Determinants of sustainability and cross-dimensional synergies: A comparison of Polish farms participating and not participating in short food supply chain

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Abstract. The prevailing view in the literature is that participation in short food supply chains (SFSCs) enhances farm sustainability. However, there is no clear consensus regarding the individual dimensions of sustainability and the relationships between them. Therefore, the aim of this article is to analyse the impact of selected variables on the economic, social, and environmental dimensions of sustainability, as well as to explore the synergies (trade-offs) between them. The analysis focuses on two groups of farms: those participating in SFSCs and those not involved, treated as a control group. The study is based on data from 199 Polish farms and applies structural equation modelling (SEM). The results indicate that participation in short supply chains leads to a more balanced and coherent sustainability profile. In particular, short selling primarily enhances social sustainability and strengthen coherence across sustainability dimensions, albeit at the cost of lower labour productivity. The findings for the environmental dimension remain ambiguous, indicating the need for further research.

Keywords: farm sustainability, short food supply chains, determinants, synergy, SEM model

JEL codes: Q01, Q12, Q13

1. INTRODUCTION

Short food supply chains (SFSCs) are commonly analysed within broader conceptual frameworks such as alternative food networks (AFNs), territorial embeddedness, resilience theory, and local food systems (Michel-Villarreal et al., 2019; Schmitt et al., 2017). Within the AFN perspective, SFSCs are viewed as alternatives to conventional agri-food systems, characterised by shorter physical and social distances, closer producer–consumer relationships, and a stronger territorial embeddedness that can foster local development and value creation (Galli et al., 2015; Sacchi et al., 2018).

The most common forms of SFSCs include farmers' markets (Yuna et al., 2016; Horská, Petriľák, et al., 2020), food hubs (Delibas, 2021), food-buying clubs (Benedek, 2023), and territorial short food supply chains (Reina-Usuga et al., 2022; Reina-Usuga et al., 2023; Nemes et al., 2023). These organizational forms are increasingly recognised for their potential contribution to economic, social, and environmental sustainability (Connolly et al., 2022; Marín et al., 2024; Mengoni et al., 2024; Török et al., 2024).

Despite these theoretical expectations, empirical evidence remains fragmented. Existing studies generally report positive economic outcomes, including improved profitability, resilience, and reduced income volatility (Collison et al., 2019; Menéndez and Molist et al., 2024), as well as social benefits related to rural employment, food security, and community engagement (Bayar, 2019; Doernberg et al., 2022). In contrast, findings regarding environmental sustainability remain inconsistent. While several studies report benefits associated with biodiversity conservation, organic farming, and shorter transport distances (Tiwari, 2021; Corvo et al., 2021), others suggest that conventional supply chains may achieve lower environmental impacts per unit of production (Csordás et al., 2022).

These inconsistencies indicate that sustainability in SFSCs cannot be assumed to be inherently superior across all dimensions. Rather, participation in SFSCs may generate both synergies and trade-offs between economic, social, and environmental sustainability. Although interactions between these dimensions have attracted growing attention, previous studies have primarily focused on economic–environmental relationships and rarely compare farms operating within SFSCs and conventional supply chains.

Against this background, this study aims to examine the relationships between economic, social, and environmental sustainability in farms participating and not participating in SFSCs. Using structural equation modelling (SEM), the three sustainability dimensions are modelled as latent constructs, allowing the identification of synergies and trade-offs between them and comparison of their structural relationships across both groups of farms. The empirical analysis is based on Polish agriculture, where small and medium-sized family farms dominate and SFSCs are increasingly promoted as a strategy to strengthen farm resilience, improve market access, and support sustainable rural development. Understanding how participation in SFSCs affects different sustainability dimensions is therefore relevant for both agricultural policy and farm management. The remainder of the paper is organised as follows. Section 2 reviews the relevant literature, Section 3 presents the methodology, Section 4 reports the empirical results, Section 5 discusses the findings, and Section 6 concludes.

2. BACKGROUND

Resilience theory frames SFSCs as organizational arrangements that can strengthen farms' adaptive capacity by reducing exposure to global market volatility, enhancing local networks, and increasing farmers' autonomy, particularly during economic crises or supply-chain disruptions (Gattone, 2024; Filippini et al., 2021). Similarly, local and regional food systems approaches emphasize the role of SFSCs in connecting production, distribution, and consumption at the local level, thereby contributing to food security, social cohesion, and environmental stewardship (Brunori and Galli, 2016; Stein and Santini, 2022; Jia et al., 2024).

