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Recognizing diversity to enable an agroecological transition: understanding the potential of family farmers in Portugal

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The agroecological transition of family farms in Portugal poses a significant challenge within the framework of the Common Agricultural Policy (CAP) and the European Green Deal. Despite their multifunctional contributions to rural territories, family farms—particularly smallholders—remain structurally disadvantaged by policy frameworks that continue to favor large-scale, high-input agricultural models. This study demonstrates that aligning family farming with agroecological principles yields tangible benefits and requires support through differentiated, typology-sensitive public policies. Using a tailored methodology, data were collected from 40 farms initially classified as conventional or agroecological. Ward's hierarchical clustering, supported by complementary significance tests, identified three distinct farmer typologies: conventional, proto-agroecological, and agroecological. These typologies reflect meaningful differences in ecological integration, systemic thinking, and social engagement. The findings highlight the need for targeted policy frameworks that recognize farm diversity and promote multiple pathways toward agroecology. This typology-based approach provides an empirically grounded foundation for designing more inclusive and context-responsive institutional support for family farmers in Portugal.

KEYWORDS

agroecology, food systems, territorial governance, policy instruments, cluster analysis

1 Introduction

The agroecological transition of family farms in Portugal is a crucial challenge within the framework of the Common Agricultural Policy (CAP) and the European Green Deal in its Farm to Fork and Biodiversity Strategies. These EU instruments predominantly support large-scale, high-input farms, limiting family farms and smallholders' access to financial and technical resources for agroecological transitions (Gava et al., 2022; Linares Quero et al., 2022; Viegas et al., 2023; Dinis, 2024).

However, family farming remains central to agricultural production in capitalist economies, despite modernization policies that have prioritized efficiency and productivity (Dinis, 2019; Costa et al., 2022). Beyond production, these farms contribute to household food security, local knowledge preservation, and natural resource conservation, playing a multifunctional role within rural communities. Nonetheless, CAP's subsidy distribution disadvantages family farms and smallholders, restricting their ability to meet new sustainability requirements while reinforcing structural inequalities that favor capital-intensive farming systems. Additionally, the implementation of Farm to Fork and Biodiversity Strategies does not fully account for the constraints faced by family farms, who often struggle with certification, regulatory compliance, and access to sustainability incentives (Prost et al., 2023; Huber et al., 2024). Larger and intensive farms, with greater financial stability and technical capacity, are better positioned to adapt, exacerbating disparities between industrialized and family farming models (Prost et al., 2023).

In Portugal, the Common Agricultural Policy (CAP) continues to inequitably support farms engaged in low-input, diversified agroecological practices—particularly those of smaller scale. Recent research shows that approximately 40% of Portuguese farmers receive no CAP support, with exclusion rates exceeding 60% for farms under two hectares (Viegas et al., 2023). Access to funding is further hindered by bureaucratic complexity, restrictive eligibility criteria, and limited administrative assistance. Meanwhile, subsidies remain heavily concentrated on large-scale, commodity-oriented farms. Mediterranean farming systems—such as orchards, olive groves, vineyards, and diversified horticulture—receive disproportionately less support compared to cereal and livestock operations, thereby discouraging transitions toward agroecology (Dinis, 2024).

Studies show that CAP Pillar I direct payments, particularly land-based subsidies, are among the least effective instruments for supporting agroecology, whereas CAP Pillar II measures, such as agri-environmental schemes, organic farming incentives, and support for short supply chains, demonstrate greater potential. However, these instruments are often underfunded and hindered by implementation challenges (Gava et al., 2022; Linares Quero et al., 2022).

A transition to agroecology among family farms requires policies that integrate farm, household, and community dynamics rather than relying on top-down modernization approaches (Costa et al., 2022). Recognizing the diverse pathways of agroecological transition—including traditional knowledge, local networks, and multifunctional rural roles—would allow for more tailored support mechanisms aligned with farmers' socio-economic and environmental contexts.

Despite the increasing recognition of farm diversity in policy research, many existing farmer classifications remain static, simplistic, and poorly integrated into CAP decision-making (Fanchone et al., 2020; Graskemper et al., 2021). Policies often neglect informal farmer networks, on-farm experimentation, and knowledge-sharing mechanisms, which are critical for agroecological transitions (Teixeira et al., 2018). Additionally, short-term policy assessments fail to account for the long-term nature of these transitions, leading to misaligned incentives and inadequate support (Prost et al., 2023).

Agroecology offers significant potential to strengthen the resilience and viability of family farms. As Costa et al. (2022) highlight, these farms are deeply rooted in traditional practices and play a multifunctional role in rural areas, yet they often face vulnerabilities due to limited technical support and exposure to environmental and health risks. Altieri (2009) and Altieri and Nicholls (2020) emphasizes that agroecological practices—grounded in ecological principles and traditional knowledge—can improve soil health, biodiversity, and productivity, resulting in more stable yields, diversified income, and improved nutritional outcomes. Bezner Kerr et al. (2021) support this perspective, noting that agroecology enhances food security and nutrition among smallholder households through direct consumption of diverse foods, increased agricultural income, and shifts in gender relations.

