GRANULAR

FOOD SYSTEMS AND LAND TENURE IN EU RURAL AREAS: STRUCTURAL TYPOLOGIES AND COMPLEMENTARY EVIDENCE

D4.3

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1. Executive Summary

This deliverable develops a territorial assessment of European rural food systems through four functional dimensions: production, environmental conditions, consumption, and trade. It also examines farmland ownership as an institutional layer that helps explain who controls the land base on which rural food systems depend. The framework supports the European Union's Long-Term Vision for Rural Areas by identifying recurring structural configurations that can inform place-sensitive policy analysis.

The production analysis identifies six regimes across Farm Accountancy Data Network regions. European agriculture is differentiated by land-use orientation, livestock intensity, input use, labour organisation, and capitalisation. The largest group consists of arable-oriented systems with moderate livestock intensity, moderate input use, and a predominantly family-based labour structure. Other regimes represent grassland-oriented livestock systems, permanent-crop systems with greater paid labour and input use, lower-input arable systems, commercially organised low-livestock arable systems, and a small group of highly intensive arable–livestock systems.

The environmental analysis identifies five agro-environmental regimes at Local Administrative Unit level. The dominant regime comprises diversified mixed farming with moderate livestock pressure and limited organic coverage. Other regimes combine organic management and lower livestock pressure, reduced crop diversification, high crop and livestock diversity, or intensive livestock production. These configurations show that environmental conditions are shaped by the interaction of land-use diversity, organic management, and livestock pressure. Their spatial distribution follows recognisable territorial patterns across Europe.

The consumption analysis identifies six adult dietary profiles based on the composition of food baskets. The profiles differ in the relative importance of dairy, cereals, meat, vegetables, fruit, juices, and alcoholic beverages. Their geographical distribution reflects broad European dietary patterns, including dairy-oriented systems in northern and western areas, grain- and meat-oriented systems in eastern and south-eastern areas, and vegetable-oriented profiles in selected Mediterranean contexts.

The trade analysis classifies countries according to import dependency, net trade direction, and the composition of net trade flows. Using food-trade data for 2022–2024, the analysis shows a continuous distribution of national trade positions. Most countries occupy intermediate positions between strong external dependence and high export orientation. The results point to different combinations of domestic production, external sourcing, and trade specialisation across European food systems.

The land-tenure analysis uses Eurostat farm-structure data for 2016 and 2020 at NUTS-2 level. It distinguishes Natural Persons, Legal Persons, and Group Holdings and examines ownership shares, changes over time, and the relationship between Legal Person ownership and farm economic performance. These findings add an institutional perspective to the four food-system typologies by showing how ownership and control of farmland may shape investment capacity, adaptation, and the organisation of rural production. The ownership results require careful interpretation because the available categories do not directly measure tenure security, land concentration, or decision-making power.

Across the four typologies, structurally similar territories form coherent spatial patterns. Robustness tests indicate that the main configurations remain stable under adjacent cluster solutions and alternative trade specifications, with changes concentrated mainly around classification boundaries. The results provide a comparative baseline for examining territorial differentiation, market dependence, environmental pressure, land control, and future food-system pathways. The typologies are descriptive analytical tools: they support comparison and policy interpretation without ranking regions or establishing causal relationships.

2. Linking Food System Assessment to LTVRA Principles

Food systems connect rural economies, land use, environmental resources, markets, and population well-being. Rural areas host much of Europe's agricultural production and land management, while also experiencing distinctive conditions of accessibility, demographic change, service provision, and market dependence. These characteristics shape how food is produced, exchanged, consumed, and governed across territories. Food-system assessment therefore provides a useful empirical entry point for examining the territorial diversity addressed by the European Union's Long-Term Vision for Rural Areas (LTVRA).

The LTVRA sets a long-term policy framework for stronger, connected, resilient, and prosperous rural areas by 2040. It emphasises territorial diversity, place-sensitive action, connectivity, environmental stewardship, economic opportunity, and the involvement of rural communities. The Vision establishes these principles at a strategic level. The present deliverable complements that framework by organising available European data into comparable territorial profiles that describe important structural conditions of rural food systems.

The assessment uses four functional dimensions: production, environmental conditions, consumption, and trade. Production describes the organisation and orientation of agricultural activity. Environmental conditions describe land-use diversity, management orientation, and livestock pressure. Consumption describes the composition of adult food baskets. Trade describes the position of national food systems in relation to external sourcing and market exchange. Farmland ownership is examined as an institutional layer because the legal organisation of land ownership is relevant to investment, adaptation, farm organisation, and the distribution of control over agricultural resources. These dimensions represent related functions within food systems, while remaining analytically distinct. They are assessed using different data sources and spatial units suited to each subject: FADN regions for production, LAUs for environmental conditions, country–adult groups for consumption, countries for trade, and NUTS-2 regions for farmland ownership. The deliverable therefore provides linked territorial evidence rather than a single classification in which every observation is assigned one combined food-system type. The framework is descriptive and comparative. It identifies recurring configurations of agricultural structure, agro-environmental context, dietary composition, trade orientation, and farmland ownership. It does not rank territories, measure policy effectiveness, establish causal relationships, or directly estimate resilience. Its results provide a baseline for subsequent analysis of territorial vulnerability, policy fit, land governance, and food-system change.

This approach reflects the complexity of food systems while maintaining a clear analytical structure. Production and environmental conditions describe the rural resource base and the organisation of land-based activity. Consumption and trade show how food systems are connected to demand and markets across space. Land ownership adds information on the institutional conditions under which agricultural land is held

and managed. Read together, these dimensions can support differentiated interpretation of the LTVRA's objectives and help identify where rural territories may face distinct constraints or opportunities. The typology-based analysis contributes to place-sensitive rural policy by showing how structural conditions vary across Europe. Its value lies in making territorial differences visible and comparable, thereby supporting future work with rural actors, policymakers, and other stakeholders. The resulting profiles can serve as an evidence base for examining which policy responses are appropriate to particular rural contexts and how food-system development relates to the LTVRA's long-term objectives.

3. Literature Review

3.1. Evolution of food systems thinking: from sectoral chains to socio-ecological systems

Food systems scholarship has undergone a substantial conceptual shift over recent decades, reflecting broader developments in sustainability science, political economy, and territorial studies. Early analytical approaches were largely sectoral, focusing on agricultural production and downstream market coordination. Over time, this perspective has been progressively challenged by research demonstrating that food-related outcomes cannot be understood by examining production or supply chains in isolation (Zurek et al., 2018; Sirdey et al., 2023; Juri et al., 2024).

Recent reviews document a clear transition toward integrated food systems thinking, in which production, consumption, spatial organization, and environmental processes are treated as interdependent components of a single system (Zurek et al., 2018; Juri et al., 2024). Rather than emphasizing linear value chains, this literature conceptualizes food systems as configurations of interacting activities that jointly generate nutritional, environmental, and socio-economic outcomes. This shift has been particularly prominent in sustainability-oriented research, where fragmented sectoral analyses are increasingly seen as inadequate for addressing systemic challenges such as climate change, malnutrition, and territorial inequalities (Caro et al., 2023).

Integrated assessment frameworks have played a key role in consolidating this perspective. Zurek et al. (2018) propose an analytical approach that links food supply organization, consumption patterns, and nutritional outcomes with environmental pressures, explicitly highlighting trade-offs between policy objectives. Similarly, Caro et al. (2023) advance an overarching framework for food system sustainability assessment that critiques siloed sectoral models and emphasizes feedbacks between biophysical constraints, economic structures, and social outcomes. These contributions position food systems as complex socio-ecological systems, in which system performance emerges from interactions rather than from individual components.

More recent synthesis work further emphasizes the dynamic and adaptive nature of food systems. Juri et al. (2024) frame food systems transformation as a multi-dimensional process shaped by interacting drivers and territorial contexts, reinforcing the view that food systems evolve through non-linear pathways characterized by feedbacks, lock-ins, and contested transition trajectories. Together, this body of literature reflects a clear

epistemological departure from chain-based or sectoral models toward systems-oriented approaches capable of capturing complexity, interdependence, and trade-offs across scales.

3.2. The complex, multi-dimensional, and contested nature of food systems

Food systems are now widely recognized as central to a range of global and territorial challenges, including environmental degradation, climate change, food insecurity, and uneven rural development. Their complexity stems not only from the diversity of actors and activities involved, but also from the coexistence of multiple, often competing objectives embedded within food system performance. Integrated assessment studies consistently show that improvements along one dimension—such as productivity, affordability, or environmental efficiency—may generate unintended consequences elsewhere (Zurek et al., 2018; Caro et al., 2023).

This recognition has led to a growing consensus that food system performance cannot be meaningfully assessed using single indicators or narrowly defined objectives. Multi-indicator frameworks highlight persistent trade-offs between nutritional adequacy, environmental sustainability, and economic viability, revealing the inherently contested nature of food system transitions (Chaudhary et al., 2018). Methodological reviews further demonstrate substantial heterogeneity in how sustainability is conceptualized and operationalized, reflecting divergent normative priorities and analytical choices across studies (Robling et al., 2023; Sirdey et al., 2023).

The complex and interconnected structure of food systems also becomes particularly visible during periods of disruption. Analyses of food system shocks, including recent global crises, show how vulnerabilities are amplified through dependencies on trade, labor mobility, and concentrated supply chains (Butler et al., 2021). Resilience-oriented studies similarly emphasize that food systems are shaped by interdependencies across spatial scales and institutional levels, making them sensitive to cascading effects and external disturbances (Roosevelt et al., 2023). These findings underscore the limitations of static or reductionist analytical approaches and reinforce the need for frameworks capable of capturing systemic risk and adaptation dynamics.

At the same time, the literature highlights the importance of territorial differentiation in shaping food system trajectories. Comparative analyses and typology-based approaches demonstrate that food systems evolve along distinct pathways depending on structural conditions, resource endowments, and institutional contexts (Marshall et al., 2021; Juri et al., 2024). This heterogeneity challenges universal policy prescriptions and strengthens the case for analytical frameworks that can distinguish between different food system configurations while remaining sensitive to place-based constraints and opportunities.

3.3. Food systems in rural regions: territorial context and structural specificity

Food systems are inherently territorial, yet rural regions have long occupied an ambiguous position in food systems scholarship. While rural areas are widely recognized as major sites of food production and natural resource management, they are often implicitly treated as supply zones rather than as complex territorial

food system contexts. The literature challenges this reductionism by emphasizing that rural regions constitute structural backbones of food systems, where production structures, demographic dynamics, market access, and ecological conditions jointly shape food system performance and trajectories (Ruerd & van Berkum, 2021; Rivera et al., 2020).

Rural regions differ structurally from urban and peri-urban contexts in ways that profoundly shape food system functioning. Lower population densities, longer distances, and weaker market accessibility affect both the organization of food supply chains and the accessibility and affordability of food for local populations, particularly through reduced retail diversity, higher transaction costs, and greater reliance on external supply channels (Ruerd and van Berkum, 2021; Herforth et al., 2020). Rural economies are also frequently more specialized and dependent on a limited set of productive activities, which increases their exposure to price volatility, market fluctuations, and external shocks (Rivera et al., 2020; Butler et al., 2021). At the same time, rural territories concentrate a large share of environmental assets and pressures—including agricultural land, water resources, and biodiversity—positioning them at the center of debates on environmental limits, climate mitigation, and adaptation within food systems (Westhoek et al., 2016; Caro et al., 2023).