From an economic perspective, SFSCs are generally associated with greater resilience, lower market uncertainty, and improved farm profitability. Their stronger orientation toward local markets reduces exposure to international disruptions, while direct producer–consumer relationships enable higher price margins and lower transaction costs (Berti and Mulligan, 2016; Van Hoyweghen et al., 2021; Collison et al., 2019; Drejerska and Sobczak-Malitka, 2023). Profitability and affordability have also been identified as key drivers of participation in SFSCs (Menéndez and Molist et al., 2024).

The literature also consistently highlights the social benefits of SFSCs. By strengthening local food systems, they support rural employment, food security, access to healthy food, and community engagement, thereby contributing to social cohesion and local development (Bayar, 2019; Doernberg et al., 2022; Corvo et al., 2021).

Evidence regarding environmental sustainability is less conclusive. Positive effects have been associated with greater crop diversity, biodiversity conservation, organic practices, and reduced food miles (Tiwari, 2021; Corvo et al., 2021). However, other studies report that longer and more centralized supply chains may generate lower environmental impacts per unit of production, particularly when measured by carbon footprint (Csordás et al., 2022).

Furthermore, several authors argue that environmental performance depends strongly on product type, supply-chain organization, and national context (Petruzzelli et al., 2023; Chiffoleau and Dourian, 2020; Evola et al., 2022; Enthoven and van den Broeck, 2021; Cui et al., 2024).

Beyond individual sustainability dimensions, previous studies have examined synergies and trade-offs between economic, environmental, and social sustainability. Most research has focused on economic–environmental interactions, reporting both synergies (Grzelak et al., 2022; Czyżewski and Guth, 2021; Galdeano-Gomez et al., 2017; Daraz et al., 2024; Arru et al., 2024) and trade-offs (Guth et al., 2022; van der Ploeg, 2016; Nicholls and Altieri, 2018; Anderson et al., 2019; Ebel, 2020; Baumer-Cardoso et al., 2020; Ait Sidhoum et al., 2022). Rüdele et al. (2024) conclude that synergies occur more frequently than trade-offs, while positive relationships between economic and social sustainability have been reported by Stępień et al. (2021), Ait Sidhoum et al. (2022), and Grzelak et al. (2022).

Building on these conceptual perspectives, this study provides a comparative empirical assessment of sustainability in farms participating and not participating in SFSCs. By jointly modelling economic, social, and environmental sustainability as latent constructs, it examines whether these dimensions reinforce each other or generate trade-offs under different supply-chain configurations.

3. METHODOLOGICAL APPROACH

3.1. Data set

The study is based on primary data collected from Polish farms using the Paper and Pencil Interview (PAPI) method and a structured questionnaire developed by the authors. Interviews were conducted between July and November 2023 in nine of the sixteen Polish provinces. Farms were randomly selected from databases provided by agricultural advisory centres, with the aim of obtaining comparable groups of farms participating and not participating in short food supply chains (SFSCs). The initial sample comprised 199 farms (94 SFSC and 105 non-SFSC), while the final analytical sample included 182 farms after data cleaning (86 SFSC and 96 non-SFSC). The dataset is publicly available at https://doi.org/10.18150/DFZQC1.

The study focused on small and medium-sized farms (up to 30 ha UAA and annual agricultural production below EUR 100,000), reflecting the dominant profile of farms engaged in SFSCs. The land criterion was established through expert consultation, whereas the economic threshold followed the Farm Accountancy Data Network (FADN) classification.

Table 1 summarizes the characteristics of the surveyed farms. Compared with the national average, the surveyed farms were larger, more productive, and managed by younger and better-educated farmers. SFSC and non-SFSC farms were broadly comparable in terms of farm size, production value, labour input, and managers' age. The main differences concerned gender structure and production profile. SFSC farms were more frequently managed by women and specialized more strongly in fruit and vegetable production, whereas non-SFSC farms exhibited higher cereal shares and livestock density. These production differences may partly explain variation in sustainability outcomes and are considered in the discussion.

Table 1. Basic characteristics of the farms under study with a division into SFSC and non-SFSC farms and with reference to data for Poland

Specifiaction	Farms surveyed on average	SFSC farms	Non-SFSC farms	Polish farms on average
Average area size (ha of UAA)	17.3.	16.0	17.9	11.6
Average output (in EUR)	49,080	48,007	50,034	34,920
Share of crop production (%)	59.0	62.9	57.1	37.3
AWU per farm	2.21	2.31	2.14	1.43
Age of the farm manager	46.8	47.1	46.6	50.7
Share of male manager (%)	76	**62*****	**90**	66

***For the share of male managers, a statistically significant difference was observed between SFSC and non-SFSC farms (for p<0.001). The nonparametric Kruskal-Wallis test was used for the analysis.
Source: own performance based on survey data and Statisics Poland, 2025.