To develop more effective public policies that support agroecology, it is essential to characterize family farms by considering their structural characteristics, production models, market integration, and agricultural practices (Huber et al., 2024). This study seeks to demonstrate that aligning family farming with agroecological principles can generate meaningful benefits and that these synergies must be acknowledged and supported through differentiated, context-sensitive public policies. By identifying and characterizing farm types along a gradient of agroecological transition, it seeks to shed light on the diversity of pathways within family farming and to reinforce the need for policy strategies that address the specific needs, constraints, and contributions of these farmers.

2 Materials and methods

To demonstrate the benefits of aligning family farming with agroecological principles—and to underscore the need for tailored public policies that support such synergies—this study employed a methodological approach that integrates two analytical frameworks: the Tool for Agroecology Performance Evaluation (TAPE), developed by the Food and Agriculture Organization of the United Nations (FAO), and the Agroecological Criteria Tool (ACT), created by Biodivision (Costa-Pereira et al., 2024). This combined methodology was specifically designed to assess farmers' agroecological performance by measuring the adoption of core agroecological principles and practices, thereby providing a robust foundation for evidence-based policy recommendations.

2.1 Sample characteristics

The methodology was applied between October 2023 and January 2024 to a sample of 40 farms distributed across five NUTS II regions of continental Portugal—North, Center, Lisbon Metropolitan Area (AML), Alentejo, and Algarve—capturing the diversity of the country's agricultural landscapes and sociocultural contexts. The sample comprised 20 matched pairs of farms, each including one agroecological and one conventional farm, located within the same territorial area. The regional distribution was as follows: Norte (*n* = 14), Centro (*n* = 6), Lisbon Metropolitan Area—AML (*n* = 8), Alentejo (*n* = 6), and Algarve (*n* = 6; Figure 1). This paired and stratified sampling approach was intended to ensure comparability by minimizing variation in farm scale, crop types, local food system characteristics, and edaphoclimatic conditions.

Farms were selected according to three main criteria to ensure internal consistency. First, all farms engaged primarily in horticultural production—accompanied by other complementary agricultural activities—to maintain a consistent production focus. Second, agroecological farms were defined by the exclusion of synthetic inputs, such as fertilizers and pesticides. The non-use of synthetic fertilizers and pesticides was applied as an initial filter to identify farms potentially aligned with agroecological principles, within a broader, multidimensional framework that does not define agroecology solely through input-based criteria but rather seeks to capture systemic transitions.

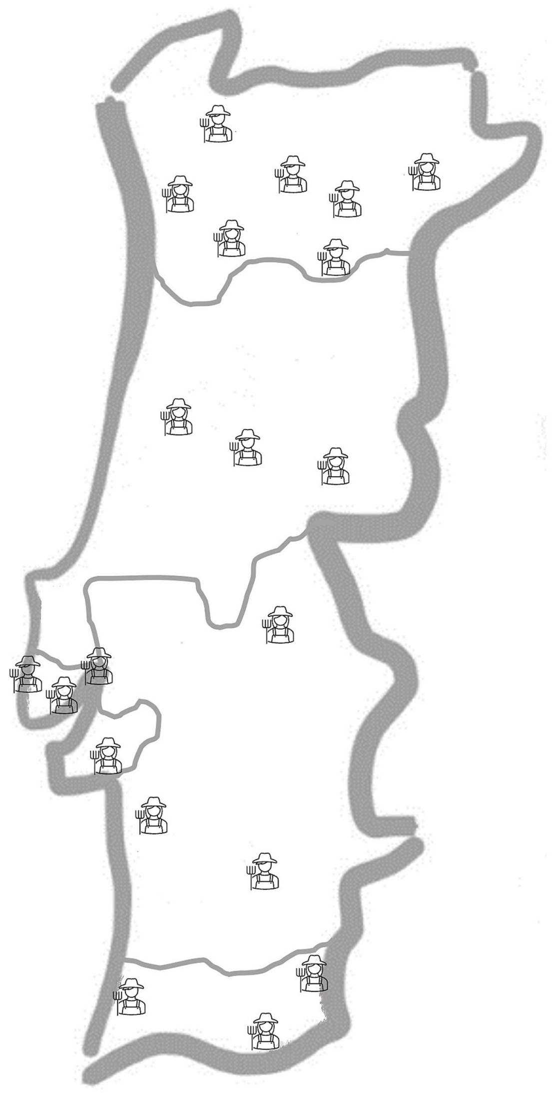

FIGURE 1
Location of the 40 farms visited (pairs of 20 agroecological/20 conventional) per NUTS II.

2.2 Data collection and analysis procedure

Data collection was carried out through field visits and semi-structured interviews using a standardized questionnaire, developed according to the methodology proposed by Costa-Pereira et al. (2024). Farmers' responses were codified in binary or scaled formats, depending on the variable type: binary variables were coded as 0 or 1, while scaled variables captured increasing levels of characteristics such as education level or household income.

Based on these responses, 26 indicators were constructed and scored on a scale from 0 to 4, with 0 indicating low performance and 4 indicating high agroecological performance (in Supplementary Materials). These indicators were grouped into 10 agroecological dimensions, encompassing both agroecosystem management and food system interactions. The eight dimensions related to the agroecosystem were: (1) plant production, (2) animal production, (3) soil regeneration, (4) water cycle regeneration, (5) pest, disease and weed management, (6) ecological synergies, (7) economic synergies, and (8) social synergies. The two dimensions relating to the local/global food system were: (9) interaction with the local food system, and (10) sharing agroecological knowledge.