Importantly, rural regions are not homogeneous. Work on rural typologies and territorial trajectories underscores that “rurality” encompasses diverse structural conditions and pathways of change, shaped by differences in demographic trends, economic bases, accessibility, and territorial organization (*Talandier 2023*; Ruerd and van Berkum, 2021). This diversity implies that food system strategies and policy levers appropriate in one rural context may be ineffective—or counterproductive—in another. Typology work in food systems research similarly argues that classification is valuable precisely because it supports differentiation, enabling more targeted interpretation of drivers and policy options (Marshall et al., 2021; Juri et al., 2024).

Food systems in rural regions are also shaped by multi-level governance and institutional contexts, even when the assessment focus is territorial functioning rather than governance evaluation. Frameworks for food system governance and policy navigation emphasize that institutional arrangements influence local innovation capacity, the organization of supply chains, and the ability of territories to respond to shocks and transitions (Chen et al., 2021; Hebinck et al., 2021). Bottom-up cases further show how local initiatives can reshape food system pathways, particularly in contexts seeking alternatives to dominant industrial paradigms (Chojnacki & Creamer, 2019; Cleveland et al., 2015). Taken together, the literature suggests that rural food systems constitute a specific analytical context characterized by concentrated production and environmental pressures, differentiated consumption conditions, strong dependence on external markets, and place-specific institutional constraints.

Recognizing this context is a prerequisite for meaningful food system assessment in rural regions, but it does not in itself define the internal structure of food systems. That structure must be derived through analytical decomposition, addressed in the following section.

3.4. Analytical decomposition of food systems: justification of the four pillars

Given the complexity and territorial specificity of food systems—particularly in rural regions—a central methodological challenge lies in identifying an analytical structure that captures essential system functions

without fragmenting analysis into disconnected dimensions. The literature converges on decomposing food systems into a limited number of core functional domains that are conceptually distinct, empirically observable, and policy-relevant, while remaining interdependent (Allen & Prosperi, 2016; Bathaei & Štreimikienė, 2023; Sirdey et al., 2023).

This work adopts production, consumption, trade, and environment as such core pillars. These pillars do not represent sectors, actors, or policy domains, but rather system functions through which food systems operate. Each pillar addresses a distinct analytical problem that cannot be fully captured by the others, while together they enable comprehensive assessment of food system performance in terms of sustainability, vulnerability, and transition pathways (Zurek et al., 2018; Caro et al., 2023).

3.4.1. Production: material transformation and territorial organization

Production constitutes the primary interface between food systems and biophysical resources. It encompasses the transformation of land, water, energy, and labor into food, and thus represents the material entry point of resources into the system. The literature consistently treats production as a distinct analytical domain, recognizing its central role in shaping food availability, rural livelihoods, and environmental pressures (Rivera et al., 2020; Robling et al., 2023). Empirical studies also emphasize that production system structure and diversity vary substantially across territories and over time, influencing both resilience and sustainability performance (Schaak et al., 2023; Marshall et al., 2021).

Crucially, production is not reducible to environmental impacts alone. Metabolic and systems-oriented approaches conceptualize food systems (and production within them) as interfaces between society and ecosystems, emphasizing flows of materials and energy rather than isolated practices (Madelrieux & Redlingshöfer, 2023; Loconto, 2020). This highlights why production must be analytically separated from environmental assessment: production structures condition environmental outcomes, but are also shaped by economic organization, institutional context, and territorial constraints (Allali et al., 2024; Robling et al., 2023).

Nor can production be collapsed into value-chain analysis. While value-chain approaches focus on coordination, governance, and value distribution, production as a pillar captures the capacity, structure, and orientation of territorial production systems, irrespective of downstream governance arrangements (Allali et al., 2024; Moretti et al., 2023).

3.4.2. Consumption: demand, diets, and social outcomes

Consumption represents a distinct and indispensable analytical pillar within food systems assessment, addressing demand-side dynamics that shape production incentives, resource use, and environmental pressures, while simultaneously determining nutritional, health, and equity outcomes. A growing body of literature demonstrates that similar production systems can generate markedly different sustainability outcomes depending on prevailing consumption patterns and dietary structures (Zurek et al., 2018; Caro et al., 2023).

Integrated food system analyses emphasize that consumption cannot be treated as a passive endpoint of supply chains. Instead, dietary preferences, affordability constraints, and access conditions actively influence how food systems operate and evolve. Zurek et al. (2018) show that nutrition and environmental outcomes are jointly shaped by consumption choices, highlighting trade-offs between dietary adequacy and ecological impact. These interactions are further reinforced by evidence that affordability and access act as structural constraints on dietary behavior, particularly for low-income and spatially remote populations (Herforth et al., 2020).

In rural regions, consumption dynamics are shaped by specific territorial conditions, including lower population density, limited retail diversity, and income constraints. Analyses of food system performance under structural and rural change indicate that rural consumption patterns often differ significantly from urban contexts, with implications for nutrition, food security, and local demand signals (Ruerd & van Berkum, 2021). Treating consumption as a standalone pillar therefore allows food system assessments to account for social outcomes and demand-side drivers without conflating them with production performance or trade structures.

By analytically separating consumption from other system functions, the framework acknowledges that dietary outcomes are not automatically aligned with production capacity or environmental efficiency. This distinction is essential for understanding how food systems perform in practice, particularly in rural regions where consumption constraints may persist despite substantial local production.

3.4.3. Trade: spatial Connectivity and telecoupling

Trade performs a distinct system function by linking production and consumption across space. Contemporary food systems are characterized by spatial decoupling, whereby production, processing, and consumption occur in different locations. Trade therefore shapes self-sufficiency, dependency, vulnerability to shocks, and the spatial distribution of environmental burdens (FAO, 2016; Butler et al., 2021). Critically, the literature cautions against framing self-sufficiency and trade openness as a binary opposition; instead, trade and domestic capacity interact in shaping food security and vulnerability, often in context-dependent ways (FAO, 2016; Rivera et al., 2024).

Foodshed analyses further demonstrate that functional food system boundaries are often defined by flows (and therefore by trade relationships) rather than administrative borders, reinforcing the need to treat trade as analytically distinct from production and consumption (Mouléry et al., 2022; Jacobi et al., 2019). This is particularly salient in rural regions, where dependence on external markets strongly conditions development trajectories and where shocks can propagate through supply chain and trade dependencies (Butler et al., 2021; Ruerd & van Berkum, 2021).

3.4.4. Environment: constraints, impacts, and system limits

The environment provides both the resource base upon which food systems depend and the constraints that limit their long-term viability. Environmental impacts such as greenhouse gas emissions, land degradation, and biodiversity loss emerge from the combined effects of production practices, consumption patterns, and trade flows (Westhoek et al., 2016; Caro et al., 2023). Comparative indicator frameworks underscore that

environmental sustainability must be evaluated as an emergent property of the food system, not solely through isolated farm-level metrics (Béné et al., 2019.; Chaudhary et al., 2019).

Territorial life-cycle and metabolic approaches demonstrate that environmental performance must be assessed at the system level to capture cumulative pressures, feedbacks, and displacement effects that cannot be attributed to individual system components alone (Lulovicova & Bouissou, 2023; Madelrieux & Redlingshöfer, 2023). Treating the environment as a standalone pillar is therefore essential for assessing climate and sustainability performance, particularly in rural contexts where environmental pressures are spatially concentrated and where ecosystems both support and constrain food system functioning.

3.4.5. Conceptual scope and analytical boundaries

Across the food systems literature, governance, resilience, and sustainability are frequently invoked as key concerns shaping food system trajectories. Governance structures influence incentives, coordination, and regulatory environments, and resilience is discussed as the capacity of food systems to absorb shocks and adapt to structural change (Chen et al., 2021; Roosevelt et al., 2023). Sustainability, in turn, functions as a normative objective guiding transformation agendas and indicator selection (Hebinck et al., 2021; Caro et al., 2023).

However, the literature also highlights conceptual ambiguity and methodological heterogeneity in how these concepts are defined and operationalized across studies and assessment tools (Roosevelt et al., 2023; Béné et al., 2023). As a result, many frameworks treat these concepts as overarching goals or interpretive lenses rather than as discrete structural components. Following this approach, the present framework does not position governance, resilience, or sustainability as explicit pillars or dimensions. Instead, these concerns inform the interpretation of performance patterns and the discussion of implications, while the analytical structure remains focused on the four core system functions.

3.5. Synthesis: implications for rural food system assessment

The literature reviewed demonstrates that rural regions are not peripheral to food systems but constitute their structural core, concentrating production and environmental pressures while experiencing distinctive accessibility conditions and strong dependence on external markets. Decomposing food systems into production, consumption, trade, and environment captures essential system functions while maintaining clear analytical boundaries between components and supporting comparative assessment across territories (Zurek et al., 2018; Caro et al., 2023). Typology-oriented approaches further support the need to characterize diversity in food system configurations and rural trajectories to inform differentiated policy responses (Marshall et al., 2021; Talandier, 2023). In this context, a parsimonious four-pillar architecture provides a robust foundation for rural-oriented food system typologies and policy-relevant interpretation.

4. Methodology

4.1. Conceptual approach

This deliverable assesses European rural food systems through four separately estimated typologies covering production, environmental conditions, consumption, and trade. The dimensions are interpreted as linked functions of food systems, while each is analysed at the spatial and statistical scale supported by its data source. Their results are therefore complementary profiles rather than components of a single combined cluster solution. Farmland ownership is analysed separately as an institutional layer that provides context for the organisation and possible transformation of rural production. The objective is to identify recurring structural configurations that support territorial comparison. The analysis does not rank regions, measure policy performance, establish causal relationships, or estimate resilience directly. Outcome indicators are generally retained for post-classification profiling, allowing the report to examine how observed emissions or economic characteristics vary across structural regimes.

The production typology describes regional differences in the organisation of farming systems and their interaction with land, labour, capital, and markets. It focuses on land-use orientation, livestock integration, input intensity, labour organisation, and capitalisation. The resulting types are interpreted as production regimes. Economic and environmental outcomes are used, where available, to profile these regimes after classification.

The environmental typology describes the agro-environmental context of local areas through land-use diversity, livestock diversity, organic management, and livestock density. These indicators capture different aspects of land-use organisation and management orientation. Livestock density is treated as a structural pressure-related variable because it links the concentration of animals to potential nutrient and emissions pressures. Emissions and economic output are retained for post-classification profiling and are not used to define cluster membership.

The consumption typology describes differences in adult food-basket composition across countries. Food categories are converted into shares of total gram-based consumption within a defined core basket, allowing the analysis to focus on relative dietary composition. Dimension reduction and clustering are used to identify interpretable dietary profiles. The profiles describe consumption structure; they do not constitute measures of diet quality, nutritional adequacy, affordability, or health.

The trade typology classifies countries using directly interpretable indicators of import dependency, net trade direction, and the composition and concentration of net trade flows. A common multi-year window is used to reduce the influence of annual variation. Rule-based categories are used because the selected dimensions have clear directional meanings and can be audited directly. The resulting classes describe national trade orientation and do not measure food security or supply-chain resilience on their own.