Following the definition proposed by Jarzębowski et al. (2020), SFSCs were defined as supply chains involving no intermediaries or a maximum of one intermediary between producer and consumer. Direct on-farm sales constituted the dominant marketing channel (85%), followed by home delivery (41%), farmers' markets (31%), fairs and festivals (24%), online sales, deliveries to restaurants or schools (17% each), and own retail outlets (12%). Fruit, vegetables, dairy products, honey, and meat products were the most frequently marketed commodities.

3.2. Methods

The analysis was conducted in two stages. In the first stage, observable variables representing the economic, social, and environmental dimensions of sustainability were selected based on the literature, expert consultation, and data availability. The economic dimension included indicators of land and labour productivity. The social dimension comprised housing conditions, health status, and a socialisation index reflecting farmers' participation in educational activities, community events, and organizations. The environmental dimension included indicators describing crop diversity, crop structure, livestock density, and pesticide use. Variables retained for the final SEM model are presented in Table 2, while detailed definitions and selection criteria are provided in the Supplementary Materials.

Table 2. List of variables used to construct the three sustainability dimensions in SEM modelling

Sustainability dimension	**Variables shaping the construct in the SEM model**	**Variable name in the SEM model**

Economic	Land productivity: agricultural production/land area in; thous. EUR/ha	e1_prodHa
	Labour productivity: agricultural production/FWU; thous. EUR/FWU	eE2_prodWU
Social	Housing conditions subjective assessment: Likert scale from 1 to 5, where 1 – very bad, 5 – very good	s1_accom
	Health and physical condition subjective assessment: Likert scale from 1 to 5, where 1 – very bad, 5 – very good	s2_health
	Socialisation index: from 0 to 3, where 0 means very low level of socialisation, 3 – very high level	s3_social
Environmental	Monoculture index: measured by the Simpson's index[1]: from 0 to 1, the higher, the higher monoculture	V1_Simpson
	Share of cereals in the total crop area: from 0 to 1 e. 0%-100%)	V2_CerealShare
	Standardised livestock units index: from 0 to 1, the higher, the higher the animal density per unit area	V3-LargeUnit
	Expenditure on pesticides: EUR/ha	V4_pesticides

Source: own performance

In the second stage, Structural Equation Modelling (SEM) was applied to identify relationships between observable indicators and the three latent sustainability constructs (economic, social, and environmental), as well as correlations among these constructs. SEM enables simultaneous estimation of measurement and structural relationships while accounting for measurement error (Hoyle, 2012; Rabe-Hesketh et al., 2007). The analytical procedure comprised five steps:

- preparation and cleaning of survey data, followed by division into SFSC and non-SFSC groups;
- descriptive statistical analysis and examination of covariance matrices;
- estimation of measurement models and full SEM models for both groups;
- evaluation of model fit using standard goodness-of-fit indices;
- comparison and interpretation of relationships between sustainability dimensions across both groups.

[1] The index is calculated according to the formula: $SI = \Sigma P_i^2$, and $P_i = n/N$, where: n – area under cultivation of a given species (ha), N – total area under cultivation of all species on arable land (ha). The range of the index value is between 0 and 1. Values close to 1 indicate a clear dominance of one or several plant species and, at the same time, low species diversity of crops.

Based on the proposed conceptual framework, twelve hypotheses were formulated. Hypotheses H1–H2 referred to the economic construct, H3–H5 to the social construct, H6–H9 to the environmental construct, whereas H10–H12 examined relationships between the three sustainability dimensions. The complete list of hypotheses is presented in Table 5 and in Supplementary Table 1.

Model fit was evaluated using the Chi-square test, Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), Standardized Root Mean Square Residual (SRMR), and information criteria (AIC and BIC), following commonly accepted SEM recommendations (Hu and Bentler, 1999; Brown and Moore, 2012; Pavlov et al., 2021).

4. RESULTS

The analysis results began with the presentation of descriptive statistics for the variables constituting the constructs in the SEM analysis (see Table 3). Data were presented separately for farms participating and not participating in short supply chains, which allowed for comparative analysis. Regarding economic variables, farms participating in short selling were characterized by higher land productivity (production per unit of area) but lower labour productivity (production per unit of work). In the latter case, this results from the fact that involvement in SFSC requires higher labour inputs, for example, in the sales management process or product processing. In the case of social dimension, SFSC farms recorded better results for all three variables. Owners of these farms rated their housing conditions, health, and physical condition better, and were also more socially engaged. This higher social involvement is not surprising, as selling via short channels requires closer interactions with the environment. For environmental governance, SFSC farms recorded lower values. As these were destimulant variables, this result indicates greater environmental sustainability of farms participating in short supply chains. This suggests that farms participating in short supply chains exhibit higher environmental sustainability scores - as reflected in the env construct - characterized by greater crop diversification, a lower share of cereals in the crop structure, more extensive animal husbandry practices, and reduced pesticide use..

