income shares may prioritise productivity, while those with greater reliance on subsidies are often more engaged in AECS (Bougherara et al. 2021; Cullen et al. 2021).

Farm output diversification and land fragmentation: The number of products offered and the number of parcels under cultivation reflect a farm's diversification and operational complexity, which may impact its ability to adopt and intensify AECS practices (Akter et al. 2016).

As the *dependent variable* are defined three farm-level measures of AECS engagement: (1) AECS subsidies in euros (log-transformed), (2) AECS subsidy as a share of total CAP subsidy, and (3) AECS subsidy per hectare (ha) of utilised agricultural area (UAA), also log-transformed. These variables capture both the adoption and intensity of AECS participation, facilitating nuanced comparisons between male- and female-headed farms.

3.2 | Methodology

3.2.1 | Justification for the Blinder–Oaxaca (B–O) Decomposition Model

The Blinder–Oaxaca (B–O) decomposition model, originally developed for analysing wage disparities in labour economics, has found extensive application in studying various socioeconomic gaps, including those related to agricultural practices. The B–O decomposition model has been used in labour economics literature to study gaps in wages and employment (Blinder 1973; Oaxaca 1973), which has later been applied in agricultural productivity gap studies (Kilic, Palacios-Lopez, and Goldstein 2015; Aguilar et al. 2015; Ali et al. 2016) and in gender-based adoption and intensity of AECS (Fertő and Bojnec 2024).

The B–O decomposition model is particularly suited for the study's objectives, as it decomposes observed differences between groups into two main components: (1) differences in endowments (characteristics) and (2) differences in coefficients, which represent the returns or outcomes associated with these characteristics. By isolating these components, the B–O decomposition model provides a detailed breakdown of whether disparities in AECS engagement are driven by variations in farm characteristics or by unequal returns on these characteristics, which may indicate underlying structural barriers or biases affecting female farmers.

In addition to mean-based decomposition, this study applies the RIF decomposition model to address potential limitations in the B–O approach. RIF decomposition allows for distributional analysis by estimating disparities across quantiles (e.g., the 10th, 25th, and 75th), offering insights into how gender differences may vary between farms with different AECS engagement levels. This approach is particularly relevant in cases where the effects of farm characteristics on AECS participation differ across low, medium, and high levels of engagement.

3.2.2 | Methodological Flowchart

To enhance clarity, a flowchart (Figure 1) is included to illustrate the methodological sequence.

Data collection and preparation: Data is gathered from the FADN, and variables are selected and transformed where necessary to facilitate statistical estimation.

Descriptive analysis: Initial descriptive statistics summarize gender-based differences in AECS engagement. The Kruskal–Wallis test is used to evaluate the statistical significance of observed differences between male- and female-headed farms.

3.2.2.1 | Blinder–Oaxaca Decomposition Analysis. Decomposition procedure: AECS adoption and intensity are decomposed into endowment and coefficient effects, with interaction effects capturing combined influences of characteristics and their returns.

Interpretation of results: Results reveal whether gender disparities in AECS adoption are attributable to different resource allocations or structural inequalities.

3.2.2.2 | RIF Decomposition for Distributional Insights. Quantile decomposition: RIF decomposition is conducted at various quantiles of AECS intensity, allowing for examination of how gender effects vary across different levels of AECS engagement.

Interpretation of quantile-specific effects: This step reveals if gender disparities are more pronounced at specific AECS intensity levels, providing a fuller picture of gender dynamics in green entrepreneurship.

Selectivity bias correction: A two-stage model addresses selection bias in AECS participation. Stage 1 involves a probit model estimating AECS participation likelihood, while Stage 2 includes the inverse Mills ratio for correction in the outcome model.

3.3 | Econometric Models

3.3.1 | Blinder-Oaxaca (B–O) Decomposition Model

The B–O decomposition is applied to quantify gender disparities in AECS engagement as follows:

$$\Delta Y = \left(\overline{X}_m - \overline{X}_f\right)\beta_m + \overline{X}_f\left(\beta_m - \beta_f\right) + \left(\overline{X}_m - \overline{X}_f\right)\left(\beta_m - \beta_f\right)$$

where, ΔY is the difference in the mean outcome (e.g., AECS adoption) between groups m (male) and f (female), $\overline{X}_m$ and $\overline{X}_f$ are the vectors of average characteristics for the two groups, β_m and β_f are the vectors of estimated coefficients (returns) for the two groups.

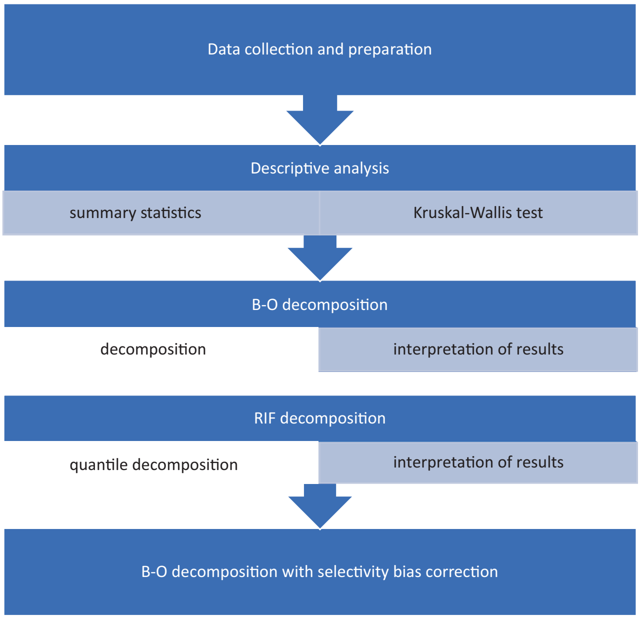

FIGURE 1 | Methodological flowchart. *Source:* Compiled by authors.

The first term represents the *endowment effect* (indicating differences due to characteristics), the second term the *coefficient effect* (captures differences in returns on characteristics), and the third term the *interaction effect* (assesses combined influences of characteristics and returns).