Farmland ownership is examined as an institutional layer of food-system structure. Ownership arrangements influence the legal basis on which agricultural land is held, transferred, managed, and reorganised. They may therefore affect access to land, investment decisions, farm continuity, organisational

scale, and the scope for changes in production and land management. The available data describe ownership categories and their regional distribution; they do not provide a complete measure of tenure security, land concentration, leasing conditions, management rights, or effective control. Land tenure is consequently analysed alongside the four typologies as contextual evidence, with its interpretation linked to production structures and rural transformation.

4.2. Data sources

The four food-system typologies and the farmland-ownership analysis use different data sources, observational units, and geographical scales. This arrangement reflects the structure and availability of the underlying datasets. Production is assessed using FADN regions, environmental conditions using Local Administrative Units, consumption using country–adult population groups, trade using countries, and farmland ownership using NUTS-2 regions.

4.2.1. Production

Production is analysed using regions defined by the Farm Accountancy Data Network (FADN), which constitute a harmonised statistical regionalisation rather than administrative units. FADN regions are specifically constructed to group together territories with similar agricultural structures in order to ensure sufficient sample sizes and statistical reliability in farm-level surveys. As such, they represent analytically meaningful production regions rather than political boundaries.

This choice has two methodological implications. First, the spatial units used for the production typology are internally coherent with respect to farming systems, input use, and land-use patterns, which improves the interpretability and stability of the resulting clusters. Second, the use of FADN regions ensures that all indicators entering the production typology are based on statistically robust observations, avoiding the noise and sparsity that would arise from using finer administrative units not designed for agricultural sampling.

4.2.2. Environment

The environmental typology is constructed at Local Administrative Unit level. LAUs are used to retain local variation in agricultural land use and management conditions within countries and larger regions. This scale supports the identification of local agro-environmental patterns that may be obscured by national or regional averages.

The environmental dataset contains indicators describing crop diversification, livestock diversification, organic land share, and livestock density. These variables are used to define the environmental regimes. Crop and livestock emissions intensity and economic output per hectare are retained as profiling variables and are used to describe the observed characteristics of the resulting regimes. They do not determine cluster membership. The LAU-level analysis provides detailed spatial coverage, but the availability and quality of indicators vary between localities. Missing values are handled through the procedure described in Section 4.3.2.

4.2.3. Consumption

Consumption is derived from the European Food Safety Authority food consumption database. The dataset is organised by country, population group, and food category. The analytical unit is the country–adult population group, since the adult category provides the most consistent basis for comparison across the countries included in the dataset.

The analysis does not impose a sub-national spatial resolution that is unavailable in the source data. Consumption profiles therefore describe national adult food-basket composition and should not be interpreted as direct measures of rural diets or as evidence of differences between rural and urban populations within countries.

Food categories are harmonised at a consistent hierarchical level and are subsequently grouped into a defined core basket. The retained categories are converted into shares of total gram-based consumption within that basket. The procedures for category selection, missing-value treatment, normalisation, dimensional reduction, clustering, and labelling are described in Section 4.3.3.

4.2.4. Trade

Trade is analysed at country level using annual FAO country-by-item data for food imports and exports. The trade dataset is combined with population data to calculate per-capita quantities and support comparisons between countries of different population size.

The baseline analysis uses a three-year common window, 2022–2024, subject to the availability of comparable import and export totals. Using a common period reduces the risk that differences in data coverage create artificial net-import or net-export classifications. Annual quantities are aggregated or averaged according to the indicator being constructed, as described in Section 4.3.4.

The country is the appropriate analytical unit for this component because the available trade data describe national food flows. The resulting classifications characterise national external food-system orientation. They do not identify the distribution of trade dependence within countries or the specific rural territories through which imports and exports move.

4.2.5. Complementary land-tenure evidence

In addition to the four core typological pillars, complementary project evidence on farmland ownership was used to contextualise institutional conditions shaping European food systems. This evidence was not incorporated into the clustering framework, because land tenure is treated as a governance and control condition rather than as a functional food-system pillar equivalent to production, environment, consumption, or trade. Instead, it provides contextual information on who controls the agricultural land base on which production systems and rural food-system transformation depend.

The land-tenure analysis used Eurostat farm-structure data at NUTS-2 level to examine farmland ownership patterns in Europe in 2016 and 2020. Ownership was classified into three categories: Natural Persons, representing primarily family farms; Legal Persons, including corporations, cooperatives, and associations; and Group Holdings, referring to farms owned, rented, or managed by multiple natural or legal persons. The analysis considered ownership shares, changes in ownership composition over time, and the relationship between increasing Legal Person ownership and farm economic performance.

This complementary evidence is used in the results to interpret land tenure as an institutional layer of food-system structure. While the four typologies describe how food systems operate through production, environmental conditions, consumption, and trade, the land-tenure analysis provides additional insight into the ownership and control conditions that may shape the capacity of rural regions to adapt, invest, and pursue sustainable food-system transitions. The full land-tenure analysis, including detailed methods, maps, and policy interpretation can in be found in Slätmo et al., 2026. A full inventory of the indicators used in each pillar, including data source, reference period, spatial resolution, and measurement definition, is provided in Appendix 1.

4.3. Indicator selection

4.3.1. Production

The production typology is constructed using indicators derived at the Farm Accountancy Data Network (FADN) regional scale, which groups territories into analytically coherent production regions in order to ensure statistical significance and comparability of farm-level observations. The indicator set is deliberately restricted to variables that describe agricultural structure and organisation, rather than environmental or economic outcomes, so that clusters represent persistent production systems rather than performance rankings.

Three core structural dimensions guide indicator selection. The first dimension captures production orientation, distinguishing regions according to whether agricultural activity is primarily crop-based, livestock-based, or mixed. This is operationalised through the relative contribution of crop and livestock output to total agricultural production at regional level. Using relative contributions rather than absolute output ensures that regions are compared on structural orientation rather than scale.

The second dimension reflects the balance and composition of livestock systems. Livestock intensity is represented using stocking density expressed relative to agricultural land, which captures how strongly livestock systems shape land use and production organisation within the region. This indicator is structural in nature: it reflects long-term system configuration rather than short-term production shocks. In addition, the relative economic weight of livestock production is retained to distinguish regions where livestock activity is present but secondary from those where it is dominant.

The third dimension captures production intensity and organisational form. This is represented through indicators describing output intensity per unit of land and labour organisation. Output per hectare is used as a proxy for production intensity, reflecting differences in input use, specialisation, and technological

orientation across regions. Labour structure is captured through the relative importance of hired versus family labour, which distinguishes regions characterised by more commercialised, capital-intensive farming systems from those dominated by family-based production. These indicators jointly describe how production is organised, rather than how profitable or environmentally efficient it is.

Indicators related to environmental impacts, emissions, or economic performance beyond structural intensity are explicitly excluded from the clustering feature set. Where such variables are available, they are retained only for post-clustering profiling in order to interpret how different production systems relate to environmental pressures or economic outcomes. This separation ensures that production types are defined by system structure and organisation, while outcomes remain analytically downstream.

Taken together, the selected indicators define a multidimensional structural space that distinguishes production systems by orientation, livestock integration, and intensity. Because all indicators are derived at the FADN regional scale, the resulting typology reflects regions that are internally coherent in production characteristics and statistically robust, supporting stable clustering and meaningful cross-country comparison.

4.3.2. Environment

The environmental typology is constructed using indicators that describe the structural agro-environmental context of local areas rather than their environmental performance. The guiding methodological principle is to characterise how agricultural land is organised and managed, not how environmentally efficient or intensive outcomes currently are. This distinction is critical for ensuring that the resulting clusters represent persistent environmental regimes rather than transient performance states driven by short-term technological, economic, or policy changes.

The clustering feature set is therefore restricted to structural land-use and management indicators that correspond to well-established environmental principles. Crop diversification is included to capture the heterogeneity of land use and cropping systems within the local area. From an environmental perspective, diversification is closely linked to ecological resilience: more diversified cropping systems tend to buffer production against climatic variability, pest outbreaks, and market shocks, while also influencing soil management practices and input dependence. Conversely, low diversification reflects structural specialisation, which can amplify vulnerability to shocks and concentrate environmental pressures spatially.

Livestock diversification is included for the same conceptual reason. It describes whether livestock activity is concentrated in a narrow set of species or distributed across multiple types, reflecting differences in production systems and land–livestock interactions rather than intensity alone. Greater livestock diversity is associated with more complex nutrient cycles and land-use interactions, while low diversity often corresponds to more specialised systems with tighter coupling between specific livestock types and land resources. Together, crop and livestock diversification describe the structural complexity of the agro-ecosystem, which is a key determinant of adaptive capacity and environmental risk exposure.

The share of agricultural land under organic management is included as a proxy for management regime orientation. Organic land share reflects systematic differences in production practices, including constraints on synthetic inputs, crop rotations, and soil management approaches. These practices are typically embedded in regulatory and institutional frameworks and therefore tend to persist over time. As such, organic land share is treated as a structural attribute of the agro-environmental context that signals long-term management orientation rather than an outcome indicator reflecting current performance.

Livestock pressure, expressed as livestock density relative to land availability, occupies an intermediate conceptual position between structural agro-environmental organisation and biophysical pressure potential. In this typology it is operationalised as average livestock units per hectare of utilised agricultural area, capturing how concentrated livestock production is within the local land base rather than the absolute number of animals. Conceptually, higher livestock density implies tighter land–livestock coupling and greater potential for nutrient loading, manure surplus, and associated management constraints, which in turn condition pathways for soil compaction and emissions formation. For that reason, livestock pressure is treated as a structural descriptor of the agro-environmental regime, while recognising that it is closer to environmental pressure mechanisms than diversification or management orientation. In the current implementation, livestock density is included in the baseline clustering feature set alongside crop diversification, livestock diversification, and organic land share, and robustness testing focuses on whether the inferred regimes are stable to alternative choices of cluster number rather than to alternative indicator sets. Where interpretation requires separating “regime structure” from “pressure intensity,” livestock density is therefore discussed explicitly as the dimension that links land-use organisation to pressure potential, while emissions intensity measures remain restricted to post-clustering profiling.

Indicators related to environmental outcomes are deliberately excluded from the clustering feature set. Emissions intensity from crop and livestock production are retained only for post-clustering profiling, allowing clusters to be interpreted in terms of their emissions signatures without defining environmental regimes by emissions performance. Similarly, economic output per hectare is retained as a profiling variable to interpret intensity and productivity differences across regimes, but it is excluded from clustering to avoid conflating agro-environmental structure with economic outcomes.

By restricting the clustering space to indicators linked to resilience, management orientation, and land–livestock structure, the environmental typology identifies structural agro-environmental regimes rather than outcome-based categories. Differences in emissions intensity or productivity therefore emerge as properties of these regimes rather than as drivers of their definition, supporting clearer causal interpretation, conceptual coherence, and greater temporal robustness.