Table 3. Descriptive statistics of the variables used in the SEM model for SFSC and non-SFSC farms

Variables	non-SFSC (n=96)				SFSC (n=86)			
	mean	SD	min	max	mean	SD	min	max
				Economic construct				
Production (euro/ha)	2 795	3 484	464	13 747	3 001	4 367	589	20 568
Production (euro/AWU)	23 380	27 724	931	72 625	20 740	23 751	846	59 992
				Social construct				
Assessment of housing conditions	4.14	0.75	2.00	5.00	4.55	0.55	3.00	5.00
Assessment of health conditions	3.81	0.95	2.00	5.00	4.17	0.91	1.00	5.00
Index of socialisation	1.13	0.82	0.00	3.00	1.60	0.86	0.00	3.00
				Environmental construct				
Monoculture index	0.66	0.28	0.00	1.00	0.50	0.35	0.00	1.00
Share of cereals	0.54	0.29	0.00	1.00	0.41	0.32	0.00	0.95
Livestock Units (LU)	0.13	0.19	0.00	0.90	0.10	0.10	0.00	0.80
Pesticides expenditure (euro/ha)	113	143	0	862	93	99	0	517

Source: own calculations based on interviews database.

In the next step a structural equation modelling (SEM) analysis was performed to verify the relationships between three latent constructs - economic, environmental, and social, as well as to examine the influence of individual variables on these constructs. Figure 1 shows the general form of the SEM model for two groups of farms (SFSC and non-SFSC), and Table 4 reveals the values for individual links. In the following sections, relationships between observed variables are not discussed in depth, as the model's correlational CFA framework focuses on structural associations among the broader sustainability constructs (ECO, SOC, ENV), without directional paths enabling classical mediations (this issue was raised by Baron and Kenny already in 1986). This approach minimizes measurement error (Bollen, 1989), though it may conceal indicator-level trade-offs—such as the negative residual covariance between s2 and v4 (cov = -0.43***, p < 0.001 in non-SFSC), indicating tensions between social and environmental dimensions masked by a positive latent-level covariance (ENV, SOC = 0.66). These nuances are acknowledged here for contextual clarity, consistent with the study's focus on latent structures. Notably, the three-indicator rule is satisfied for SOC and ENV, ensuring identification and allowing for meaningful interpretation of such patterns.

Figure 1. SEM model for SFSC farms (left side) and non-SFSC farms (right side)

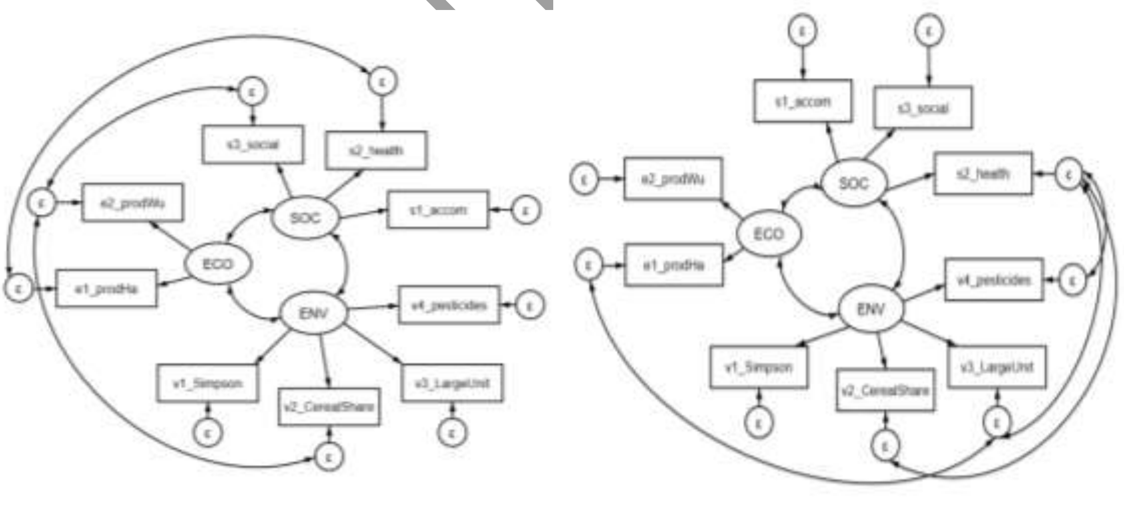

Table 4. SEM model parameters with factor intensity (standardized values) Beta(v1)=-1.