3.3.2 | Recentered Influence Function (RIF) Decomposition

While the B–O decomposition provides insights into mean differences between groups, it does not account for how disparities may vary across the distribution of outcomes. This limitation is addressed by the RIF decomposition, an advanced method that allows for the analysis of the gender gap differences in AECS participation across the entire distribution of intensity, not just the mean.

The RIF decomposition is based on the concept of influence functions, which are tools from robust statistics used to measure the sensitivity of a statistical functional (like a quantile, variance, or Gini coefficient) to small changes in the data. The RIF approach extends the traditional B–O decomposition by allowing the decomposition of differences at various points of the outcome distribution, such as different quantiles (e.g., the median, 25th percentile, or 75th percentile). This is important in our study because the impact of explanatory variables on AECS participation may not be uniform across all farms. For instance, factors influencing participation among small-scale farms may differ from those affecting larger farms. By utilizing the RIF decomposition, we can: first, *examine distributional effects* on how the gender gap varies at different points in the distribution of AECS subsidies, providing insights into whether disparities are more pronounced among low-intensity or high-intensity farms.

Second, *identify heterogeneous impacts* to understand whether certain factors have a stronger influence on AECS participation at different levels of subsidy intensity. Finally, *provide evidence* to develop more targeted policy recommendations that consider the varying needs and challenges of different farm groups.

The RIF for a given outcome Y and quantile q is defined as:

$$\mathrm{RIF}(Y; q) = q + \frac{1\{Y \leq q\} - \tau}{f_Y(q)}$$

where q is the quantile of interest, τ is the probability associated with quantile q (e.g., $\tau = 0.5$ for the median), and $f_Y(q)$ is the density of Y at the quantile q. The RIF essentially transforms the outcome variable in a way that the decomposition can be applied to any distributional statistic, not just the mean.

The RIF decomposition then applies a similar breakdown as the B–O decomposition but does so at different points across the distribution. This allows researchers to see how the factors contributing to the gap might differ between, say, farms at the lower end of the ACES subsidy income distribution versus those at the higher end. It provides a more complex view of the disparities, highlighting where interventions might be most needed or most effective.

3.3.3 | Addressing Selectivity Bias

B–O decomposition is not path-dependent and quantifies the relative contribution of factors to the gender gap. We employ a threefold decomposition, namely, the AECS intensity gap is divided into three parts. First, the endowment effect reflects the mean increase in women's AECS intensity if they had the same characteristics as men. Second, the coefficient effect quantifies the change in women's AECS intensity when applying the men's coefficients to the women's characteristics. Third, the interaction effect measures the simultaneous effect of differences in endowments and coefficients.

A critical consideration in our analysis is the potential for selectivity bias. The AECS subsidies are observed only for farms who are participating in the AECS programme, and this might be a selective group. This self-selection may lead to biased estimates if unobserved factors influencing participation are correlated with the outcome variables. To address this issue, we incorporate methods to correct for selectivity bias in our decomposition analysis. Thus, we estimate the B-O decomposition model with the selectivity bias (Heckman, 1979; Neuman and Oaxaca 2004; Slavchevska 2015; Gelbach 2016). This approach involves: *first stage* (*selection equation*) modelling the probability of AECS participation using a probit regression, where the dependent variable is a binary indicator of participation, and the explanatory variables include factors that influence the decision to participate. *Second stage* (*outcome equation*) estimating the outcome equations for AECS subsidy intensity, including the inverse Mills ratio derived from the first stage to correct for selectivity bias. By incorporating the correction for selectivity bias, we aim to obtain consistent and unbiased estimates of the coefficients used in the decomposition analysis.

4 | Results

4.1 | Outcome Variables for AECS Adoption and AECS Adoption Intensity

The descriptive statistics are presented for the three outcome variables linked to AECS subsidy at the farm-level separately for female- and male-headed farms. The variables are expressed in natural logarithm (ln) to normalise their distributions: AECS subsidies (in euro), AECS subsidies/total CAP subsidies (in %), and AECS subsidies/total UAA per ha (in euro) (Table 1 and Figure 2).

The voluntarily implemented AECS measures with the related AECS subsidies are constituent part of CAP measures and subsidies. Except for AECS subsidy, female-headed farms received a slightly higher AECS subsidies/total CAP subsidies and AECS subsidy per ha of UAA than male-headed farms, but as shown by *p* value of Kruskal–Wallis test, the difference is not statistically significant. Hungarian female-headed farms do not experience higher intensity of AECS subsidies than male-headed farms. These findings are inconsistent with previous research arguing that female-headed farms are more agri-environmentally oriented than other farms (Unay-Gailhard and Bojnec 2021; Fertő and Bojnec 2024).

The Kernel density functions presented in Figure 2 further illustrate the distribution of AECS variables between male-headed and female-headed farms. The overlapping distributions reinforce the conclusion that differences in AECS adoption intensity between genders are minimal and statistically insignificant.

These findings challenge the notion that female farmers are inherently more inclined toward agri-environmental practices. The lack of significant differences in AECS adoption intensity suggests that gender may not be a determining factor in engagement with AECS measures among Hungarian farms, or that other factors may be overshadowing potential gender differences.

4.2 | Characteristics of Farms and Explanatory Variables

The descriptive statistics in Table 1 are presented to highlight significant differences in the characteristics of male- and female-headed farms for explanatory variables: for human capital variables (age and share of family labour), economic size of farm, sources of income (share of market income and share of off-farm income), number of products offered by farm and number of parcels operated by farm.

Except for age of farm head/manager and the share of family labour, mean values for male-headed/managed farms are higher than for female-headed/managed farms. The share of family labour is significantly higher on female-headed/managed farms who are almost 2 years older than male headed/managed farms. The gender-based differences are statistically significant, except for the number of products that are offered by farms.

TABLE 1 | Descriptive statistics of means of variables and Kruskal–Wallis test.