4.3.3. Consumption

The consumption typology begins with mean consumption by food category for each country–population group. In practice, the adult population group is used as the analytical population because it is the only demographic group consistently available across all countries in the dataset. The analytical unit is therefore the country–adult group. While this restriction reflects data availability, it is also methodologically appropriate: dietary structures vary systematically across age groups due to physiological requirements, institutional

settings, and life-course effects. Restricting the analysis to adults ensures cross-country comparability and prevents demographic heterogeneity from confounding national dietary regimes.

It is not the raw mean consumption values that enter the typology. The fundamental feature construction choice is compositional: consumption is expressed as category shares within a defined “core basket.” The core basket consists of substantive food categories that represent habitual dietary allocation, including cereals and cereal-based products, vegetables and vegetable products, fruit and fruit products, meat and meat products, fish and other seafood, milk and dairy products, eggs and egg products, legumes, nuts and oilseeds, fats and oils, sugar and confectionery, composite dishes, fruit and vegetable juices, and coffee, tea, and cocoa. These categories collectively capture the principal macronutrient and food-group structure of adult diets across countries.

A limited set of categories is excluded from the core basket to improve comparability and interpretability. Water and water-based beverages are removed to prevent hydration differences and survey-reporting conventions from dominating the compositional structure. In addition, highly heterogeneous or special-purpose groups—such as food supplements, products for non-standard diets, isolated ingredients and additives, and residual “other” categories—are excluded so that the retained basket reflects substantive diet composition rather than poorly comparable or auxiliary groupings.

After defining the core basket, two coverage constraints are applied conceptually. First, observations must exhibit sufficient category coverage to be meaningful representations of dietary structure. Second, categories must be sufficiently present across observations to contribute reliably to the latent structure. Missing category values are imputed using category means, a conservative strategy that avoids imposing strong distributional assumptions while preserving overall category balance. Within each observation, the imputed core-basket totals are then normalised to shares that sum to one. The resulting feature space is explicitly compositional: each dimension represents the relative prominence of a category within the adult dietary basket.

A separate, controlled-vocabulary labelling layer is constructed for interpretability. Food categories are mapped into a limited set of broad baskets, with a subset designated as headline baskets and another subset designated as secondary qualifiers. This mapping operates exclusively at the interpretation stage and does not constrain component extraction or clustering. The methodological objective is to prevent cluster names from being driven by narrow or idiosyncratic categories and to ensure that labels remain structurally comparable and suitable for cross-country mapping.

4.3.4. Trade

The trade typology is built from engineered indicators that are intended to be directly interpretable and stable under modest data volatility. The base quantities are import and export quantities by item, restricted to a single physical unit to ensure comparability across items. Country-level totals are computed separately for imports and exports and then averaged over a recent rolling window defined as the last common years for which both import and export totals are available. This “common-years” design avoids artefacts where a country appears net import- or export-oriented simply because one side is missing for the most recent year.

Three families of indicators are then constructed. The first is trade magnitude and net position, including per-capita imports and exports and per-capita net trade, which normalises for country size using population in a reference year aligned to the trade window. The second is import dependency, defined as the share of total trade volume accounted for by imports within the same window. This ratio is then discretised into low, medium, and high dependency bands using fixed thresholds, which supports communication and comparability.

The third family describes composition and concentration. To avoid conflating net trade position with gross trade composition, the script constructs an “extra flow” basket that includes only the net-direction items: for net importers, items where imports exceed exports; for net exporters, items where exports exceed imports. Composition is summarised by classifying each item as animal-based, crop-based, or mixed based on keywords, and then computing the shares of the extra flow accounted for by animal versus crop items. Concentration is summarised using dominance shares and standard diversity metrics. A mapping-oriented taxonomy is then assigned using explicit rules: a country’s extra-flow basket is classified as animal-dominant, crop-dominant with single-item dominance, crop-dominant without single-item dominance, or genuinely mixed. Separately, diversification statistics such as top-item shares and concentration indices are computed for imports and exports to provide additional descriptive context even when the extra-flow taxonomy is the primary typological label.

4.4. Typology construction

4.4.1. Statistical approach

Across the four pillars, the construction of types follows a common methodological principle: structural similarity is identified first in a controlled feature space, and grouping is performed only after ensuring that the representation of that space is statistically coherent and interpretable. The objective is to define regimes based on underlying structure rather than on raw indicator magnitudes or performance outcomes.

For Production and Environment, the indicator sets consist of multiple structural variables that are conceptually related and empirically correlated. Direct clustering in the original indicator space would risk overweighting high-variance dimensions and embedding collinearity into the distance structure. To avoid this, a reduced latent representation is constructed prior to clustering. Principal components are extracted from scaled structural indicators, and a compact set of components is retained to capture the majority of variance while preserving interpretability. Clustering is then performed in this reduced space. This approach stabilises similarity relationships, prevents dominance by any single indicator, and expresses regimes along interpretable gradients rather than raw metrics.

In Consumption, dimensionality reduction is also applied, but the logic differs slightly because the feature space is compositional. Dietary structure is expressed as shares within a core basket, meaning that variation reflects relative allocation rather than absolute intake. Principal components are extracted from the standardised compositional shares, and varimax rotation is applied to enhance interpretability. Rotation is a theoretical choice: it encourages components that correspond more closely to coherent dietary gradients

rather than diffuse statistical mixtures. Clustering is subsequently performed on a limited number of rotated component scores to produce a parsimonious typology that reflects dominant dietary structures.

Trade follows a different logic. Rather than applying latent representation and clustering, trade types are constructed using directly interpretable metrics derived from flow quantities and population-normalised measures. Rule-based classification is applied to these metrics to assign countries to categories. This design prioritises transparency and auditability, reflecting the fact that trade position and dependency are inherently directional and threshold-based constructs rather than latent structural gradients.

Across all pillars, the statistical construction of types is therefore guided by two principles: dimensional coherence in the representation of structural indicators, and methodological consistency between the nature of the data and the grouping strategy applied to it.

Clustering in the latent component space is performed using partitioning algorithms consistent with the structure of each domain. For Production and Environment, K-means clustering with multiple random initialisations is applied to the retained principal component scores in order to ensure convergence to stable partitions. For Consumption, hierarchical clustering using Ward's minimum-variance method is applied to rotated component scores, preserving continuity with the variance-minimisation logic of principal components. All structural indicators are scaled prior to component extraction to prevent dominance by high-variance variables. For the environmental typology, robust scaling based on interquartile ranges is employed to reduce sensitivity to extreme values at the local scale, while standardisation is applied in Production and Consumption to preserve relative gradient structure.

The number of clusters is determined through a structured diagnostic procedure rather than fixed a priori. For each domain, solutions across a range of cluster numbers are evaluated using multiple criteria, including within-cluster variance (elbow diagnostics), silhouette scores, Davies–Bouldin indices, and minimum cluster size thresholds. Final cluster numbers are selected by balancing statistical compactness, separation quality, and interpretability of resulting regime structures. This approach ensures that the typologies reflect stable structural regimes rather than artefacts of a single arbitrary partition.

4.4.2. Interpretive translation and labelling

Once statistical groupings or classifications are defined, a separate interpretive layer translates them into communicable regime descriptors. This separation between statistical definition and linguistic labelling is intentional. Clusters are defined purely by structural similarity, and labels are generated post hoc to describe their dominant characteristics. Outcome indicators are used only for profiling and interpretation, not for defining membership.

In Production and Environment, labels are derived from the relative signatures of structural indicators within each cluster. Production types are expressed as regime descriptors that communicate dominant orientation and intensity characteristics without collapsing into purely performance-based language. Environmental types are described in terms of diversification regime, management orientation, and land–livestock structure, with emissions or productivity indicators reserved for downstream profiling rather than definition. This ensures that regimes represent structural agro-systems rather than normative performance rankings.

In Consumption, labelling operates through a constrained vocabulary derived from the controlled mapping of food categories into broader baskets. Headline baskets are selected based on systematic positive deviations from the overall mean structure, while secondary qualifiers are introduced only under strict conditions to prevent inflation of descriptors. This produces readable, stable cluster names that remain comparable across countries and robust to minor compositional shifts. In Trade, labels are constructed by combining net direction, dependency band, and diversification taxonomy into composite descriptors.

Together, these procedures ensure that statistical structure and interpretive communication remain analytically distinct. Types are defined by data-driven grouping strategies appropriate to each domain, and labels translate those structures into regime descriptions that are stable, comparable, and suitable for mapping and reporting.

4.5. Sensitivity analysis and robustness assessment

To ensure that typological classifications are not artefacts of specific parameter choices or modelling assumptions, structured robustness analyses are conducted across all four pillars. Sensitivity testing evaluates the stability of regime definitions under alternative specifications of clustering parameters, dimensional reduction choices, and classification thresholds.

For Production and Environment, robustness is assessed primarily through variation in the number of clusters (K-sensitivity). Cluster solutions are estimated across a defined range of K values surrounding the baseline specification. Stability is evaluated using silhouette scores, Davies–Bouldin indices, within-cluster variance diagnostics, and minimum cluster size constraints. In addition, adjusted Rand indices (ARI) and cross-tabulation matrices are computed to quantify the degree of reassignment of spatial units across alternative K solutions. This allows identification of structurally stable regimes versus partitions sensitive to marginal K changes.

For the Consumption typology, robustness testing is conducted along two dimensions: (i) variation in the number of retained rotated components, and (ii) variation in the number of clusters applied to the component space. Ward linkage distances, silhouette diagnostics across K values, and pairwise ARI statistics between solutions are used to evaluate stability. This dual sensitivity framework ensures that dietary regime classifications are not dependent on a single dimensional reduction choice.

For the Trade typology, robustness analysis focuses on deterministic parameter sensitivity rather than latent structure. Two dimensions are evaluated: (i) variation in the multi-year averaging window used to stabilise trade flows, and (ii) variation in dependency threshold definitions used to discretise import-dependency levels. For each alternative specification, country-level label changes are quantified relative to the baseline classification, and switch-rate statistics are computed. This procedure allows explicit assessment of the sensitivity of trade regime assignments to window length and threshold calibration.

Across pillars, robustness is therefore operationalised as reassignment stability under controlled parameter variation. Regime definitions are considered structurally stable when the majority of spatial units retain classification under adjacent parameter choices and when diagnostic metrics indicate consistent separation structure. This systematic robustness architecture enhances confidence that identified typologies represent persistent structural regimes rather than modelling artefacts.

5. Results

5.1. Production typology

5.1.1. Analytical framework

The production typology was developed using harmonised FADN regional data aggregated over the most recent three-year window available for each region. Observations were weighted by the number of farms represented to ensure that the resulting typology reflects structural agricultural reality rather than survey sampling artifacts.

The analytical framework captures agricultural structure across five dimensions: land-use orientation (shares of arable land, permanent crops, and grassland), livestock intensity (stocking density), input intensity (fertiliser, energy, specific and veterinary costs), labour regime (share of paid versus unpaid labour), and capital intensity (machinery, fixed assets, and buildings). Monetary indicators were transformed using a log function to reduce skewness, and all variables were robust-scaled prior to dimensionality reduction to mitigate the influence of extreme values.

5.1.2. Dimensional structure of European production systems

Principal Component Analysis (PCA) was applied to reduce collinearity and summarise structural variation. The first four principal components explain approximately 83% of total variance, exceeding the predefined 80% threshold. The scree profile (Figure P1) displays a clear elbow after the fourth component, indicating diminishing marginal explanatory power beyond that point and supporting the retention of four components for clustering. Retaining four components preserves the majority of structural information while ensuring clustering stability and interpretability.