Parameters	mon-SFSC (0)			SFSC (1)		
	Coef.	Std. Err	P>z	Coef.	Std. Err	P>z
e1	0.83	0.13	0.00***	0.64	0.26	0.02*
e2	0.88	0.14	0.00***	0.28	0.14	0.05*
s1	0.69	0.11	0.00***	0.55	0.11	0.00***
s2	0.19	0.13	0.15	0.51	0.12	0.00***

s3	0.56	0.11	0.00***	0.61	0.11	0.00***
v1	-0.28	0.12	0.02*	-0.63	0.12	0.00***
v2	-0.42	0.12	0.00***	-0.80	0.13	0.00***
v3	-0.31	0.13	0.02*	-0.21	0.12	0.08
v4	0.65	0.13	0.00***	0.27	0.12	0.02*
cov(eco,soc)	0.22	0.14	0.12	0.70	0.33	0.04*
cov(eco,env)	-0.23	0.15	0.05*	0.46	0.25	0.05*
cov(env,soc)	0.66	0.16	0.00***	0.50	0.15	0.00***
cov(e1,v3)	0.31	0.14	0.03*	-	-	-
cov(s2,v2)	0.40	0.11	0.00***	-	-	-
cov(s2,v3)	0.17	0.10	0.09	-	-	-
cov(s2,v4)	-0.43	0.14	0.00***	-	-	-
cov(e1,s2)	-	-	-	-0.35	0.19	0.05*
cov(e2,s3)	-	-	-	-0.22	0.14	0.11
cov(e2,v2)	-	-	-	0.32	0.19	0.09

Source: own calculations based on interviews database.

Economic variables (e1 and e2) have a statistically significant, positive impact on economic sustainability, with the strength of this relationship being higher for farms not participating in SFSCs. The signs for relationships are consistent with the accepted hypotheses. In the case of social variables (s1, s2, and s3), a statistically significant, positive relationship with social dimension is observed for all three elements in SFSC farms, while in non-SFSC farms, this significance applies to s1 (assessment of housing conditions) and s3 (level of socialization). Similarly to above, the signs for relationships are consistent with the accepted hypotheses. In turn, among environmental variables, all four are statistically significantly associated with environmental dimension for non-SFSC farms, while for SFSC farms, this relationship applies to three cases (v3 is excluded). In contrast to the economic and social areas, the signs of relationships between variables v1, v2 and v3 and environmental sustainability are negative. The exception is the variable v4, which is positively related, i.e. differently than assumed in the hypothesis. Regarding the relationships between the constructs themselves, in farms participating in short supply chains, statistically significant, positive relationships were observed between three pairs of dimensions: economic and social, economic and environmental, and environmental and social, which is consistent with the assumptions of our hypotheses. Thus, it can be concluded that in the case of SFSC farms, there is a coherence between the three areas of sustainability. However, in the case of non-SFSC farms, the same positive relationship applies to the environmental-social pair. In the case of the economic-social pair, the relationship turned out to be statistically insignificant, while in the case of the economic-environment pair, a negative relationship was observed. Therefore, a trade-off occurred between the pair of economic sustainability and environmental actions. Table 5 synthetically presents the described results in relation to the adopted hypotheses.

Table 5. The results of the SEM model against the background of the adopted hypotheses

No.	**Relation**	**nonSFSC**			**SFSC**	
		Expected sign	**SEM result**	**Conclusion**	**SEM result**	**Conclusion**
H1	Land productivity has a positive impact on economical dimension/construct	+	+	accepted	+	accepted
H2	Labour productivity has a positive impact on economical dimension/construct	+	+	accepted	+	accepted
H3	Good housing conditions have a positive impact on social dimension/construct	+	+	accepted	+	accepted
H4	Good health condition has a positive impact on social dimension/construct	+	not significant	no basis for accepting/ rejecting the hypothesis	+	accepted
H5	High level of socialisation has a positive impact on social dimension/construct	+	+	accepted	+	accepted
H6	Crop monoculture has a negative impact on environmental dimension/construct	-	-	accepted	-	accepted
H7	High share of cereals has a negative impact	-	-	accepted	-	accepted

	on environmental dimension/construct				
H8	High animal density per unit area has a negative impact on environmental dimension/construct	-	-	accepted	not significant	no basis for accepting/ rejecting the hypothesis
H9	High usage of pesticides has a negative impact on environmental dimension/construct	-	+	rejected	+	rejected
H10	economic and social dimensions/constructs are positively correlated	+	not significant	no basis for accepting/ rejecting hypothesis	+	accepted
H11	economic and environmental dimensions/constructs are positively correlated	+	-	rejected	+	accepted
H12	environmental and social dimensions/constructs are positively correlated	+	+	accepted	+	accepted

Source: own performance.