	Male	Female	Total	*p*
ln(AECS subsidy)	8.831 (1.807)	8.507 (1.870)	8.804 (1.815)	0.013
ln(AECS/total CAP subsidy)	2.875 (1.388)	2.884 (1.196)	2.875 (1.373)	0.928
ln(AECS/total land)	4.291 (1.860)	4.381 (1.931)	4.298 (1.866)	0.503
Economic size (1000 Euro)	515.611 (1828.941)	185.556 (372.024)	487.604 (1755.340)	0.009
Age (year)	60.093 (10.785)	61.971 (10.533)	60.252 (10.775)	0.016
Share of family labour (%)	48.472 (37.397)	60.900 (34.680)	49.526 (37.328)	<0.001
Share of market income (%)	71.383 (17.295)	68.359 (16.663)	71.126 (17.259)	0.015
Share of off-farm income (%)	4.670 (12.632)	3.005 (8.635)	4.529 (12.351)	0.062
Number of products	4.918 (3.168)	4.722 (2.717)	4.901 (3.132)	0.388
Number of parcels	29.724 (54.937)	17.368 (15.100)	28.675 (52.848)	0.001
Poultry	0.072 (0.258)	0.105 (0.308)	0.075 (0.263)	0.079
Fruits	0.120 (0.325)	0.144 (0.351)	0.122 (0.327)	0.315
Other field crop	0.127 (0.333)	0.172 (0.379)	0.131 (0.338)	0.066
Field crop	0.340 (0.474)	0.330 (0.471)	0.339 (0.473)	0.777
Pork	0.049 (0.216)	0.062 (0.242)	0.050 (0.219)	0.413
Wine	0.055 (0.227)	0.000 (0.000)	0.050 (0.218)	<0.001
Dairy	0.126 (0.332)	0.163 (0.370)	0.129 (0.335)	0.130
Mixed	0.089 (0.284)	0.024 (0.153)	0.083 (0.276)	0.001
Horticulture	0.023 (0.149)	0.000 (0.000)	0.021 (0.142)	0.028
N	2254	209	2463	

Note: Mean values with standard deviation in the parentheses. The *p* value is based on the Kruskal–Wallis test, which compares the difference between male and female-headed or managed farms.

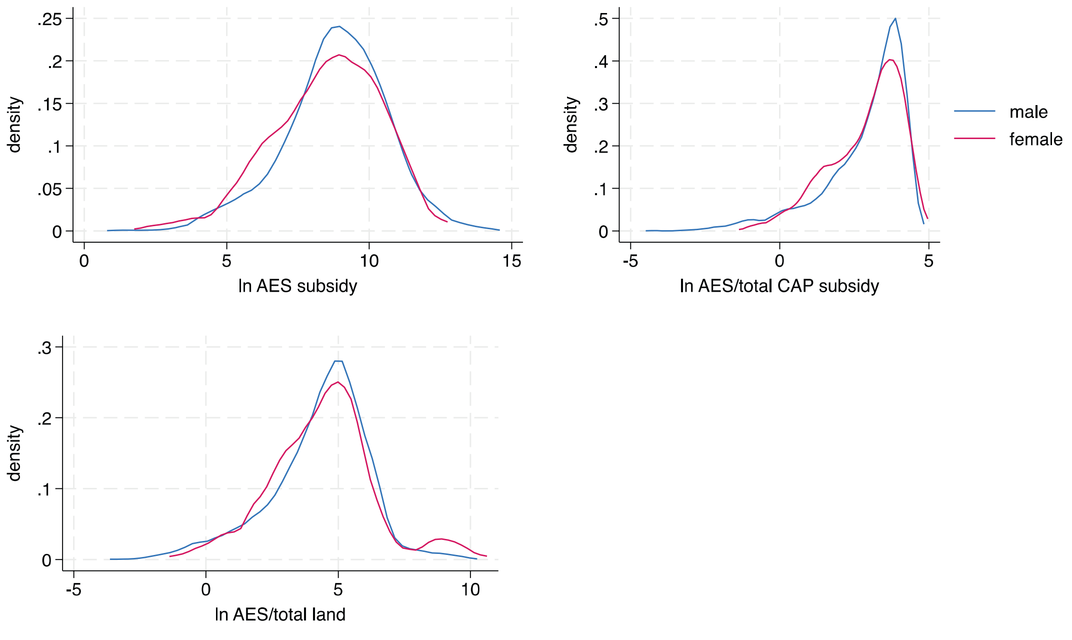

FIGURE 2 | Kernel density functions of AECS variables.

Gender inequality is also evident in Hungarian FADN farms, similar to other countries in the CEE region (Fertő and Bojnec 2024). Female-headed/managed farms are significantly smaller than male-headed/managed farms measured by standard output for economic size of agricultural holdings.

According to the distribution of farms by type of farming, female-headed/managed farms are significantly more oriented in poultry and other field crops, while male-headed/managed farms in wine, horticulture and mixed farming. Differences for other types of farming are not statistically significant.

4.3 | Econometric Results

To further investigate the gender differences in AECS adoption and intensity, we employ the B–O decomposition method, along with robustness checks using the RIF decomposition. The econometric results are presented for three outcome variables expressed in natural logarithm (ln) and estimated by the B–O decomposition selection models: AECS subsidy for adoption, and share of AECS subsidy in total CAP subsidies, and AECS subsidy per total UAA for adoption intensity. We use these three dependent model variables to conduct a robustness check for aggregate decomposition (Table 2), aggregate decomposition with RIF (Table 3), and detailed decomposition (Table 4).

4.3.1 | The B-O Aggregate Decomposition

While the gender gap in most studied variables is in favour of men, women do make the difference in the received ACES subsidies in total CAP subsidies and received AECS subsidies per total UAA on Hungarian farms. The B–O aggregate decomposition results confirmed the gender gap in favour of male-headed farms in the received AECS subsidies, with a difference of 0.324 (Table 2). The endowment effect is positive and significant (1.122), indicating that differences in characteristics between male and female-headed farms explain a substantial portion of the gender gap in AECS subsidies received. This suggests that male-headed farms have attributes (such as larger economic size) that contribute to higher subsidy receipts.