Each dimension incorporated multiple indicators. For example, the soil regeneration dimension includes practices related to soil fertility management and soil–plant systems, while plant production includes seed management and the integration of trees into cropping systems. Economic synergies reflect internal input use, income stability, and renewable energy adoption. Ecological synergies assess the farm's integration with the surrounding landscape. Social synergies capture working conditions, gender and youth empowerment, and food security. The sharing of agroecological knowledge includes access to information, traditional know-how, and farmer-to-farmer knowledge exchange. This multidimensional structure allowed for a comprehensive and nuanced assessment of each farm's agroecological performance, serving as a basis for subsequent clustering and policy-relevant analysis (Table 1).

The methodology included a specific section on public policy preferences to identify the institutional levers that farmers perceive as most effective in supporting the agroecological transition. Farmers were asked to indicate their preferred types of policy measures across four categories: (1) regulatory measures, such as the prohibition or taxation of synthetic chemical pesticides; (2) certification controls to ensure credibility and accessibility of agroecological certification systems; (3) economic support, including subsidies and financial incentives tailored to agroecological farming; and (4) education and awareness-raising initiatives targeting farmers, consumers, and society more broadly.

The analytical process aimed to classify farms according to their level of agroecological adoption and identify key patterns of differentiation. For this purpose, hierarchical clustering was applied to the indicator matrix, using Euclidean distance to compute the distance matrix and Ward's method for linkage. Ward's method was selected for its ability to minimize within-cluster variance and enhance the interpretability of the resulting clusters (Johnson and Wichern, 2007).

To assess the robustness of the clustering solution, three additional approaches were tested. First, alternative hierarchical methods—centroid and complete linkage—were applied. Centroid linkage evaluates cluster similarity based on the distance between group means, while complete linkage calculates the maximum distance between observations across clusters, thereby reinforcing internal cohesion. Second, K-means clustering was conducted to minimize intra-cluster variability and explore potential alternative segmentations. This cross-validation framework allowed for the testing of consistency and stability in the cluster solution.

To validate and refine the clustering further, a sensitivity analysis was performed on the grouped questionnaire data. Each agroecological dimension was tested to evaluate its capacity to discriminate between clusters. Given the small sample size and the ordinal nature of much of the data, the non-parametric Kruskal–Wallis test was used to assess the statistical significance of differences across clusters. Following this, Principal Component Analysis (PCA) was conducted on each dimension to identify the most explanatory indicators contributing to overall variance and cluster differentiation (Peres-Neto et al., 2003). To deepen the analysis, individual significance tests were applied to the key

TABLE 1 Indicators distribution per agroecological dimension.

10. Agroecological dimension	26 Indicators
1. Plant production	1. Integration with trees
	2. Seed management
2. Animal production	3. Animal species management
	4. Animal welfare
3. Soil regeneration	5. Soil fertility management
	6. Soil–plant management system
4. Water cycle regeneration	7. Water saving
5. Pest, disease and weed management	8. Pest and disease management
	9. Registration of production and pests, diseases and weeds
6. Ecological synergies	10. Integration: crops/animals
	11. Connectivity between elements of the agroecosystem and the landscape
	12. Biodiversity
	13. Biomass and non-biomass recycling
7. Economic synergies	14. Energy production and renewal
	15. Use of internal inputs
	16. Diversity of production activities and services
	17. Stability of income/production and ability to recover from disturbances/environmental resilience and ability to adapt to climate change
8. Social synergies	18. Production and household needs/ adequate food and nutritional awareness
	19. Dignification of farmers/working conditions
	20. Women's empowerment
	21. Youth empowerment and emigration
9. Interactions with the Local Food System	22. Producer networks, consumer relations and presence of intermediaries
	23. Empowerment of producers/mechanisms to reduce vulnerability/Participation of producers in the governance of land and natural resources
	24. Relations with the community
10. Sharing agroecological knowledge	25. Local or traditional identity and awareness: includes traditional knowledge for food preparation
	26. Access to agroecological knowledge and producers' interest in agroecology.

variables identified through PCA within each dimension. These results were examined alongside the indicator-level scores to enrich the interpretation of intra- and inter-cluster similarities and differences.

To ensure statistical rigor in profiling the identified clusters, assumptions of normality and homogeneity of variance for multidimensional scaling (MDS) scores were first tested. Depending on the distributional properties, either parametric (ANOVA) or non-parametric (Kruskal–Wallis) tests were performed. All statistical analyses were carried out using IBM SPSS Statistics software (version 29), with a significance level set at 5% ($p < 0.05$).

3 Results

The average farm size across all regions was approximately 9 hectares and the average age of farmers ranged from 50.3 years in Alentejo to 57.5 years in Centro. Education levels also varied, with Norte displaying the highest average level (equivalent to a licentiate degree), and AML the lowest (typically professional training or secondary education). Farming experience, measured by the number of years engaged in agricultural activity, varied widely across the sample. Farmers in AML reported the highest average years of experience (35 years), while Alentejo reported the lowest average (12 years). Taken together, these variables provide important contextual insight into the demographic and structural profile of the sampled farms, which may influence the capacity to adopt agroecological practices (Table 2).