At the end of the results section, it is worth mentioning the model fitting. Both models converged and showed excellent goodness-of-fit. For the non-SFSC group, the model showed a non-significant chi-square statistic ($\chi^2(20) = 18.432$, $p = 0.559$), indicating no significant difference between the model and the data. Other fit indices, such as RMSEA = 0, CFI = 1.000, and TLI = 1.021, confirm an excellent model fit. The standardized root mean squared residual (SRMR) was 0.062, and the coefficient of determination (CD) was 0.971, further supporting the model's predictive power. For the SFSC group, the SEM also yielded robust fit statistics: $\chi^2(21) = 16.795$, $p = 0.723$, RMSEA = 0, CFI = 1.000, and TLI = 1.105. The SRMR was 0.053, and CD reached 0.931. These results confirm the appropriateness of the model structure for this subgroup. For all models, no modification indices were reported, as all MI values were less than 3.841. Prior to estimation, descriptive statistics and the covariance matrix were analysed.

5. DISCUSSION

5.1. Economic dimension

In line with hypotheses H1 and H2, both land and labour productivity were found to have a positive influence on economic performance. However, the strength of these relationships varied between groups. Non-SFSC farms exhibited stronger effects, particularly with regard to labour productivity, whereas SFSC farms displayed weaker associations. This divergence suggests that participating in short supply chains alters the relationship between productivity and sustainability. The higher labour demands inherent in SFSC operations (e.g. direct marketing, product processing and customer interaction) reduce the importance of labour efficiency as a driver of economic sustainability. Although this reduces economic efficiency per worker (as shown by the model), this issue can be viewed from the perspective of its potential implications for local employment and the multifunctional role of agriculture. This is consistent with studies that have identified labour intensity as a structural characteristic of localised food systems (Marsden et al., 2000; Kneafsey et al., 2013, Mundler and Jean-Gagnon, 2019). Nevertheless, the positive effect on land productivity observed in both groups highlights the pivotal role of efficient land use in ensuring the economic viability of farms (Latruffe 2010). The positive and significant effect of land productivity on economic constructs is intuitive: farms that achieve a higher output per hectare make more efficient use of their primary production factors. In contexts where land is limited, productivity improvements directly increase profitability and resilience (Latruffe et al., 2017). This relationship remains consistent across both SFSC and non-SFSC farms, indicating that land productivity is a universal factor in achieving economic sustainability.

5.2. Social dimension

The findings strongly support hypotheses H3–H5 for SFSC farms, confirming that housing and health condition, as well as social engagement all contribute to perceived social sustainability. For non-SFSC farms, however, only housing setting and socialisation were significant, with no effect observed for health (H4). SFSC farms' stronger performance across social indicators highlights the importance of relational embeddedness and community interaction, which are fostered by direct sales models (Brunori et al., 2016). Higher social engagement among SFSC farmers may also reinforce subjective well-being and health perception, thereby creating a feedback loop between social capital and individual sustainability outcomes. Kneafsey et al. (2013) pointed out that in the EU, social values (such as access to quality products and direct contact with producers) are typically emphasised in SFSCs over environmental or economic values. These findings are in line with the work of Floriš et al. (2022) who state the ability of farmers operating in the SFSC to produce added-value products and improve their social situation. A higher subjective assessment of housing quality greatly enhances social sustainability. Adequate housing reflects material well-being, stability, comfort and security. Better living conditions improve the quality of life for farming families and strengthen their social standing within the community (Wojewódzka-Wiewiórska et al. 2020). Self-assessed health significantly contributes to social dimension, particularly in SFSC farms (Charatsari et al. 2020). Good health underpins the ability to engage actively in farming, local networks, and civic activities (Nummela et al. 2008). The stronger effect in SFSC farms may reflect the fact that direct marketing and diversification require high physical and social engagement, making health a more central component of sustainability. A high level of socialisation directly enhances social dimension (Martins et al. 2023). Active participation in community life fosters trust, mutual support and collective resilience. For farmers, social engagement reduces isolation and provides access to shared knowledge and resources, facilitating cooperation in areas such as marketing and resource use. Socialisation is particularly integral to SFSC farms because short supply chains depend on frequent interaction with consumers, markets, and local institutions (Dupé et al. 2025).