The robustness tests confirmed that women received more AECS subsidies per total CAP subsidies and AECS subsidies per total UAA, but the differences between male and female-headed farms are not statistically significant. The endowment effects are positive and significant, but the overall difference is negligible and not significant. This indicates that while female-headed farms may have characteristics that could lead to higher AECS intensity, the actual differences are not statistically significant in the aggregate. These results to a lesser extent confirmed women pro-active adoption intensity of the AECS as they received the greater share of AECS subsidies in total CAP subsidies and higher AECS subsidies per ha of UAA.

The B–O aggregate decomposition analysis shows that endowment effect plays an important role in the received AECS subsidies, while unlike for Slovenia (Fertő and Bojnec 2024), the coefficient effect is positive but statistically insignificant for both the received AECS subsidies and the normalised outcome indicators (AECS subsidies per total CAP subsidies and AECS subsidies per total UAA, respectively). These results imply that the returns to characteristics are similar between male and female-headed farms. Consequently, the interaction effect is significantly negative for each of three specified dependent variables: received AECS subsides and both the normalised outcome indicators. These results suggest that the combined differences in characteristics and their returns reduce the overall gender gap.

4.3.2 | The B-O Detailed Decomposition

The B–O detailed decomposition confirmed that the gender gap between women- and men-headed farms in received AECS subsidies is driven by economic farm size, the share of family labour, and the number of parcels that are operated by farms, but deteriorated by the share of market income and the dairy type of farming within the endowment effect (Table 3). This suggests that male-headed farms receive more AECS subsidies because they have larger farms, more family labour, and operate more parcels. Conversely, female-headed farms with a higher share of market income and the dairy type of farming may receive more AECS subsidies, potentially due to greater engagement with market-oriented environmental practices.

TABLE 2 | Results from Blinder–Oaxaca aggregate decomposition.

	ln(AECS subsidy)	ln(AECS/total CAP subsidy)	ln(AECS/total land)
Male	8.831***	2.875***	4.291***
Female	8.507***	2.884***	4.381***
Difference	0.324**	−0.009	−0.090
Aggregate decomposition			
Endowments	1.122***	0.335***	0.730***
Coefficients	0.139	0.034	0.002
Interaction	−0.937***	−0.378***	−0.823***

*$p<0.1$.
**$p<0.05$.
***$p<0.01$.

TABLE 3 | Results from Blinder–Oaxaca detailed decomposition.

	ln(AECS subsidy)	ln(AECS/total CAP subsidy)	ln(AECS/total land)
Endowments' effect			
Economic size (1000 Euro)	0.732***	0.196*	0.526***
Age (year)	0.012	0.008	0.020
Share of family labour (%)	0.150***	0.019	0.048
Share of market income (%)	−0.163**	−0.070**	−0.115**
Share of off-farm income (%)	−0.017	−0.001	0.001
Number of products	0.022	0.008	−0.002
Number of parcels	0.325***	0.105	0.125
Poultry	0.034	0.023	0.057
Fruits	0.127	0.120	0.202
Other field crop	−0.021	−0.021	−0.039
Field crop	0.021	0.015	0.022
Pork	0.000	0.000	0.000
Wine	0.065	0.080	0.122
Dairy	−0.166***	−0.148***	−0.235***
Mixed	0.000	0.000	0.000
Horticulture	0.000	0.000	0.000
Coefficients' effect			
Economic size (1000 Euro)	−0.371***	−0.093*	−0.268***
Age (year)	0.042	0.023	0.580
Share of family labour (%)	−0.363	0.124	0.027
Share of market income (%)	1.737***	0.865**	1.290**
Share of off-farm income (%)	0.047	0.003	0.008
Number of products	−0.127	−0.371*	−0.471*
Number of parcels	−0.464***	−0.184*	−0.244*
Poultry	0.073	0.078	0.154**
Fruits	0.267***	0.205***	0.302***
Other field crop	0.249*	0.186*	0.365***
Field crop	0.097*	0.056	0.051
Pork	0.000	0.000	0.000
Wine	0.174**	0.131**	0.217**
Dairy	0.037	0.027	0.032
Mixed	0.000	0.000	0.000
Horticulture	0.000	0.000	0.000
Constant	−1.260	−1.014	−2.041*
Interactions' effect			
Economic size (1000 Euro)	−0.660***	−0.166*	−0.477***
Age (year)	−0.001	−0.001	−0.018

(Continues)

TABLE 3 | (Continued)

	ln(AECS subsidy)	ln(AECS/total CAP subsidy)	ln(AECS/total land)
Share of family labour (%)	0.074	−0.025	−0.006
Share of market income (%)	0.077*	0.038	0.057*
Share of off-farm income (%)	0.026	0.002	0.004
Number of products	−0.005	−0.015	−0.019
Number of parcels	−0.330***	−0.131*	−0.173*
Poultry	−0.012	−0.013	−0.025
Fruits	−0.070	−0.053	−0.079
Other field crop	0.007	0.005	0.011
Field crop	−0.020	−0.012	−0.011
Pork	−0.045***	−0.013	−0.059***
Wine	−0.039	−0.029	−0.049
Dairy	0.101**	0.072*	0.085*
Mixed	0.000	0.000	0.000
Horticulture	−0.040***	−0.036***	−0.064***

*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

The change in women's intensity within the coefficient effect is driven by the share of market income as well as the fruits, field crop, and wine types of farming, but deteriorated by economic farm size and the number of parcels operated by farms. These results imply that increases in farm size do not translate into proportional increases in AECS subsidies for female-headed farms. This could indicate structural barriers or inefficiencies affecting female farmers.

Within the simultaneous interaction effect, the gender gap is driven by the share of market income and dairy type of farming, and deteriorated by economic farm size, the number of parcels operated by farms, and pork and horticulture types of farming. These results suggest that female-headed farms benefit more from their market income in terms of AECS subsidies received, possibly due to better integration of market activities with environmental practices. This could indicate farmers' socioeconomic trade-offs in adoption of ACES, finding reported by Bjørnåvold et al. (2022) for France.