3.1 Indicators matrix analysis

Three clusters of farmers were identified based on their performance across the 26 agroecological indicators. To characterize the clusters, the mean and standard deviation of each of the 26 agroecological indicators were calculated, followed by the application of mean comparison tests to assess statistically significant differences among clusters. This analysis enabled the identification of patterns across clusters and the detection of indicators that contributed most to their differentiation (Table 3).

The analysis of the 26 agroecological indicators across the three clusters revealed statistically significant differences for the vast

TABLE 2 Sociodemographic characteristics of the farms by NUTS II region.

Region	Number of farms	Avg. farm area (ha)	Avg. age	Avg. education level (1–8)	Avg. years as farmer
Norte	14	9.80	50.8	4.71	23.4
Centro	6	6.50	57.5	4.17	33.8
AMLisboa	8	6.60	57.0	4.00	35.0
Alentejo	6	6.52	50.3	4.33	12.0
Algarve	6	15.47	51.8	4.50	29.7

majority of variables, highlighting the heterogeneity in agroecological practice adoption among the sampled farms. Only three indicators—*youth empowerment and emigration, producer networks and consumer relations, and relations with the community*—did not show statistically significant variation across clusters. These dimensions, which are more closely linked to broader social dynamics and community-level interactions, appear to be less sensitive to the structural and operational differences captured through the clustering process, or may require larger sample sizes to detect significant variation.

Among the indicators that did differentiate the clusters, *integration with trees, water saving, and biodiversity* presented significant variation across all three clusters. These practices are central to ecological design and conservation, offering critical insight into the extent and nature of the agroecological transition processes underway on these farms.

Cluster 2 consistently achieved the highest scores across most indicators, reflecting a strong commitment to integrated, diversified, and ecologically grounded farming systems. Farmers in this cluster demonstrated widespread adoption of agroecological management practices, particularly in areas such as *seed systems, pest and disease control, energy use, income stability, and biodiversity enhancement*. This group also reported higher levels of social and institutional engagement, with especially strong scores in indicators related to *working conditions, gender equity, and traditional knowledge*. The overall profile of Cluster 2 represents farms that are not only adopting agroecological practices but are also consolidating their ecological and social strategies within a broader systems-based approach.

In contrast, **Cluster 3** presented the lowest mean scores across most agroecological dimensions. This group lagged particularly in key indicators such as *biodiversity, water saving, integration with trees, and pest and disease management,* signaling narrow ecological integration. Nevertheless, Cluster 3 exhibited notable similarities with Cluster 1 in several areas, including *animal species management, animal welfare, integration of crops and animals, use of internal inputs, and diversity of production activities and services.* In the domain of social synergies—especially *production and household needs, working conditions, women's empowerment, and traditional knowledge*—Cluster 3 also aligns closely with Cluster 1. These findings suggest that, despite more limited ecological integration, the two clusters exhibit relatively similar profiles in the social domain.

Cluster 1 occupies an intermediate or transitional position between Clusters 2 and 3, with moderate scores across most indicators. It demonstrated strong performance in indicators as *soil fertility management, soil–plant management, landscape connectivity, and biomass recycling*, showing close alignment with Cluster 2 in these areas. However, in other indicators—such as *animal integration, production diversity, and social empowerment*—Cluster 1 is closer to Cluster 3. This dual alignment positions Cluster 1 as a strategic leverage point for transition: these farms may already have a foundation of practices and knowledge that, with targeted support, could be deepened into more integrated agroecological systems.

In sum, the clustering analysis identified three distinct yet interrelated profiles that do not represent a linear hierarchy but rather diverse expressions of agroecological engagement. The most significant contrasts were observed between Clusters 2 and 3, where differences in several key indicators exceeded two points. These findings underscore the diversity of agroecological strategies among family farms in Portugal and highlight the importance of differentiated, typology-sensitive approaches to support the agroecological transition.

3.2 Understanding differences and similarities among farmers

To further investigate which variables contributed most to cluster differentiation, sociodemographic, technical, and economic characteristics—organized according the 10 agroecological dimensions—are presented and used to compare the three identified clusters. This information was collected through the questions answered by the farmers during the survey (Table 4).

Based on the indicators and characteristics of the farmers included in each cluster, it is possible to define them as agroecological (Cluster 2), proto-agroecological (Cluster 1) and conventional (Cluster 3) farmers. These typologies are not merely statistical groupings, but reflect meaningful patterns in farming strategies, social organization, ecological integration, and cultural identity.

3.3 Agroecological farmers

The agroecological farmers, represented by Cluster 2, are the most advanced in terms of agroecological integration and systemic thinking. These farmers are also relatively young, with an average age of 49, and report high levels of formal education, often at the university level. With an average of 16 years of experience, they demonstrate a coherent and deliberate adoption of agroecological principles across multiple dimensions. Their practices include the use of trees for both soil fertility enhancement and erosion prevention, biological pest control methods such as the use of ladybirds and multifunctional plants, and the complete exclusion of synthetic pesticides. Farms in this cluster tend to incorporate structured ecological elements, including flower strips and stone walls, to support biodiversity, although some features like nesting sites for birds and bats remain underutilized. These farmers also engage in composting and renewable energy production, with many partially

TABLE 3 Mean values and standard deviations of the 26 agroecological indicators by cluster, along with the results of significance tests.