5.3. Environmental dimension

The results concerning environmental sustainability present a more complex picture. As hypothesised, monoculture (H6) and cereal share (H7) had a negative impact on environmental performance in both groups, whereas high animal density (H8) was significant only for non-SFSC farm. For SFSC farms, the lack of significance of H8 may reflect more extensive, small-scale husbandry practices that mitigate environmental pressures. A higher monoculture index worsens environmental sustainability, as expected. Concentrating production on a single crop reduces biodiversity, depletes soil nutrients, and increases vulnerability to pests and diseases (Altieri, 1999). Farms with high monoculture levels are therefore more reliant on chemical inputs and less resilient to environmental shocks. Similarly, a high cereal share in crop structure has a negative effect on environmental dimension (Yang et al. 2024). Large cereal dominance is associated with reduced crop rotation, higher fertilizer requirements, and a narrowing of on-farm biodiversity (Moss et al. 2020). These practices not only degrade soil health but also increase the ecological footprint of farming (Stoate et al., 2001). The standardized livestock unit index highlights the environmental risks of intensive animal husbandry. High animal densities per hectare are linked to nutrient surpluses, water pollution, and greenhouse gas emissions (Steinfeld et al., 2006). While moderate livestock densities can contribute to nutrient cycling and landscape management, excessive stocking levels exert pressure on ecosystems. The weaker effect in SFSC farms may reflect smaller herd sizes and more extensive practices. Notably, pesticide use (H9) exhibited an unexpected positive correlation with environmental sustainability in both groups, contradicting the hypothesis. This result may appear counterintuitive, as pesticides are typically considered detrimental to ecosystems. However, several explanations can be proposed:

1. Threshold effects. At low or moderate levels, pesticide use may not generate severe ecological harm, while still contributing to crop protection and yield stability (https://pesticidefacts.org/topics/necessity-of-pesticides/). This aligns with the concept of integrated pest management, where judicious pesticide use reduces pest pressure without excessive environmental costs (Muniz-Junior et. al 2023).
2. Efficiency in diversified systems. In SFSC farms, expenditure on pesticides might reflect targeted and efficient use within diversified crop systems, where lower overall input levels reduce the ecological footprint despite some financial outlay (Pecenka et al. 2021).
3. Measurement limitation. Because the variable is measured as expenditure (EUR/ha), it may capture cost rather than absolute chemical load. Farmers who invest in newer, more effective (and possibly more expensive but lower-dose) pesticides could appear to have higher expenditures despite applying fewer active ingredients (Guinet et al. 2023).
4. Farmers' perception and reporting. It is possible that farms reporting some pesticide use are better managed overall, integrating pest management into a broader sustainability strategy, compared to farms that report minimal expenditures but rely on less sustainable alternatives.

This anomaly highlights the need for more precise ecological indicators (e.g., pesticide application rates in active substance (kg/ha) or toxic units) rather than purely financial expenditure. It also suggests that pesticide use should not be treated as a strictly linear harmful factor, but rather as a context-dependent practice whose impact depends on intensity, type, and management strategy (Cooper & Dobson, 2007; Guinet et al. 2023).

5.4. Inter-construct relationships between sustainability dimensions

The correlations among the three sustainability dimensions further highlight the structural differences between SFSC and non-SFSC farms. In SFSC farms, all three correlations (H10–H12) were positive and significant, indicating systemic coherence across economic, social and environmental dimensions. This integrative pattern reflects the multifunctionality of SFSCs, where economic performance coexists with community well-being and ecological stewardship (Schermer et al., 2011). Similar results can be found in the work of Malak-Rawlikowska et al. (2019) who showed that producers participating in SFSCs often experience higher economic and social outcomes. There are also ambiguous environmental results, depending on indicators used. This supports the idea that SFSCs tend to have coherence among dimensions, but that environmental-economic trade-offs are context-dependent. In contrast, non-SFSC farms exhibited clear trade-offs: the economic–environmental relationship (H11) was negative, while the economic–social relationship (H10) was not statistically significant, which was also a topic in the work of Ait Sidhoum, Dakpo and Latruffe (2022) in Spanish farms conditions and Czyżewski and Guth (2021) for the EU FADN data context. These findings corroborate the long-standing debate about the tensions between economic efficiency and environmental sustainability in conventional farming (Tilman et al., 2002). Therefore, participation in the SFSC appears to reduce such trade-offs, fostering complementarities among sustainability goals.