Unlike to our expectations, age of head/manager of farm is less important for receiving AECS subsidies. This finding is consistent with the finding for Slovenia (Fertő and Bojnec 2024), and can be related to various factors such ecological-economic trade-offs in the adoption of AECS, succession problems or lack of entrepreneurial spirits in green farming with persistence of existing farming practices that can be less focused on the implementation of AECS measures.

The robustness tests confirmed that women's increase in intensity of AECS subsidies per total CAP subsidies is due to economic farm size at 10% significance level, which is deteriorated by the share of market income and dairy type of farming within the endowment effect.

The change in women's intensity within the coefficient effect is driven by the share of market income as well as fruits, other field crop and wine types of farming, and deteriorated at 10% significance level by economic farm size, the number of products offered by farms and the number of parcels operated by farms.

Within the simultaneous interaction effect, the gender gap in AECS subsidies per total CAP subsidies is explained by dairy type of farming at 10% significance level and deteriorated by horticulture type of farming and at 10% significance level by economic farm size and the number of parcels operated by farms.

The increase in women's intensity vis-à-vis men in AECS subsidies per total UAA is explained by economic farm size, which is deteriorated by the share of market income and dairy type of farming.

Within the coefficient effect, the change in women's intensity in AECS subsidies per total UAA is explained by the share of market income as well as poultry, fruits, field crop and wine types of farming, but deteriorated by economic farm size, the number of products offered by farms, and the number of parcels operated by farms.

Within the simultaneous interaction effect, women vis-à-vis men intensity in AECS subsidies per total UAA is driven by the share of market income and dairy type of farming and deteriorated by economic farm size, the number of parcels operated by farms, pork and horticulture types of farming.

The economic farm size does matter for women's increase/change in AECS intensity. The economic farm size reduces in women's intensity gap in AECS subsidies in total CAP subsidies

TABLE 4 | Blinder–Oaxaca RIF decomposition.

ln(AECS subsidy)	q10	q25	q50	q75	q90
Male	6.495***	7.804***	8.940***	10.032***	10.994***
Female	5.942***	7.324***	8.732***	9.933***	10.815***
Difference	0.553**	0.479**	0.207	0.098	0.179
Decomposition					
Explained	0.106	0.078	0.139**	0.233***	0.336***
Unexplained	0.447**	0.401*	0.068	−0.134	−0.157
ln(AECS/total CAP subsidy)					
Male	0.868***	2.253***	3.330***	3.874***	4.140***
Female	1.244***	2.005***	3.230***	3.842***	4.093***
Difference	−0.376**	0.248	0.100	0.032	0.047
Decomposition					
Explained	−0.151	−0.025	−0.026	−0.015	0.002
Unexplained	−0.225	0.274	0.127	0.047	0.045
ln(AECS/total land)					
Male	1.739***	3.355***	4.615***	5.455***	6.267***
Female	2.154***	3.303***	4.558***	5.353***	6.328***
Difference	−0.415*	0.052	0.057	0.102	−0.061
Decomposition					
Explained	−0.285*	−0.055	−0.012	−0.022	−0.089
Unexplained	−0.131	0.107	0.069	0.124	0.028

*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

and in AECS subsidies per total UAA intensity, respectively, but similarly as the number of parcels operated by farms increase the change in women's intensity within the coefficient and interaction effects, respectively.

Age of head/manager of farm is insignificantly associated with AECS subsidies, AECS subsidies per total UAA, and the share of AECS subsidies in total CAP subsidies. Except for AECS subsidies in endowment effect, the share of family labour is insignificantly associated with all three outcome dependent variables in endowment, coefficient, and interaction effects. These finding are consistent with the most recent research (Fertő and Bojnec 2024), but largely inconsistent with the other previous research on green job creation in agriculture and in rural areas (Unay-Gailhard and Bojnec 2019).

Contrary to economic farm size, the share of market income is significantly inversely associated with received AECS subsidies, the share of AECS subsidies in total CAP subsidies and AECS subsidies per total UAA in the endowment's effects, and significantly positively associated in the coefficient's effects and to a lesser extent in the interaction's effects.

Mixed results by types of farming are suggesting their specificities and peculiarities in relation with received AECS subsidies and both the normalised outcome indicators.

These results and findings can be important for better understanding technological adjustments towards green AECS practices (Morris, Henley, and Dowell 2017) and for the monitoring of CAP policies and the implementation of practices with raising awareness on the importance of green farming activities (Tom et al. 2023).

4.3.3 | The Recentered Influence Function Decomposition

The B–O RIF decomposition models are estimated to check the robustness of the B-O aggregate decomposition results. The gender-based differences vary across different quantiles of the AECS subsidy distribution. The gender gaps with male-headed farms receiving more AECS subsidies are observed significant on the lower quantile (q), but the difference becomes statistically insignificant for the higher quantiles, indicating that the gender gap diminishes among farms receiving higher AECS subsidies: for AECS subsidy after q25 quantiles (Table 4).

Contrary to the significant positive gender-based differences for AECS subsidy, which means that male-headed/managed farms received more AECS subsidies, the significant negative difference is for AECS subsidies per total CAP subsidies for q10 quantile and for AECS subsidies per total UAA for q10 quantile implying that the adoption intensity of AECS is higher for female-headed farms, but at the low level of AECS intensity.

Figure 3 further illustrate the estimated gender-based effects across quantiles of the AECS subsides variables. It reinforces the explained gender-based differences that vary across different quantiles of the AECS subsidy distribution and in AECS adoption intensity between genders.

4.3.4 | The B–O Decomposition With Selection Bias

Table 5 shows the B–O decomposition analysis results, accounting for selection bias, to examine gender differences in AECS subsidy outcomes across three dependent variables: ln(AECS subsidy), ln(AECS/total CAP subsidy), and ln(AECS/total land).