10 Agroecological dimensions	26 Indicators	Cluster 1 (mean ± standard deviation)				Cluster 2 (mean ± standard deviation)				Cluster 3 (mean ± standard deviation)				Sig.
1. Plant production	1. Integration with trees	**2,50**	±	**1,05**	**a**	**3,65**	±	**0,61**	**b**	**1,06**	±	**0,83**	**c**	**0,000**
	2. Seed management	1,50	±	1,52		**2,18**	±	**0,64**	**a**	**0,94**	±	**0,43**	**b**	**0,000**
2. Animal production	3. Animal species management	0,50	±	0,55	a	**2,18**	±	**0,95**	**b**	0,76	±	0,56	a	**0,000**
	4. Animal welfare	1,83	±	1,47	a	**3,65**	±	**1,00**	**b**	1,53	±	1,07	a	**0,000**
3. Soil regeneration	5. Soil fertility management	3,17	±	1,17	a	4,00	±	0,00	a	**0,88**	±	**0,33**	**b**	**0,000**
	6. Soil–plant management system	2,83	±	0,98	a	4,00	±	0,00	a	**0,76**	±	**0,66**	**b**	**0,000**
4. Water cycle regeneration	7. Water saving	**2,33**	±	**1,03**	**a**	**3,65**	±	**0,61**	**b**	**1,29**	±	**0,99**	**c**	**0,000**
5. Pest, disease and weed management	8. Pest and disease management	2,17	±	1,47		**4,00**	±	**0,00**	**a**	**0,12**	±	**0,33**	**b**	**0,000**
	9. Registration of production and pests, diseases and weeds	1,33	±	1,75		**2,41**	±	**1,33**	**a**	**0,29**	±	**0,47**	**b**	**0,000**
6. Ecological synergies	10. Integration: crops/animals	0,83	±	0,75	a	**3,18**	±	**1,07**	**b**	1,06	±	0,83	a	**0,000**
	11. Connectivity between elements of the agroecosystem and the landscape	2,67	±	1,21	a	3,82	±	0,53	a	**0,59**	±	**0,51**	**b**	**0,000**
	12. Biodiversity	**2,33**	±	**1,03**	**a**	**3,82**	±	**0,53**	**b**	**0,65**	±	**0,61**	**c**	**0,000**
	13. Biomass and non-biomass recycling	3,00	±	0,89	a	3,97	±	0,12	a	**1,00**	±	**0,87**	**b**	**0,000**
7. Economic synergies	14. Energy production and renewal	1,00	±	0,89		**1,59**	±	**1,06**	**a**	**0,59**	±	**0,62**	**b**	**0,016**
	15. Use of internal inputs	1,33	±	0,52	a	**3,06**	±	**0,83**	**b**	1,06	±	0,43	a	**0,000**
	16. Diversity of production activities and services	**2,33**	±	**0,82**	**a**	**3,94**	±	**0,24**	**b**	**1,41**	±	**1,00**	**a**	**0,000**
	17. Stability of income/production and ability to recover from disturbances	2,17	±	0,98		**2,88**	±	**1,05**	**a**	**1,65**	±	**0,86**	**b**	**0,004**
8. Social synergies	18. Production and household needs/ adequate food and nutritional awareness	2,00	±	1,26	a	**3,06**	±	**0,97**	**b**	1,59	±	0,71	a	**0,001**
	19. Dignification of farmers/working conditions	2,17	±	1,33	a	**3,47**	±	**0,72**	**b**	1,29	±	1,05	a	**0,000**
	20. Women's empowerment	2,50	±	0,84	a	**3,65**	±	**1,06**	**b**	1,94	±	1,30	a	**0,000**
	21. Youth empowerment and emigration	1,17	±	0,75		2,24	±	1,60		1,18	±	0,88		0,091
9. Interactions with the Local Food System	22. Producer networks, consumer relations and presence of intermediaries	2,83	±	1,47		**3,59**	±	**0,80**	**a**	**2,41**	±	**1,28**	**b**	**0,004**
	23. Empowerment of producers/mechanisms to reduce vulnerability/ governance participation of producers	1,00	±	0,63		1,65	±	1,22		0,94	±	0,83		0,110
	24. Relations with the community	2,67	±	1,51		3,24	±	1,09		2,82	±	1,13		0,408
10. Sharing agroecological knowledge	25. Local or traditional identity and awareness	2,17	±	0,98	a	**3,35**	±	**0,70**	**b**	2,12	±	0,78	a	**0,000**
	26. Access to agroecological knowledge and producers interest in agroecology.	1,67	±	1,63		**3,94**	±	**0,24**	**a**	**0,06**	±	**0,24**	**b**	**0,000**

Values with different superscript letters indicate statistically significant differences between clusters at the 5% significance level ($p < 0.05$) are highlighted in gray.

supplying their own energy needs through solar panels. Socially, they are highly engaged and score significantly higher in indicators related to gender equity, with women frequently involved in decisions regarding animal production, economic activities, and major household assets. Economically, this group shows greater diversification of income sources and improved access to credit. Their practices align with the concept of "transformative agroecology" as described by Altieri and Nicholls (2020), in which farms function as ecologically embedded, socially empowered, and territorially anchored systems. These farmers exemplify a comprehensive, integrated model of agroecological farming that extends beyond agronomic practices to encompass cultural identity, political engagement, and systemic resilience.