Inspection of PCA loadings clarifies the substantive meaning of the retained components (Figure P2). PC1 captures roughly one-third of total variance and is dominated by land-use orientation and capital/input intensity, with the strongest positive loading on the share of permanent crops, accompanied by higher energy, fertiliser, and specific costs and higher capital proxies (machinery, buildings, fixed assets), contrasting with larger farm size and more extensive land-use structures. PC2 captures a distinct gradient separating permanent-crop and paid-labour systems from livestock- and cost-intensive configurations, with negative loadings on stocking density and multiple cost variables (including veterinary and specific costs). PC3 primarily differentiates commercially organised, input-intensive arable systems (higher fertiliser costs, paid labour, and arable share) from more family-labour and grassland-associated structures (negative loading on unpaid labour and grassland share). PC4 isolates an additional axis linked to veterinary-cost intensity and grassland association, contrasting with more arable-leaning and unpaid-labour configurations. Taken together, the loadings confirm that the PCA space organises European production regions along interpretable structural contrasts—crop orientation (permanent vs arable/grassland), livestock/cost intensity, labour regime, and capitalisation—which subsequently underpin the cluster solution.

Figure P1 - PCA explained variance

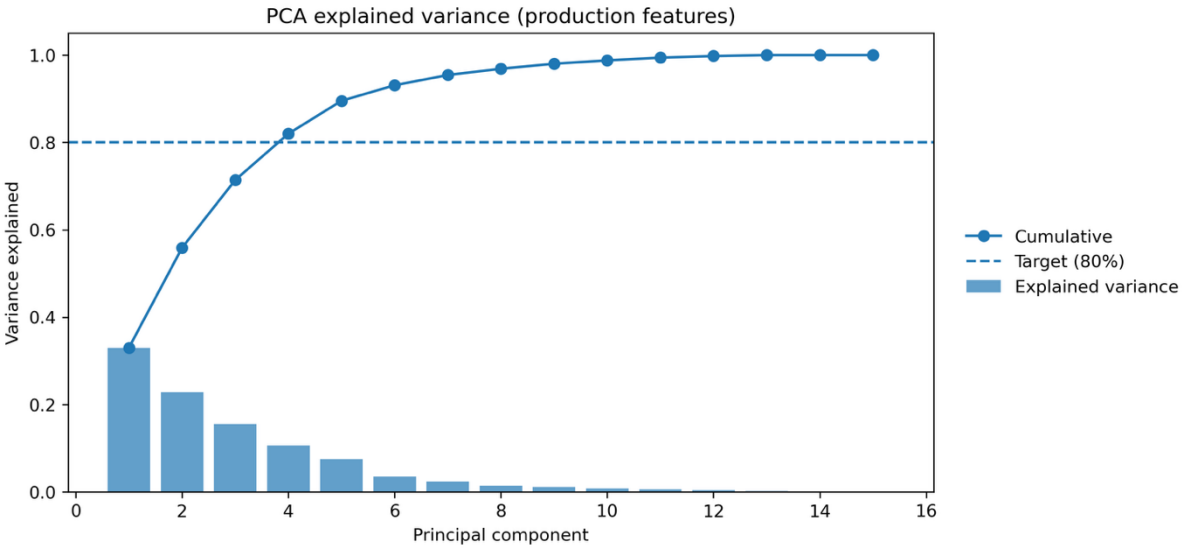
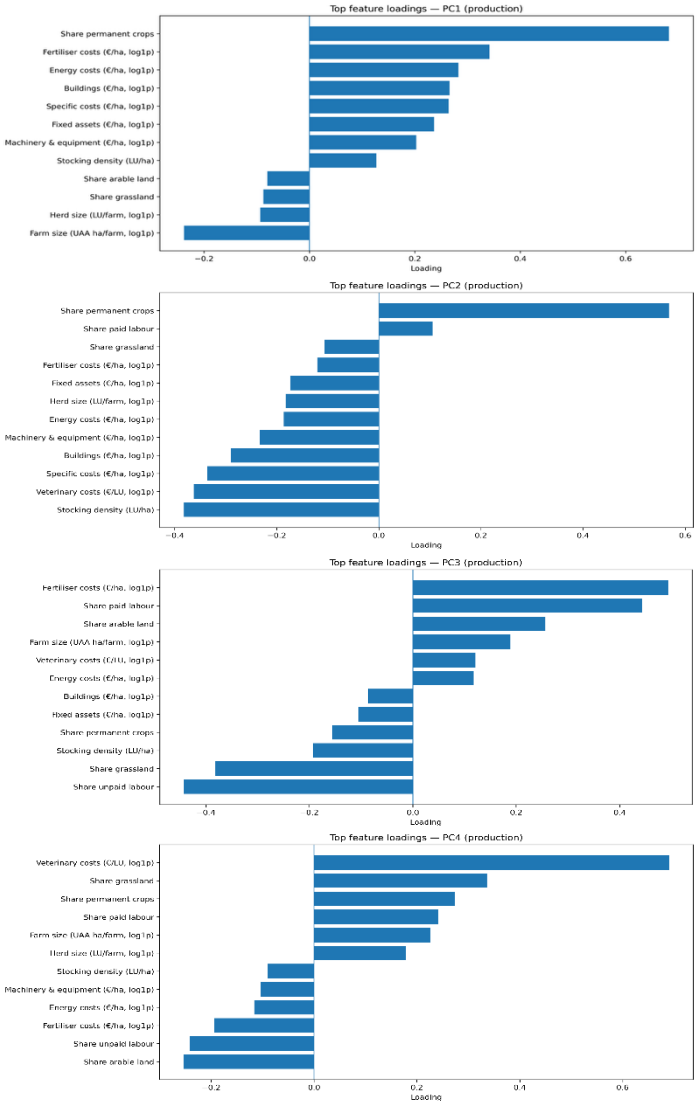


Figure P2 - Principal component loadings

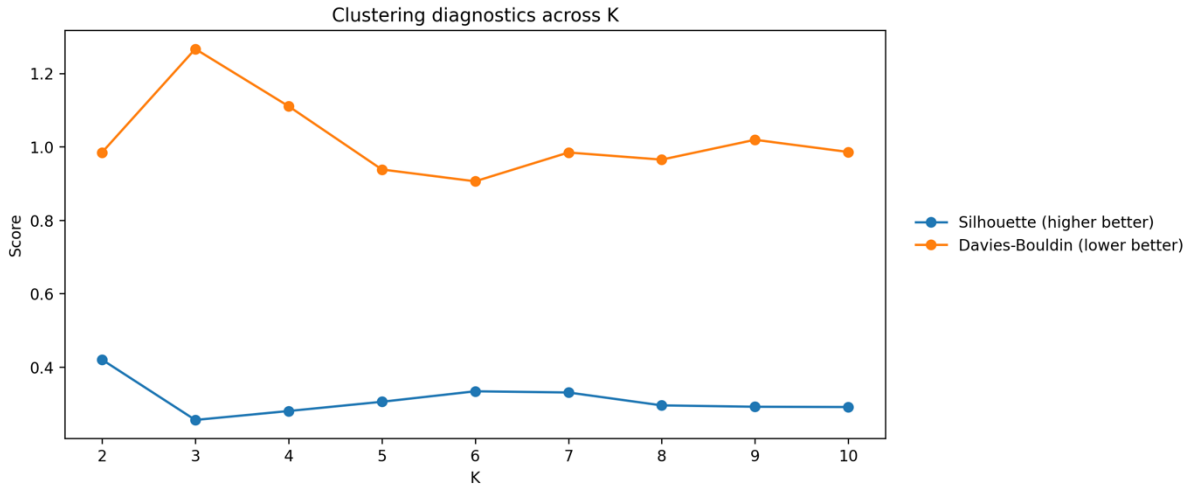


5.1.3. Selection of the cluster solution

Cluster solutions were evaluated for K values ranging from 2 to 10 using silhouette score (higher indicates better separation) and Davies–Bouldin index (lower indicates more compact and distinct clusters) in Figure P3. As expected, the strongest statistical separation is observed at K=2, reflecting a broad structural dichotomy within European production systems. However, such a solution collapses meaningful heterogeneity.

Between K=4 and K=6, separation remains acceptable while interpretability increases substantially. Beyond six clusters, additional fragmentation yields limited analytical gain. The six-cluster solution therefore represents a balanced configuration, preserving structural differentiation without over-segmentation. The selected K=6 solution provides a typology that is both statistically defensible and substantively interpretable.

Figure P3 - Clustering diagnostics across k



5.1.4. Structural composition of the six production types

Table P1 summarises the structural profile of the six production regimes identified by the clustering procedure, reporting for each cluster the number of regions assigned to the type alongside the mean values of land-use composition, livestock intensity, input intensity (specific, energy, and fertiliser expenditures per hectare, log-transformed), labour organisation, and capital indicators. Figure P4 complements these descriptive statistics by presenting standardized centroids (z-scores), illustrating how each regime deviates from the overall regional mean across structural dimensions.

Land-use orientation emerges as the primary axis separating clusters. Nineteen regions form a grassland-oriented regime in which 80% of land is grassland and stocking density reaches 1.0 LU/ha. These systems rely predominantly on unpaid labour (80%), reflecting livestock-oriented production embedded in family-based labour structures. The standardized centroids show strong positive deviations in grassland share and livestock intensity, coupled with above-average reliance on unpaid labour.

Fifteen regions constitute a permanent-crops-oriented regime, where 60% of land is devoted to perennial crops. These systems combine moderate livestock intensity (0.4 LU/ha) with comparatively high input

expenditures (log fertiliser costs 6.0; energy 5.9) and a relatively high share of paid labour (40%). In standardized space, this cluster exhibits clear positive deviations in permanent crop share, input intensity, and labour commercialization, distinguishing it structurally from both grassland and arable systems.

European agricultural production remains structurally dominated by arable-oriented regimes, but these display substantial internal differentiation. The largest cluster, comprising 65 regions, represents an arable-oriented regime with moderate livestock intensity (0.9 LU/ha), moderate input intensity (log specific costs 7.0), and a mixed labour structure in which unpaid labour remains dominant (80%) but paid labour plays a supporting role. With approximately 70% of land under arable cultivation, this configuration lies close to the overall mean across most dimensions and forms the structural centre of European agriculture.

A second arable-oriented cluster (21 regions) shares a similar land-use composition (80% arable land) but exhibits substantially lower livestock intensity (0.3 LU/ha) and reduced input expenditures (log specific costs 6.0; fertiliser 4.6). The standardized centroids reveal negative deviations in fertiliser, energy, and capital-related indicators, identifying this cluster as a lower-intensity arable configuration with more limited capitalisation and moderate reliance on unpaid labour (70%).

A third arable regime (20 regions) is differentiated primarily by labour organisation rather than physical structure. With 90% arable land and very low livestock intensity (0.2 LU/ha), it combines moderate input intensity (log specific costs 6.5) with a markedly higher share of paid labour (70%). The centroid profile shows strong positive deviations in paid labour and corresponding negative deviations in unpaid labour, indicating commercially organised arable systems in which hired labour substitutes for family labour.