For ln(AECS subsidy), male farmers have a mean of 8.831, while female farmers have a higher mean of 10.897, but the −2.065 difference is not statistically significant. The endowments

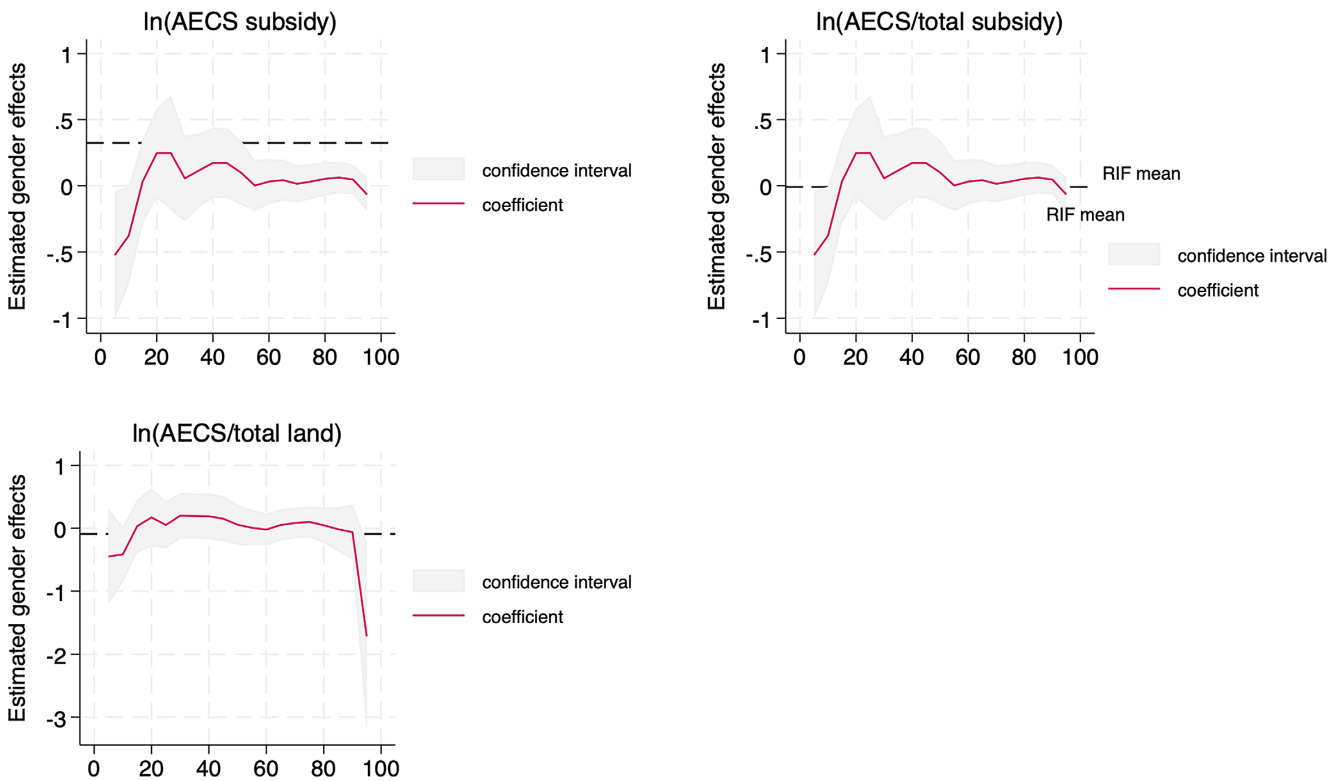

FIGURE 3 | Estimated gender effects by AECS variables.

TABLE 5 | Results from Blinder–Oaxaca aggregate decomposition with selection bias.

	ln(AECS subsidy)	ln(AECS/total CAP subsidy)	ln(AECS/total land)
Male	8.831***	2.875***	4.291***
Female	10.897***	3.455**	4.946***
Difference	−2.065	−0.580	−0.655
Aggregate decomposition			
Endowments	1.094***	0.328**	0.723***
Coefficients	−2.250	−0.537	−0.562
Interaction	−0.909***	−0.371***	−0.816***

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

component significantly contributes to this difference, suggesting female farmers' observable characteristics favour AECS subsidy allocation. The coefficients component is negative but not significant, and the interaction term is significantly negative, indicating combined characteristic differences disadvantage male farmers.

A similar pattern appears for ln(AECS/total CAP subsidy) and ln(AECS/total land). For ln(AECS/total CAP subsidy), male farmers have a mean of 2.875 compared to 3.455 for females. The endowments component is significant, while the interaction term is significantly negative. For ln(AECS/total land), the mean values are 4.291 for males and 4.946 for females. The endowments component contributes significantly, and the interaction term remains significantly negative.

Overall, these findings suggest that female farmers' higher AECS subsidies are due to favourable endowments rather than differential treatment, with negative interaction terms highlighting how male farmers' characteristics and their rewards contribute to relative subsidy disadvantages. This emphasises the importance of considering both characteristics and their interaction with policy in assessing gender-based AECS subsidy disparities.

5 | Discussion

This study advances understanding of gender dynamics in the adoption and intensity of AECS measures, focusing on Hungarian farms as a case within CEE and EU countries. The findings confirm that male-headed farms receive higher AECS subsidies, largely due to structural advantages such as larger economic scale and greater resource access. However, when these factors are controlled, female-headed farms demonstrate similar AECS adoption intensity, indicating that gender disparities are driven by systemic resource inequalities rather than behavioural differences or lack of commitment to sustainable practices (Njuki et al. 2022; García-Sánchez and Enciso-Alfaro 2024). This highlights the resilience of female farmers in achieving comparable engagement with fewer resources.

Our results for the Hungarian FADN farms confirmed that while male-headed farms exhibit a higher degree of adoption of AECS subsidies, women-led farms exhibit a similar or a slightly higher degree of environmental friendliness compared to male-headed farms in terms of intensity of AECS subsidies. Female farmers received less AECS payments than male farmers, but there are no differences in AECS subsidies per total CAP subsidies and AECS subsidies per total UAA as clearly confirmed by Kruskal-Wallis tests. This could indicate opportunities for women in AECS and the development of sustainable agriculture the green circular economy (Nhamo and Mukonza 2020; Tourtelier, Gorman, and Tracy 2023).