3.4 Conventional farmers

The conventional farmers, represented by Cluster 3, are the most experienced group in the sample, with an average of 40 years of farming activity. They are generally older (average age of 59) and tend to have lower levels of formal education, typically having completed secondary education or less. Their farming systems are rooted in long-standing practices and intergenerational knowledge, reflecting deep familiarity with local crops and livestock conditions. While these farmers continue to rely on conventional practices, particularly the use of synthetic herbicides and animal-origin fertilizers, they play an essential role in the rural economy. Their agricultural approach is shaped by practical experience and continuity, often emphasizing productivity and land stewardship in the face of changing policy and market dynamics. As highlighted by Fonseca et al. (2024) and Williamson et al. (2024), these systems face significant ecological challenges, including soil degradation and biodiversity loss, which may compromise long-term resilience. With appropriate incentives and peer-based learning opportunities, conventional farmers could gradually adopt low-input or regenerative practices, paving the way for partial transitions.

3.5 Proto-agroecological farmers

The proto-agroecological farmers, represented by Cluster 1, occupy a transitional position between conventional and agroecological systems. They are generally younger, with an average age of 49, and possess relatively high levels of formal education, including a high proportion with university degrees. With an average of 20 years of farming experience, they blend conventional and agroecological practices. Their scores are intermediate across most agroecological dimensions, but they align more closely with agroecological farmers in practices such as intercropping, soil fertility management—including the use of trees for soil fertility—landscape connectivity, and biomass recycling. Although ecological synergies are present, these are often underdeveloped or unstructured, with limited use of features such as stone shelters or flower strips. Their waste management practices and approaches to animal sourcing also differ significantly from both of the other groups. As such, proto-agroecological farmers demonstrate partial ecological integration and growing engagement with agroecological principles but have yet to adopt a fully systemic approach. Their position within the agroecological transition continuum suggests strong potential for advancement, especially with appropriate institutional support and targeted technical assistance. As described by Horstink et al. (2023), Matthews (2022) and van der Ploeg et al. (2019), this group fits the definition of "proto-agroecological"—systems that are moving toward agroecology through incremental practice adoption, innovation, and community engagement. Overall, this group consists of experienced and technically informed farmers who balance conventional and agroecological practices but have yet to fully engage in structured agroecological approaches.

3.6 Addressing public policies

In relation to public policy preferences, four questions were included in the survey to assess farmers' perspectives on institutional measures to support agroecological transitions. Among these, statistically significant differences between clusters emerged only for support for regulatory measures aimed at restricting harmful inputs, such as synthetic pesticides, including, for example, the creation of taxes on the application of synthetic pesticides. This preference was particularly prominent among agroecological farmers, although it was also mentioned by farmers in the proto-agroecological and conventional clusters, indicating a broader awareness of the environmental impacts of input-intensive practices.

While the other policy-related questions did not show statistically significant differences between clusters, several of these variables were retained in the PCA and offer relevant insights for policy design. Notably, financial support through subsidies was mentioned across all groups. However, some farmers expressed concerns about subsidy dependence, highlighting the need for support structures that promote autonomy and resilience. In addition, several respondents emphasized the importance of continuous and accessible technical assistance, particularly through public extension services or similar advisory mechanisms. The need for improved transparency and enforcement in agroecological certification processes was also raised, underscoring the relevance of effective oversight in building trust and credibility in certification processes.

4 Discussion/conclusion

This study applied an integrated, data-driven methodology to identify key differentiating indicators and characteristics among family farms in Portugal, enabling the development of a typology-based framework for supporting agroecological transitions. By distinguishing three distinct farmer typologies—conventional, proto-agroecological, and agroecological—the analysis highlights the diverse capacities, strategies, and sociocultural orientations shaping agroecological engagement across rural territories.

These typologies are not fixed categories but represent dynamic positions along a continuum of transformation. Each group plays a distinct and strategic role in promoting a more socially just and ecologically resilient agri-food system.

Agroecological farmers constitute the most advanced typology in terms of ecological integration, systemic thinking, and community involvement. Agroecological farmers emphasize the importance of

TABLE 4 Results of the significance tests applied to the three clusters, including mean values, standard deviations, and *p*-values.