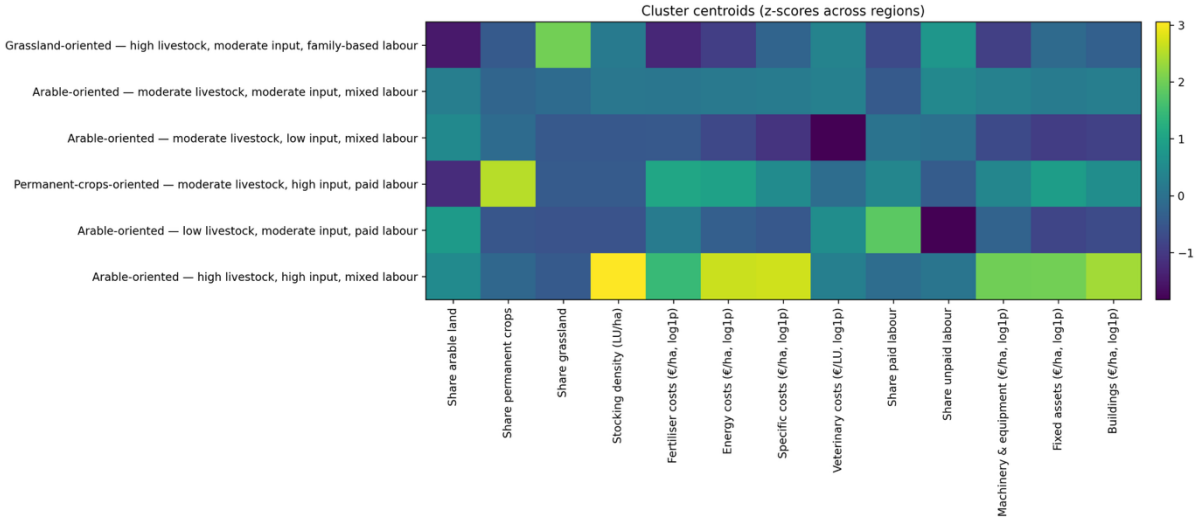
At the intensive end of the spectrum, a small but structurally distinct cluster of six regions captures arable-oriented systems characterised by extremely high livestock density (3.9 LU/ha) and very high input intensity (log specific costs 9.1; energy 7.1; fertiliser 6.3). Although still predominantly arable in land use (80%), these systems exhibit pronounced positive deviations across livestock density, input expenditures, and capital indicators such as machinery, buildings, and fixed assets. Their small size indicates geographic concentration rather than marginal statistical artefact and places them at the upper bound of the European production intensity gradient.

Capital variables reinforce these structural gradients, peaking in the high-intensity arable–livestock cluster and remaining comparatively subdued in low-input regimes. Overall, the typology captures a multidimensional production spectrum defined by land-use specialization, livestock intensity, input intensity, labour organisation, and capital investment. Moderate arable systems form the backbone of European production, while grassland and permanent-crop systems represent distinct agro-structural specialisations. High-intensity arable–livestock regimes, although geographically concentrated, occupy the extreme end of the structural distribution and remain clearly differentiated from the European production centre.

Table P1- Cluster features

production label	n regions	Share arable land	Share grassland	Share permanent crops	Stocking density (LU/ha)	Specific costs (€/ha, log1p)	Energy costs (€/ha, log1p)	Fertiliser costs (€/ha, log1p)	Share paid labour	Share unpaid labour
Grassland-oriented — high livestock, moderate input, family-based labour	19	20%	80%	0%	1.0	6.6	4.6	3.9	20%	80%
Arable-oriented — moderate livestock, moderate input, mixed labour	65	70%	20%	10%	0.9	7.0	5.3	5.1	20%	80%
Arable-oriented — moderate livestock, low input, mixed labour	21	80%	10%	10%	0.3	6.0	4.7	4.6	30%	70%
Permanent-crops-oriented — moderate livestock, high input, paid labour	15	30%	10%	60%	0.4	7.3	5.9	6.0	40%	60%
Arable-oriented — low livestock, moderate input, paid labour	20	90%	10%	0%	0.2	6.5	5.0	5.2	70%	30%
Arable-oriented — high livestock, high input, mixed labour	6	80%	10%	10%	3.9	9.1	7.1	6.3	30%	70%

Figure P4 - Standardized cluster centroids across regions



5.1.5. Spatial distribution across Europe

The spatial overlay of the six production regimes reveals a strongly structured European agricultural landscape rather than a dispersed or random pattern (Figure P5).

The dominant Arable-oriented — moderate livestock, moderate input, mixed labour regime forms the geographic backbone of continental Europe. It extends broadly across large parts of France, Germany, Poland, and central Europe, creating a continuous belt of structurally “average” arable systems. This regime occupies the spatial centre of the production landscape, both statistically and geographically.

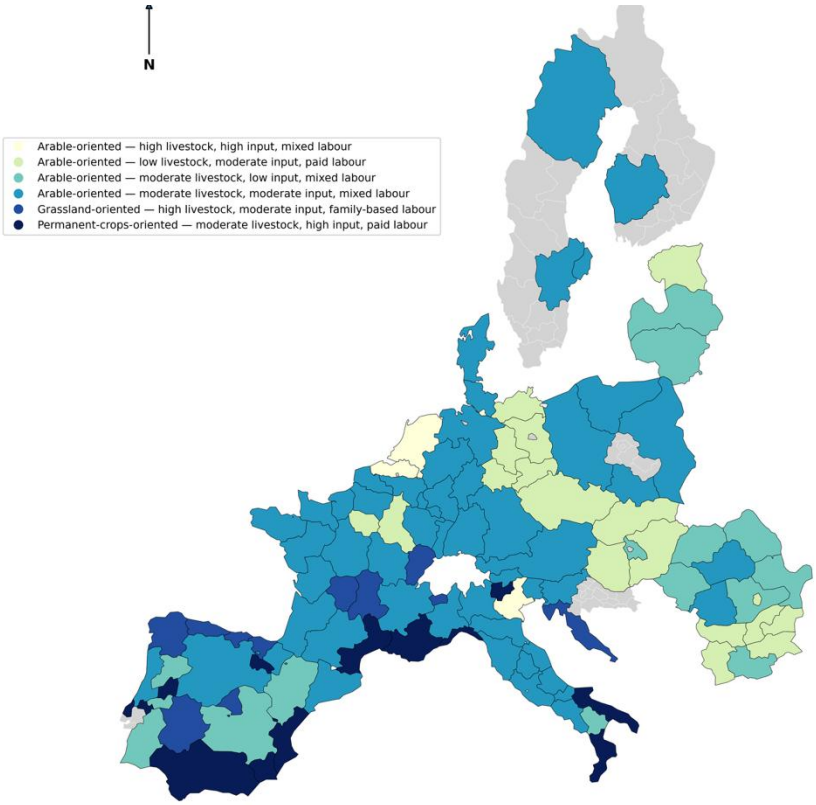
The Grassland-oriented — high livestock, moderate input, family-based labour configuration appears in more clearly defined clusters rather than in a continuous belt. It concentrates in livestock-intensive regions, particularly in parts of western France, northern Spain, and alpine-influenced zones. Its spatial coherence reinforces its interpretation as a livestock-specialised structural regime rather than a statistical residual category.

The Permanent-crops-oriented — moderate livestock, high input, paid labour systems are geographically concentrated in southern Europe. Their presence is most visible in Mediterranean regions, where perennial agriculture dominates land use. The clustering of this regime along southern latitudes confirms the structural link between climatic suitability, crop specialisation, and labour-commercialisation patterns identified in the PCA structure.

Within arable systems, spatial differentiation becomes more nuanced. The Arable-oriented — moderate livestock, low input, mixed labour regime appears in parts of eastern and south-eastern Europe, forming distinct pockets that contrast with higher-input arable regions. The Arable-oriented — low livestock, moderate input, paid labour systems are more fragmented but show identifiable concentrations in regions characterised by commercially organised arable farming.

At the intensive end of the spectrum, the Arable-oriented — high livestock, high input, mixed labour regime is spatially rare and highly concentrated. Its limited geographic footprint—visible only in a small number of regions—confirms that it represents a structurally extreme but geographically bounded production model. The clustering of these high-intensity systems suggests territorial concentration rather than diffuse over-fragmentation by the clustering algorithm.

Figure P5 - Spatial distribution of production regimes



Overall, the map demonstrates that structural production regimes align with coherent territorial patterns shaped by agro-climatic conditions, historical land-use specialisation, and production intensity gradients. Moderate arable systems dominate the European mainland, while livestock-oriented, permanent-crop, and high-intensity regimes form clearly delineated regional clusters. The spatial coherence of these regimes confirms that the typology captures meaningful agro-structural differentiation rather than abstract statistical partitioning.

5.1.6. Robustness and internal consistency

Robustness of the production typology was assessed by evaluating the sensitivity of the clustering solution to alternative numbers of clusters (K), while holding all preprocessing steps constant. The full pipeline—multi-year filtering, weighted aggregation, indicator construction, imputation, scaling, and PCA—remained fixed. Only the final KMeans partitioning stage was varied across K values from 2 to 10. The main specification uses K = 6.

Internal clustering diagnostics support the selected solution. While the silhouette score is highest at K = 2, reflecting a broad structural dichotomy, separation remains stable for K values between 5 and 7. The Davies–Bouldin index reaches its minimum at K = 6 (0.926), indicating the most favorable balance between cluster compactness and separation among tested specifications. The inertia profile displays a clear elbow around K = 5–6, after which reductions become incremental rather than structural. Together, these metrics suggest that K = 6 captures meaningful differentiation without excessive fragmentation.

To examine structural stability, the baseline K = 6 solution was compared with adjacent specifications (K = 5 and K = 7). Partition similarity measured by the Adjusted Rand Index indicates strong agreement between K = 6 and K = 7 (ARI = 0.811), while agreement is more moderate between K = 6 and K = 5 (ARI = 0.562). Region-level matching confirms this asymmetry: 92.5% of regions retain their closest corresponding cluster when moving from K = 6 to K = 7, compared to 82.9% when reducing to K = 5. This pattern indicates that the six-cluster structure is closer to a locally stable configuration than to a forced consolidation into five regimes.

Sensitivity is concentrated in specific production regimes rather than distributed uniformly. Under K = 5, the grassland-oriented, high-livestock configuration loses its distinct identity, reflecting the merging of a substantively coherent regime when cluster resolution is reduced. Under K = 7, changes occur primarily within arable systems, where additional subdivision refines internal heterogeneity without altering the broader land-use structure. Most clusters remain highly stable across specifications.

Overall, the evidence indicates that the production typology is structurally robust. The six-cluster configuration is supported by internal validity metrics and demonstrates high stability relative to nearby alternatives. Variations in K affect specific boundaries but do not alter the fundamental organisation of European production systems. The baseline specification therefore provides a statistically defensible and substantively coherent representation of agro-structural diversity across regions.

5.2. Environmental typology

5.2.1. Analytical framework

The environmental typology was constructed at the Local Administrative Unit (LAU) level to capture agro-ecological structure and management orientation across European territories. Unlike the production pillar, which focuses on economic and structural farm characteristics derived from FADN, the environmental pillar isolates land-use diversity and management intensity dimensions that shape ecological pressure and agro-environmental regimes.