In addition to the applied advanced O–B econometric models, the crucial novelty to the analysis is the applied the O–B RIF function decomposition to experiment the robustness of the results, offering a detailed disaggregation of the factors contributing to gender disparities. The results show that structural endowments such as farm size, availability and access to economic resources, and number of parcels favour male-headed farms, yet female-headed farms exhibit higher AECS intensity at lower subsidy levels. This suggests that female farmers prioritise sustainable practices despite resource constraints, underscoring the need for targeted policy interventions to support their engagement (Unay-Gailhard and Bojnec 2021; Fertő and Bojnec 2024).

The RIF decomposition highlights that the gender gap is more pronounced at lower levels of AECS subsidy receipt, suggesting that smaller female-headed farms may face greater challenges in accessing AECS subsidies. Conversely, female-headed farms exhibit higher AECS intensity at the lower end of the distribution, implying a stronger commitment to AECS measures relative to their resources. While the gender-based differences are observed for the lower quantiles with AECS subsidies in favour of male-headed farms the gender-based differences disappeared or are negative for AECS subsidies per total CAP subsidies and AECS subsidies per total UAA for higher quantiles after q10 implying that the intensity of AECS subsidies is higher for female-headed farms. The mitigation of gender-based disparities is important to promote climate-resilient development (Eastin 2018; Andrijevic et al. 2020; Bazel-Shoham et al. 2024), farm, agricultural and rural resilience (Rathi 2022; Czyżewski, Prędki, and Brelik 2024) particularly with empowering women in green entrepreneurship in farms, food systems and green rural development (Njuki et al. 2022; Fertő and Bojnec 2024).

The results for the Hungarian FADN farms indicate that male-headed farms receive higher AECS subsidies primarily due to larger economic farm size, greater economic resources, and operating more parcels. These factors contribute significantly to AECS adoption and can increase in women's AECS intensity in the endowment effect in the decomposition analysis. Within the latter effect, the share of family labour and the number of parcels operated by farms, respectively, are important only for AECS adoption. On the other hand, the share of market income and dairy type of farming cause reduction in AECS adoption and in women's AECS adoption intensity.

The coefficient effects are less significant, suggesting that differences in how characteristics translate into AECS subsidies are not the main drivers of the gender gap. The change in women's AECS adoption intensity when applying the men's coefficients to the women's characteristics within the coefficient effect are driven by the share of market income, fruits, other field crop, and wine types of farming. On the other hand, they are deteriorated by economic farm size, the number of products offered by farms and the number of parcels operated by farms. However, for AECS adoption intensity, the differences between male- and female-headed farms are not statistically significant in the aggregate, indicating that when controlling for farm size and other characteristics, female farmers are equally engaged in agri-environmental practices.

The simultaneous effect of differences in endowment and coefficient effects in interaction effect is partly driven by the share of market income and dairy type of farming. On the other hand, it is deteriorated by economic farm size, the number of parcels operated by farms, pork and horticulture types of farming.

The statistical significance of our findings varies across different variables and quantiles. The significant endowment effects for economic farm size and number of parcels highlight the importance of these factors in explaining the gender gap in AECS subsidies. However, coefficient effects are generally not significant, suggesting that differences in returns to characteristics are less influential.

To sum up, the gender gaps are diminishing in trade-offs between economic farm size and the share of market income depending on types of farming. The importance of farm size and types of farming for AECS adoption was also argued by Unay-Gailhard and Bojnec (2015). The possible links between farm diversification strategies, dietary diversity and farm size were also addressed in a cross-country sample study for South and Southeast Asian countries (Tacconi et al. 2023). The number of products offered by farms and the number of parcels operated by farms play mediating role in the adoption of environmentally-friendly farming technologies, activities, and practices. This could be linked to economies of scope and operational costs (Valtiala et al. 2023).

These evidence-based findings provide important contributions and implications for the EU's CAP to achieving the sustainable development goals (Raimo et al. 2024). Addressing structural barriers—such as unequal access to land, credit, and advisory services—can enhance female farmers' participation in AECS measures. Policy responses should include simplified application processes, fostering an enabling environment for equality and empowerment in agri-food systems, targeted financial incentives, and capacity-building programs aimed at smaller farms led by women (Lecoutere, Spielman, and Van Campenhout 2023; Lecoutere, Kosec, et al. 2023; Lecoutere, Achandi, et al. 2023). Additionally, fostering cooperative models, producers' association activities, community and digital technology networks can empower female farmers by facilitating resource sharing, information and access to green technologies and sustainability (Akter et al. 2020; Nhamo and Mukonza 2020; Lecoutere, Spielman, and Van Campenhout 2023; Szalkowski and Johansen 2024).

Therefore, among policy implications, policies should focus on providing support to female farmers to expand their farm size and resources in the circular economy and green entrepreneurship contributing to sustainability (Coluccia, Palmi, and Krstić 2023; Pickson et al. 2024). This could include better access to credit, land, information and training programmes on green entrepreneurship that empower women in agriculture and entrepreneurial journey (Schaltegger, Loorbach, and Hörisch 2023; Vuciterna et al. 2024).

In addition, there is a need for designing targeted AECS programmes and measures that are more accessible to smaller and female-headed farms, cooperation and networking in green women's entrepreneurship (Chen and Barcus 2024; Kuppan et al. 2024). This can help reduce the gender gap. Role of incentive mechanisms and institutional quality on women's empowerment simplifying application processes and providing technical assistance could enhance participation (Qaiser, Rehman, and Arshed 2023; Raina, Zavalloni, and Viaggi 2024).

Efforts should be addressed to eliminate structural barriers that limit female farmers' access to land, resources, on- and off-farm diversification activities, and biodiversity conservation (El Benni and Schmid 2022; Lima and Cunha 2024). Gender-sensitive agricultural and employment policies particularly for younger female farmers can contribute to levelling the playing field (Unay-Gailhard and Bojnec 2021; Balezentis et al. 2021; Tsambou et al. 2024).