10 Agroecological dimensions	Variables /questions	Cluster 1 (mean ± standard deviation)				Cluster 2 (mean ± standard deviation)				Cluster 3 (mean ± standard deviation)				Sig.
Sociodemographic characteristics	Education: 1 CEB to Doctorate	5,17	±	2,04		**5,82**	±	**0,53**	**a**	**2,71**	±	**1,36**	**b**	**0,000**
	Years been a farmer	20,17	±	1,26	a	15,76	±	0,78	a	**39,47**	±	**1,41**	**b**	**0,013**
	Employment/occupation situation: self-employed with or without employees to retired or unemployed	3,67	±	1,21		**4,00**	±	**1,06**	**a**	**2,76**	±	**1,44**	**b**	**0,045**
	Age	49,00	±	0,41		**49,12**	±	**0,73**	**a**	**58,59**	±	**0,62**	**b**	**0,048**
	Other professions: did not have/ had connected to the food system	0,83	±	0,75		1,06	±	0,56		0,71	±	0,69		0,253
Dimension 1. Plant Production	Production System (conventional, integrated production, organic, biodynamic, regenerative, other)	**0,50**	±	**0,55**	**a**	**1,00**	±	**0,00**	**b**	**0,00**	±	**0,00**	**c**	**0,000**
	Do intercropping	**0,50**	±	**0,55**	**a**	**1,00**	±	**0,00**	**b**	**0,00**	±	**0,00**	**c**	**0,000**
	Use crop diversity between rows	0,67	±	0,52		1,00	±	0,00			±	0,00		**0,000**
	Trees used to increase soil fertility	**0,17**	±	**0,41**	**a**	**1,00**	±	**0,00**	**b**	**0,06**	±	**0,24**	**c**	**0,000**
	Trees used as a barrier to soil erosion	0,33	±	0,52		**0,94**	±	**0,24**	**a**	**0,00**	±	**0,00**	**b**	**0,000**
Dimension 2. Animal production	Meat production	0,67	±	0,52		**0,41**	±	**0,51**	**a**	**0,88**	±	**0,33**	**b**	**0,014**
	Place where you buy the animals	**0,50**	±	**0,55**	**a**	**1,82**	±	**1,29**	**b**	0,88	±	0,99		**0,016**
	Use of antibiotics	2,33	±	1,86		**3,76**	±	**0,97**	**a**	**2,82**	±	**1,13**	**b**	**0,003**
Dimension 3. Soil regeneration	Fertilizers of animal origin are the most frequently used	0,17	±	0,41	a	0,00	±	0,00	a	**0,94**	±	**0,24**	**b**	**0,000**
	Fertilizers of mineral origin are the most frequently used	0,83	±	0,41	a	0,94	±	0,24	a	**0,12**	±	**0,33**	**b**	**0,000**
	Other soil conservation practices	1,83	±	1,17	a	1,82	±	0,88	a	**0,12**	±	**0,33**	**b**	**0,000**
	After harvesting the crops soil usually remains cover/not cover	2,33	±	1,86		**3,53**	±	**1,33**	**a**	**0,29**	±	**0,59**	**b**	**0,000**
	The farmer parents/grandparents have used manure on the farm	0,33	±	0,52		**0,53**	±	**0,51**	**a**	**1,00**	±	**0,00**	**b**	**0,001**
Dimension 4. Water cycle regeneration	Water used for farming comes from a pond	0,50	±	0,55		**0,41**	±	**0,51**	**a**	**0,06**	±	**0,24**	**b**	**0,031**
	Preserve water in a pond	0,67	±	0,52		0,47	±	0,51		0,12	±	0,33		**0,018**
Dimension 5. Pest and disease management	Use of synthetic fungicide	0,33	±	0,52			±	0,00		1,00	±	0,00		**0,000**
	Use of synthetic insecticides	0,50	±	0,55		0,00	±	0,00		1,00	±	0,00		**0,000**
	Use of synthetic herbicides	0,33	±	0,52		**0,00**	±	**0,00**	**a**	**0,88**	±	**0,33**	**b**	**0,000**
	Biological control with multifunctional plants	0,33	±	0,52		1,00	±	0,00			±	0,00		**0,000**
	Biological protection promote natural enemies	0,50	±	0,55		**0,88**	±	**0,33**	**a**	**0,00**	±	**0,00**	**b**	**0,000**
Dimension 6. Ecological synergies	There are some spaces for functional biodiversity, but they are not very well structured	1,50	±	0,84	a	2,00	±	0,87	a	**0,59**	±	**0,51**	**b**	**0,000**
	Islands or strips of flowers	0,33	±	0,52		**0,76**	±	**0,44**	**a**	**0,00**	±	**0,00**	**b**	**0,000**
	Stone shelters	1,00	±	0,00	a	0,71	±	0,47	a	**0,29**	±	**0,47**	**b**	**0,004**

(Continued)

TABLE 4 (Continued)