To sum up, the results of the SEM analysis reveal important differences in the internal structure of sustainability between farms participating in short food supply chains and those operating outside such systems. In SFSC farms, the observed positive and statistically significant relationships between all three sustainability dimensions indicate a high degree of coherence, suggesting that economic, social, and environmental objectives are mutually reinforcing rather than competing. This finding supports the notion that SFSCs create conditions conducive to integrated sustainability, where improved economic outcomes may be accompanied by enhanced social relations and environmentally responsible practices.

In contrast, non-SFSC farms exhibit a more fragmented sustainability structure. While the positive relationship between environmental and social dimensions suggests that socially embedded practices may still support environmental responsibility, the absence of a significant link between economic and social sustainability, along with the negative relationship between economic and environmental dimensions, points to a clear trade-off. This trade-off implies that economic performance in non-SFSC farms may be achieved at the expense of environmental actions, likely due to stronger market pressures, longer supply chains, and limited opportunities to internalize environmental benefits through higher prices or closer consumer relationships.

The negative associations observed for several environmental variables further indicate that environmentally oriented practices may impose short-term economic costs, particularly in farms not integrated into SFSCs. Conversely, the positive relationship of variable v4 with environmental sustainability suggests that certain environmental actions may be more easily aligned with farm performance, highlighting the heterogeneous nature of environmental strategies.

These findings have several implications. From a theoretical perspective, they support the view that sustainability should be analysed as an interdependent system rather than isolated dimensions, with institutional arrangements such as SFSCs playing a crucial mediating role. SFSCs appear to foster complementarities rather than trade-offs, supporting integrated sustainability frameworks. From a practical standpoint, participation in SFSCs may help farmers mitigate sustainability trade-offs by enabling better valorisation of social and environmental efforts. However, this may come at the cost of lower conventional productivity indicators, highlighting the need for tailored performance assessment tools. Finally, from a policy perspective, the results underline the importance of targeted support for SFSC development, through targeted measures such as investment in local infrastructure, advisory services, and incentives that reward environmental and social outcomes, as well as incentives that reduce the economic burden of environmental practices in conventional supply chains.

6. CONCLUSIONS

The results demonstrate that participation in short food supply chains (SFSCs) creates a more balanced and coherent sustainability profile than conventional farming systems do. Overall, the analysis suggests that participation in SFSCs primarily enhances social sustainability and fosters coherence across sustainability domains, albeit at the cost of reduced labour productivity. From a policy perspective, this highlights the need to support SFSC farms by compensating for their higher labour demands through measures such as training, cooperative marketing and digital platforms. In terms of the environment, the findings reaffirm the risks associated with monoculture and cereal dominance, while the counterintuitive result regarding pesticides highlights the need for more refined indicators to better capture ecological impacts..

6.1. Limitations

While the study provides meaningful insights into the structural dynamics of sustainability across SFSC and non-SFSC farms, several limitations should be acknowledged. The sample sizes for both groups (SFSC = 86; nonSFSC = 96) were adequate for SEM, particularly given the relatively simple model structure, although larger samples would further strengthen the generalisability and stability of parameter estimates. The distribution of some variables, such as pesticide usage, exhibited skewness and extreme values; however, SEM with maximum likelihood estimation is generally robust to such deviations, and all models demonstrated excellent fit. Several observed indicators, including the monoculture index and cereal share, were treated as continuous variables despite having ordinal characteristics, which is a common practice in SEM, although alternative approaches such as GSEM could be considered in future research. Although no serious multicollinearity issues were detected, some correlations between observed variables were relatively high, particularly between e1 and e2 in the non-SFSC group; however, this did not compromise overall model validity. Certain covariances, such as those between economic and environmental dimensions in the SFSC group, were only marginally significant, reflecting the complexity of relationships in real-world agricultural systems rather than model misspecification. The models were carefully specified based on theoretically grounded hypotheses, yet as with any empirical study, there is always the possibility of omitted variables, such as farm size, policy influences, or regional factors. Finally, the cross-sectional nature of the data limits causal inference; however, the identified associations provide a valuable basis for understanding sustainability dynamics in agricultural contexts.

Compliance with the Pre-Publication Policy

The authors affirm that the material in the manuscript has not been published, is not being published or considered for publication elsewhere, and will not be submitted for publication elsewhere unless rejected by the journal editor or withdrawn by the authors.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and materials

Data and materials will be made available on request.

Ethical Approval

Ethical approval statement do not apply to this research.

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