Finally, capacity building and digitalization by providing education and training on green entrepreneurship and sustainable agriculture, innovation and digitalization tailored to female farmers can improve their capacity, information, digital sustainability and eco-environmental sustainability to adopt and benefit from AECS measures (Kreft, Huber, Wuepper, and Finger 2021; Avelar et al. 2024; Lei and Yang 2024; Meinhold, Wagner, and Dhar 2024).

The broader relevance of these findings and policy implications extends to other CEE countries and EU countries with similar socio-economic conditions. Many post-socialist economies face persistent gender disparities in land ownership and other agricultural resources, mirroring the Hungarian context. Our presented insights offer a foundation for comparative analyses across CEE countries, with implications for addressing gendered barriers to sustainable agricultural practices (Njuki et al. 2022; Shortall and Marangudakis 2022, 2024). Empowering female farmers can have transformative effects, not only advancing pro-environmental behaviour and sustainability but also enhancing community resilience in the face of ecological challenges and socio-economic development in agriculture and in rural areas (Adebayo 2024; Kyoi, Uchiyama, and Mori 2024).

In conclusion, this study underscores the importance of integrating gender-sensitive approaches into agricultural policies to promote equity and sustainability. By addressing structural barriers and creating inclusive support mechanisms, policymakers can align AECS measures with the Sustainable Development Goals, particularly Goal 5 (Gender Equality) and Goal 13 (Climate Action) (Guerrero, Guariso, and Castañeda 2024; Gyimah, Appiah, and Appiagyei 2024; Sanchez Flores et al. 2024). These results provide actionable insights for tailoring AECS policies to enhance their inclusivity and effectiveness across diverse regional and socio-economic contexts.

6 | Conclusions

This study provides critical insights into the gender dynamics influencing the adoption and intensity of agri-environment-climate scheme (AECS) measures within Hungarian farms, highlighting systemic resource inequalities as key drivers of gender disparities. Therefore, it offers nuanced insights into how gender dynamics influences sustainable agricultural practices.

Our analysis confirms that while male-headed farms receive greater total AECS subsidies, primarily due to larger economic farm sizes and greater access to resources, female-headed farms demonstrate similar levels of AECS adoption intensity when these structural factors are controlled, underscoring their strong commitment to sustainable practices. This suggests that the disparities in AECS subsidies are rooted not in a lack of commitment or capability among female farmers but in systemic inequalities that limit their access to resources such as land and financial capital.

These findings contribute uniquely to the fields of gender dynamics and green entrepreneurship by demonstrating the resilience and potential of female farmers in advancing environmental sustainability despite resource constraints. These findings highlight the critical importance of addressing structural inequalities to support female farmers' capacity for green entrepreneurship. By levelling the playing field, female farmers can fully contribute to environmental sustainability. Empowering women in agriculture can have multiplier effects, enhancing household livelihoods and promoting community development.

Based on these findings, actionable policy recommendations emerge. First, gender-sensitive agricultural policies under the EU's CAP should address structural barriers, such as unequal access to land, credit, and advisory services. Simplifying AECS application processes and providing targeted financial and technical support to female-headed farms, particularly smaller ones, can enhance their participation. Second, capacity-building initiatives, such as training programs on sustainable practices, green technologies and green entrepreneurship, should focus on empowering female farmers. Third, fostering cooperative models and community networks can facilitate resource sharing and strengthen the social capital of female farmers, enabling them to overcome resource limitations.

The policy implications are clear: fostering an inclusive approach that enhances access to resources for female farmers can contribute significantly to sustainable agricultural development. Tailored interventions are necessary to bridge the gender gap and enable women to play a more active role in environmental sustainability. Such interventions may include targeted support programs, simplified application processes, and comprehensive training on green technologies. Additionally, policies promoting equal land rights and inheritance laws can address fundamental issues of land access.

The broader implications of these findings extend to other EU countries and regions with similar socio-economic conditions. Most of CEE countries face analogous challenges related to gender disparities in land ownership, resource availability and resource access, and farm management. This study offers a framework for analysing and addressing the interplay between gender dynamics and environmental sustainability in diverse contexts, providing a pathway for more inclusive and effective sustainability policies.

While this research sheds light on important gender dimensions in sustainable agriculture, it acknowledges certain limitations. The study focuses on Hungarian farms, so the findings may not be directly generalizable to other contexts with different socio-economic dynamics. Future research could build on this research framework by exploring gender dynamics in AECS adoption across other EU countries or extend to other regions with differing socio-economic and agricultural structures. Longitudinal studies examining how evolving policies influence gendered engagement in AECS measures would also be valuable. Additionally, research that explores the intersectionality of gender and integrates intersectional perspectives—such as the interplay of gender, age, education, and ethnicity—could deepen understanding of the barriers and opportunities faced by diverse groups of farmers.

Overall, this research contributes to the literature by presenting gender dynamics as a vital lens through which sustainable agricultural policies should be evaluated. It underscores the importance of integrating gender-sensitive approaches in environmental policy design to promote both equality and sustainability strengthening the resilience of agricultural systems to climate challenges. By addressing structural barriers and enhancing support for female farmers, policymakers can foster inclusive agricultural development that aligns with the Sustainable Development Goals, particularly Goal 5 (Gender Equality) and Goal 13 (Climate Action), promoting female empowerment in green entrepreneurship that can drive broader adoption of sustainable practices. This can ensure long-term environmental and economic sustainability in the agricultural sector. Finally, this study provides evidence-based actionable insights and a foundation for advancing gender equality and environmental sustainability in agriculture, contributing to a more equitable and resilient future, contributing and fostering a more equitable and resilient food system for future generations.

Author Contributions

Imre Fertő: conceptualization, data curation, formal analysis, investigation, methodology, funding acquisition, project administration, software, visualization, writing – original draft, writing – review and editing. **Štefan Bojnec:** conceptualization, methodology, investigation, validation, visualization, funding acquisition, project administration, writing – original draft, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the Hungarian Ministry of Agriculture but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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