Clustering was based exclusively on structural indicators reflecting land-use composition and management orientation: crop diversification, livestock diversity, share of organic land, and livestock density (LSU per hectare of utilised agricultural area). These indicators describe the configuration of farming systems rather than their performance outcomes. Emissions per hectare (crops and livestock) and economic output per hectare were retained for post-clustering profiling but were not included in the clustering feature space, ensuring that typology formation reflects structural configuration rather than outcome performance.

Missing values were imputed using median imputation. All clustering variables were scaled using a RobustScaler (median and interquartile range) to mitigate the influence of heavy tails and extreme LAU-level values. Principal Component Analysis (PCA) was applied to reduce collinearity and denoise the structural feature space prior to clustering.

This framework ensures that the environmental typology represents structural agro-ecological regimes rather than emission intensities or economic performance gradients.

5.2.2. Dimensional structure of environmental systems

PCA was applied to the four structural indicators. The first principal component explains approximately 62% of total variance, with the second component raising cumulative explained variance to roughly 79%. The third component increases cumulative variance beyond the predefined 85% retention threshold, while four components capture nearly the full variance structure. The cumulative explained variance profile (Figure E1) shows a steep increase between PC1 and PC2, followed by diminishing incremental contributions beyond PC3. Retaining three components therefore preserves over 85% of structural variance while avoiding unnecessary dimensional fragmentation.

Inspection of the PCA loadings (Figure E2) clarifies the substantive meaning of the retained components. The dominant dimension (PC1) is primarily driven by livestock density, defining a strong livestock-pressure axis that separates high-intensity territories from lower-pressure systems. PC2 is largely structured by the share of organic land, capturing an organic-orientation gradient distinct from livestock intensity. PC3 is dominated by crop diversification, differentiating diversified crop systems from more specialised configurations. Together, these components reveal a multi-axis environmental structure organised around livestock pressure, organic management orientation, and crop diversification, rather than a single linear intensity continuum.

Figure E1 - PCA explained variance

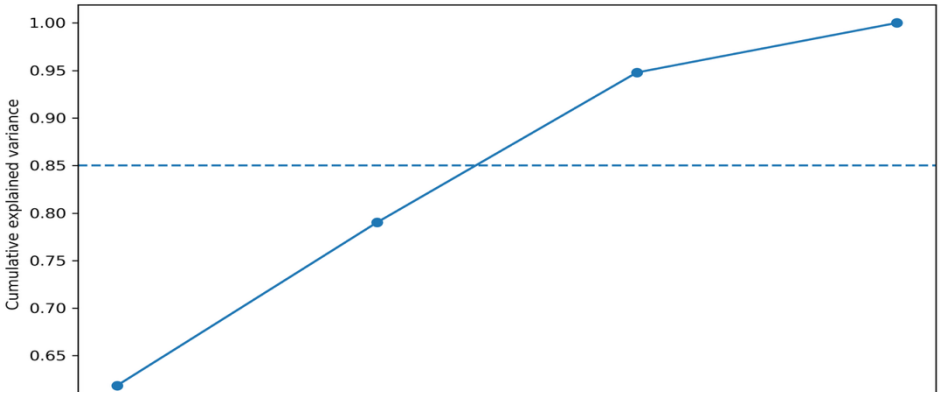
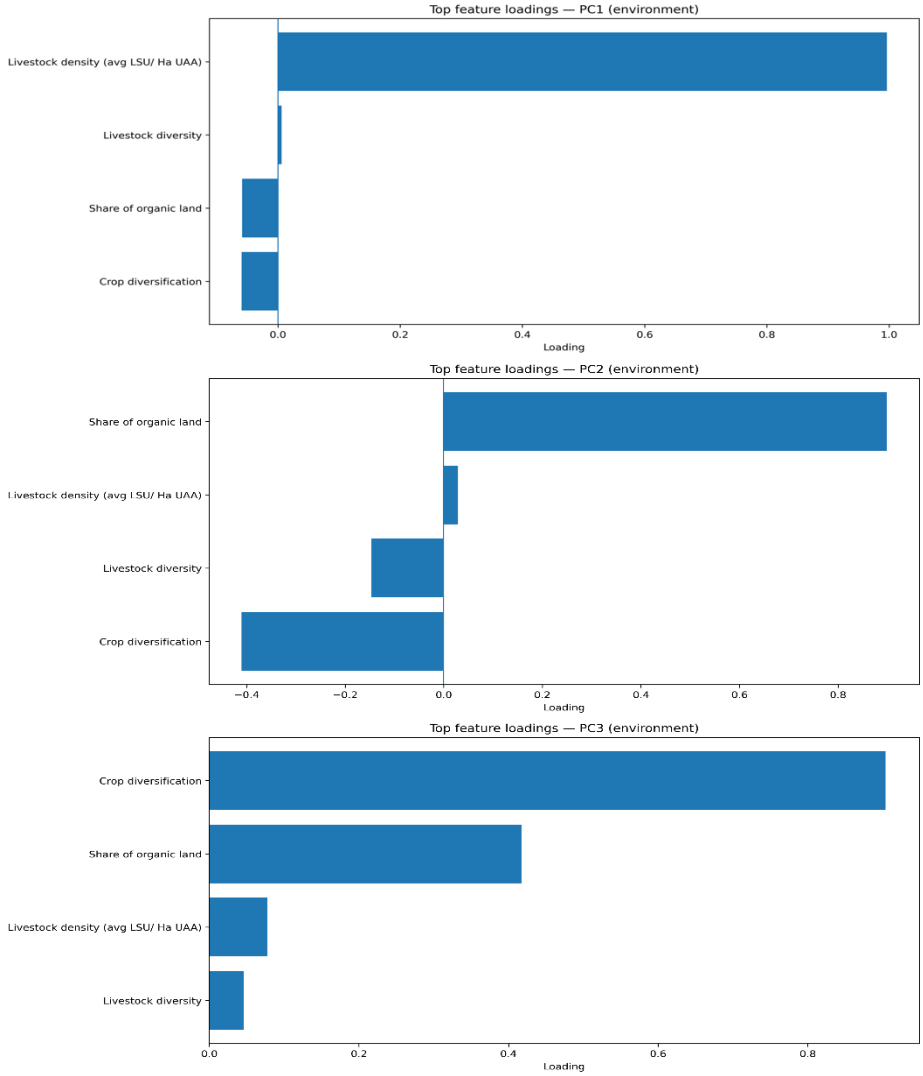


Figure E2 - Principal component loadings



5.2.3. Selection of the cluster solution

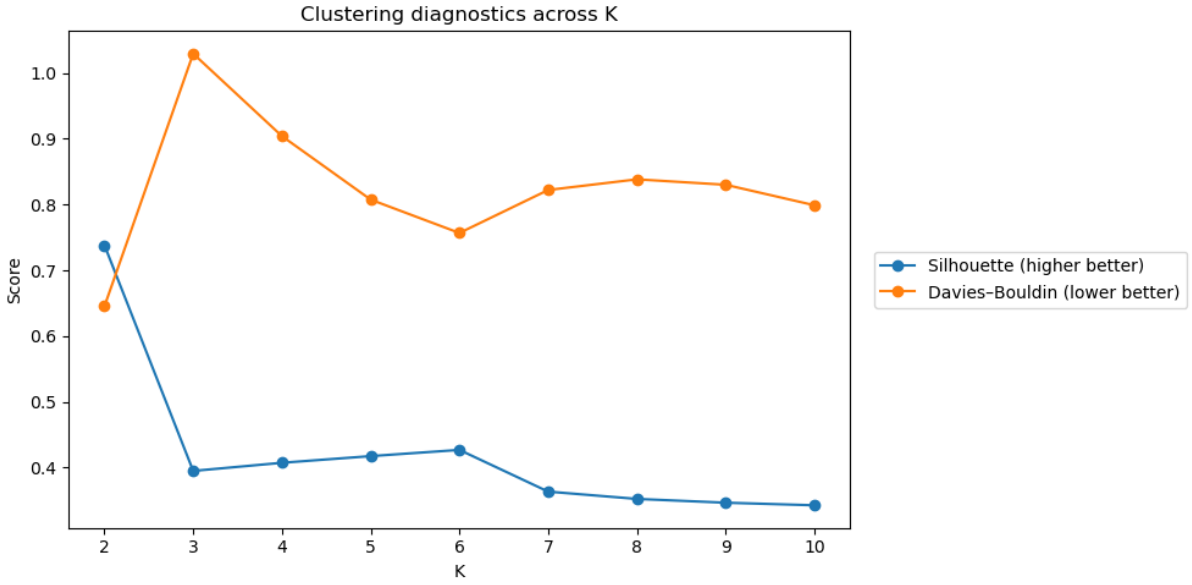
Cluster solutions were evaluated (Figure E3) for K values ranging from 2 to 10 using the silhouette coefficient (higher indicates better separation) and the Davies–Bouldin index (lower indicates more compact and distinct clusters). Consistent with typical behaviour in heterogeneous territorial datasets, K = 2 yields the highest silhouette score, reflecting a coarse structural dichotomy. However, such a partition collapses meaningful environmental heterogeneity.

Between K = 4 and K = 6, separation metrics stabilise. The silhouette coefficient increases slightly from K = 5 to K = 6 (approximately 0.42 to 0.43), while the Davies–Bouldin index reaches a local minimum at K = 6. However, the magnitude of improvement from K = 5 to K = 6 is marginal, and does not indicate the emergence of a qualitatively distinct structural regime.

Importantly, visual inspection of the PCA space shows a continuous structural gradient rather than a clearly separable sixth regime. Increasing K beyond five primarily subdivides existing mixed-diversity configurations rather than revealing a new agro-environmental type. In line with the production pillar, the selected solution balances statistical separation with interpretability and structural coherence.

Accordingly, the five-cluster solution (K = 5) is retained as the baseline specification.

Figure E3 - Clustering diagnostics across k



5.2.4. Structural composition of the five Environmental types

The environmental typology reveals a European agro-ecological landscape that is far from uniform. The clustering procedure identifies five distinct configurations that differ systematically in land-use diversification, livestock pressure, organic orientation, emissions intensity, and economic performance (Table E1). Figure E4 complements these descriptive statistics by presenting standardized centroids (z-scores relative to the overall LAU mean), clarifying how each regime deviates across structural indicators.

The most extensive configuration—comprising more than 63,000 LAUs—represents diversified mixed farming systems with moderate livestock pressure. These territories form the structural backbone of European agriculture. They combine relatively high crop diversity (0.62) and livestock diversity (0.65) with moderate livestock density (0.56 LSU/ha). Organic shares remain limited (6%), while emissions from crops per hectare are comparatively high (5.81 tCO_2eq/UAA), reflecting input-dependent mixed systems. Economic output per hectare is substantial (€10,868), indicating commercially viable but not extreme production intensity. In standardized terms, this cluster lies close to the overall mean across most dimensions, functioning as a reference configuration within the European environmental landscape.