10 Agroecological dimensions	Variables /questions	Cluster 1 (mean ± standard deviation)				Cluster 2 (mean ± standard deviation)				Cluster 3 (mean ± standard deviation)				Sig.
Dimension 7. Economic synergies production factors	Produce their composting	0,50	±	0,55		**0,88**	±	**0,33**	**a**	**0,12**	±	**0,33**	**b**	**0,000**
	Quantity of utilized energy purchased	1,17	±	0,75		**1,59**	±	**1,12**	**a**	**0,59**	±	**0,62**	**b**	**0,008**
	Destination of non-organic waste	2,83	±	0,41	a	3,00	±	0,00	a	**1,53**	±	**0,80**	**b**	**0,000**
	Consider composting in agricultural environments important	0,83	±	0,41		**1,00**	±	**0,00**	**a**	**0,29**	±	**0,47**	**b**	**0,000**
Dimension 7. Economic synergies farm characterisation	It's easy to get credit if needed	0,33	±	0,52		**0,59**	±	**0,51**	**a**	**0,18**	±	**0,39**	**b**	**0,044**
	Having access to credit	0,33	±	0,52		**0,59**	±	**0,51**	**a**	**0,18**	±	**0,39**	**b**	**0,044**
Dimension 7. Economic synergies farmers' incomes	The majority of the household's income comes from other internal sources	0,17	±	0,41		**1,59**	±	**1,73**	**a**	**0,29**	±	**1,21**	**b**	**0,019**
Dimension 8. Social synergies gender equality	Women usually make the decisions about animal production	0,33	±	0,52		**0,76**	±	**0,44**	**a**	**0,35**	±	**0,49**	**b**	**0,032**
	Women own the resources for other economic activities within the holding	0,33	±	0,52		**0,76**	±	**0,44**	**a**	**0,35**	±	**0,49**	**b**	**0,032**
	Women usually make the decisions about the other economic activities of the holding	0,33	±	0,52		**0,76**	±	**0,44**	**a**	**0,35**	±	**0,49**	**b**	**0,032**
	Women own most of the family's main assets	0,33	±	0,52		**0,76**	±	**0,44**	**a**	**0,35**	±	**0,49**	**b**	**0,032**
	Women usually make the decisions about the main assets of the family	0,33	±	0,52		**0,76**	±	**0,44**	**a**	**0,35**	±	**0,49**	**b**	**0,032**
Dimension 8. Social synergies equity for women	If they wanted to, women think they could make decisions about major farm expense	1,33	±	1,63		**1,71**	±	**1,90**	**a**	**3,00**	±	**1,73**	**b**	**0,040**
Dimension 10. Sharing agroecological knowledge	Habit of sharing knowledge with other farmers	1,83	±	1,47		**2,82**	±	**0,73**	**a**	**1,71**	±	**1,21**	**b**	**0,004**
	Have an idea of what agroecology is and often share knowledge on the subject	0,67	±	1,03		**1,88**	±	**0,33**	**a**	**0,00**	±	**0,00**	**b**	**0,000**
Public Policy	Ban/tax on the use of chemically synthesized pesticides	1,83	±	2,48		**3,29**	±	**1,93**	**a**	**0,76**	±	**1,48**	**b**	**0,005**

Statistically significant differences ($p < 0.05$) are highlighted in gray. Values with different superscript letters indicate significant differences between clusters at the 5% significance level.

regulatory measures, particularly restrictions on synthetic pesticide use, as well as recognition and stable institutional support. Public policy can enhance their contributions by designating them as reference farms, ensuring procurement frameworks that prioritize agroecological products, and investing in territorial governance structures that embed agroecology into local planning, extension services, and education systems.

Conventional farmers, while the least aligned with agroecological practices, remain a foundational part of rural economies. They are deeply connected to their land, embedded in intergenerational knowledge systems, and well-integrated in local community life. For this group, the transition could be facilitated through targeted awareness-raising programs, demonstration farms, and incentive schemes that reward incremental changes such as cover cropping, composting, and reduced chemical input use. The implementation of peer-to-peer mentoring and locally contextualized training, delivered through trusted rural institutions, would be essential to enabling this gradual changes.

Proto-agroecological farmers emerge as a critical intermediary group—technically competent, ecologically aware, and socially embedded. While they have begun integrating agroecological principles, they remain partially dependent on conventional inputs. Their potential as catalysts of local transition underscores the importance of policy measures that support experimentation, capacity-building, and access to land and credit.

These findings highlight the importance of interpreting agroecological transitions not only through observable practices or demographic profiles, but also through the lens of broader structural conditions. As Hinrichs (2014) observes, transitions to sustainability may unfold in very different ways depending on farmers' initial access to resources, infrastructure, land, and economic stability. Even when farmers appear demographically similar, their trajectories can diverge substantially due to contextual factors that shape their capacity to engage with agroecological principles. Recognizing this diversity is crucial for designing support mechanisms and public policies that are sensitive to the differentiated realities of family farmers.

The study's findings stress that an effective agroecological transition cannot be achieved through uniform or top-down policy frameworks. Instead, it requires a multi-pathway strategy that recognizes the heterogeneity of farming systems and provides flexible, context-responsive support. Avoiding binary classifications between "good" and "bad" farmers, public policy should foster inclusive learning ecosystems, adaptive instruments, and participatory governance structures. Importantly, agroecology is not only a technical or environmental shift—it is also a cultural and social process. Recognizing farmers as co-creators of knowledge and territorial sustainability is fundamental to achieving systemic change.

In this context, a reorientation of the Common Agricultural Policy (CAP) is urgently needed, particularly in Southern Europe. Echoing van der Ploeg et al. (2019), the study supports redirecting CAP funding toward agroecological practices that enhance food quality, ecosystem services, employment, and territorial cohesion. Transitioning from scale-based to function-based subsidies would strengthen the ecological and social performance of family farming systems.

A key limitation of this study is its relatively small sample size (*n* = 40), which, while suitable for exploratory cluster analysis, may not fully capture the diversity of family farming across Portugal. Consequently, the findings should be interpreted with caution regarding broad generalization. Future research involving larger and more geographically diverse samples is essential to validate and expand these typologies and to inform more robust and evidence-based agroecological policies.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

IC-P: Writing – original draft, Conceptualization, Formal analysis, Investigation, Methodology. AA: Supervision, Writing – review & editing. FD: Supervision, Writing – review & editing. CC: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing, Formal analysis.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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