A second large regime—low-intensity, organic-oriented mixed farming systems—accounts for nearly 11,600 LAUs. These territories stand out primarily through their markedly higher organic share (28%), which constitutes a strong positive deviation in the centroid profile. Livestock density remains relatively low (0.48 LSU/ha), and crop and livestock diversity are balanced (0.56 and 0.57 respectively). Emissions per hectare from crops are substantially lower than in the mainstream diversified regime (2.59 tCO_2eq/UAA), and livestock-related emissions are also modest (0.06). Economic output per hectare (€7,578) is lower, consistent with less input-intensive and more environmentally oriented systems. This configuration illustrates a structurally distinct agro-ecological model characterised by diversification combined with lower livestock pressure and stronger organic integration.

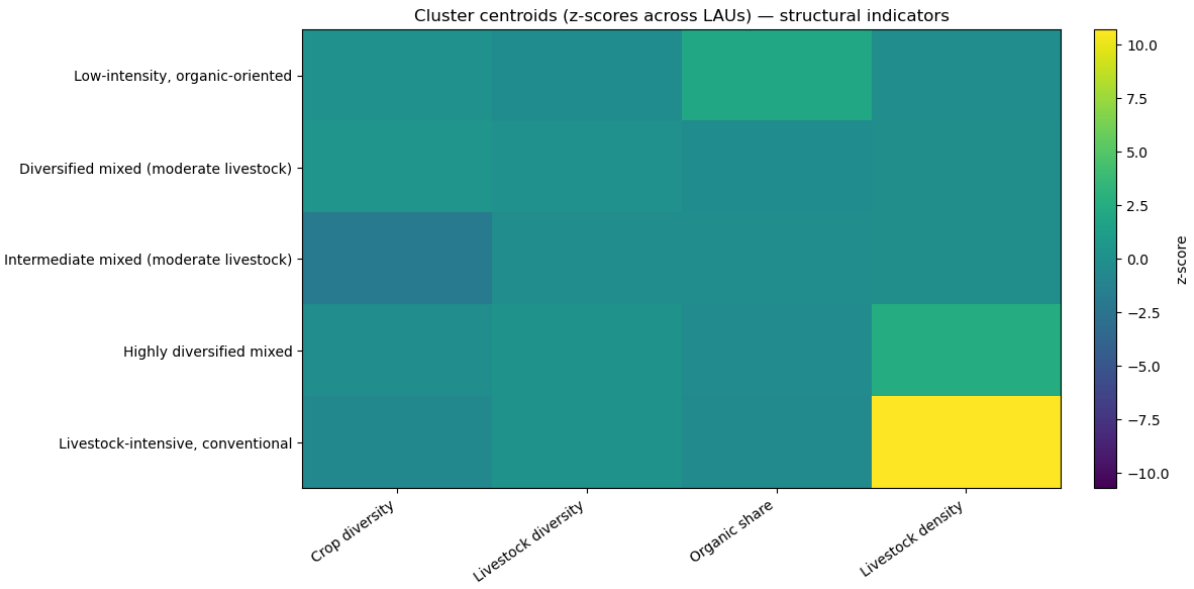
Intermediate mixed farming systems, encompassing over 15,000 LAUs, are differentiated less by intensity and more by composition. Crop diversity drops sharply (0.13), while livestock diversity remains moderate (0.59). Livestock density increases slightly to 0.62 LSU/ha, and organic shares remain limited (7%). Crop-related emissions are moderate (2.76), and economic output per hectare (€11,732) exceeds that of the dominant diversified cluster. The centroid pattern indicates modest or negative deviations in diversification indicators, suggesting that this regime represents a more specialised or structurally simplified mixed system positioned between highly diversified territories and more concentrated production models.

Importantly, emissions and economic output do not follow a single linear intensity gradient. Instead, they vary according to the interaction between diversification, livestock pressure, and management orientation. The centroid heatmap confirms that the typology captures distinct combinations of structural features rather than a binary distinction between “intensive” and “extensive” systems. European environmental regimes therefore form a layered and multidimensional landscape composed of dominant diversified mixed systems, organic-oriented territories, transitional mixed configurations, structurally complex livestock-integrated systems, and a small but economically and environmentally extreme livestock-intensive regime.

Table E1 - Cluster features

Cluster label	n LAUs	Crop diversity	Livestock diversity	Organic share	Livestock density	Tco2eq emissions/UAA crops	Tco2eq emissions/UAA livestock	Economic output per HA
Low-intensity, organic-oriented mixed farming systems	11,589	0.56	0.57	0.28	0.48	2.59	0.06	7,578
Diversified mixed farming systems with moderate livestock pressure	63,537	0.62	0.65	0.06	0.56	5.81	0.07	10,868
Intermediate mixed farming systems with moderate livestock pressure	15,210	0.13	0.59	0.07	0.62	2.76	0.04	11,732
Highly diversified mixed farming systems with moderate livestock pressure	4,535	0.47	0.70	0.05	3.48	2.89	0.22	14,594
Livestock-intensive, conventional farming systems	300	0.37	0.67	0.04	12.41	1.56	0.44	21,150

Figure E4- Cluster centroids for structural indicators



5.2.5. Spatial distribution across Europe

The spatial overlay of environmental regimes at LAU level reveals a highly textured and territorially layered agro-ecological landscape (Figure E5).

The dominant Diversified mixed farming systems with moderate livestock pressure regime forms a broad continental backbone. It is particularly extensive across central and eastern Europe, as well as large parts of France and the Iberian Peninsula, where it appears as a continuous dark band across rural territories. This regime represents the structural “baseline” of European agro-ecology.

The Intermediate mixed farming systems with moderate livestock pressure configuration appears interwoven within this dominant matrix. It forms transitional corridors across central Europe and parts of northern Italy, indicating zones where diversification declines but livestock pressure remains moderate. Rather than forming isolated enclaves, these areas often appear as buffer belts between more clearly specialised territories.

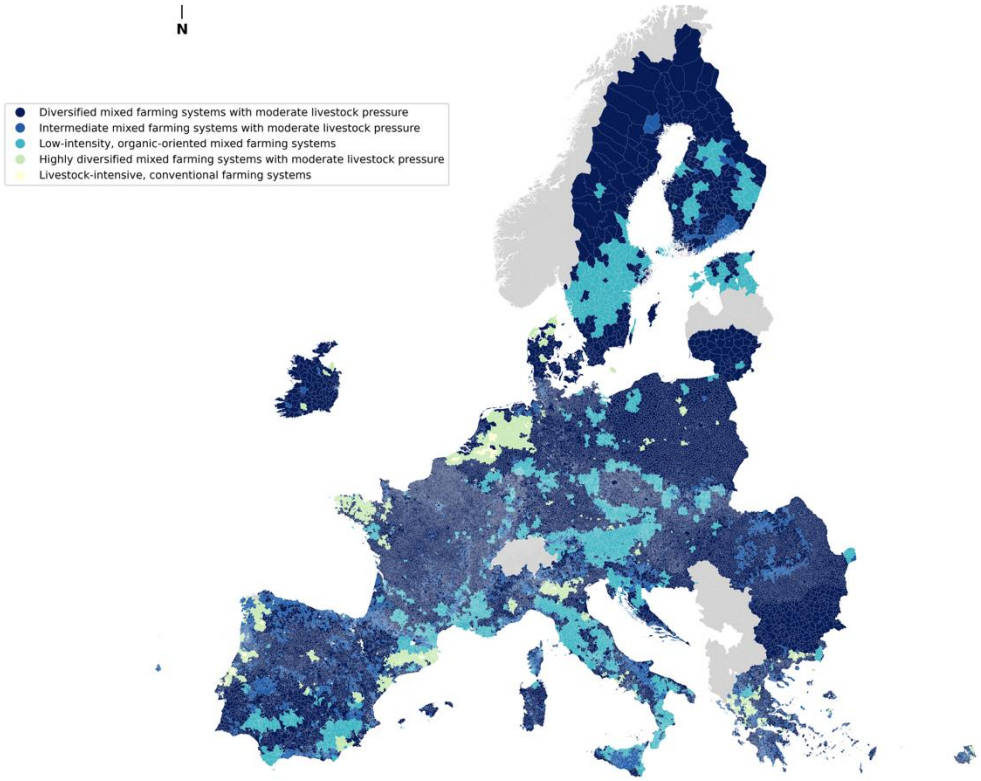
The Low-intensity, organic-oriented mixed farming systems are spatially more selective. They cluster in identifiable pockets—particularly in parts of central France, southern Germany, northern Spain, and scattered areas of central Europe. The patchwork appearance reflects localised management orientation rather than macro-regional structural dominance.

The Highly diversified mixed farming systems with moderate livestock pressure are visible as concentrated clusters rather than continuous expanses. They are especially noticeable in Alpine-influenced zones and parts of northern Italy, where complex topography and mixed land-use systems coincide. These areas often align with structurally heterogeneous agricultural landscapes combining crop and livestock diversification.

At the extreme end of the intensity spectrum, the Livestock-intensive, conventional farming systems are geographically rare but clearly concentrated. They appear in limited, sharply delineated territories—most prominently in parts of southern Spain and selected high-density livestock regions elsewhere. Their spatial concentration confirms that this regime represents a territorially bounded structural configuration rather than diffuse high-intensity agriculture.

Overall, the environmental map demonstrates that European agro-ecological regimes form a multi-scalar pattern: a dominant diversified backbone, interwoven transitional mixed systems, locally concentrated organic-oriented territories, topographically linked diversification hotspots, and geographically bounded high-livestock intensity zones. The absence of random dispersion and the presence of coherent territorial clustering confirm that the typology reflects underlying land-use structure and management orientation rather than statistical artefacts of clustering.

Figure E5 - Spatial distribution of environmental regimes



5.2.6. Robustness and internal consistency

Robustness of the environmental typology was evaluated by varying the number of clusters around the five-cluster baseline while holding preprocessing, indicator construction, scaling, and PCA specifications constant. Partition similarity measured using the Adjusted Rand Index reveals strong agreement between the five- and six-cluster solutions (ARI = 0.851), whereas agreement between the five- and four-cluster specifications is more moderate (ARI = 0.705). This asymmetry indicates that increasing resolution to six clusters primarily refines the existing agro-ecological structure, while reducing to four clusters induces more substantial consolidation.

Region-level retention analysis reinforces this interpretation. When moving from K = 5 to K = 6, 94.2% of LAUs remain within their closest corresponding cluster, demonstrating high structural continuity. In contrast, 87.6% of LAUs retain their closest match when reducing to K = 4. The larger reassignment share under K = 4 reflects the merging of distinct environmental regimes rather than minor boundary adjustments.

Inspection of the crosstab matrices clarifies the nature of these changes. Under K = 4, consolidation primarily affects the differentiated mixed farming configurations, where two structurally distinct regimes—diversified mixed systems and intermediate mixed systems—are merged into a broader composite category. This merger reduces differentiation along the diversification axis. In contrast, the transition to K = 6 does not disrupt the core five regimes; instead, it subdivides the diversified mixed farming systems into two internally differentiated subgroups, refining variation in livestock pressure and diversification without altering the broader typological architecture. The livestock-intensive conventional cluster and the organic-oriented mixed systems remain highly stable across specifications.

Taken together, these results indicate that the five-cluster configuration represents a locally stable structural partition of Europe's agro-environmental landscape. Increasing cluster resolution beyond five yields incremental refinement rather than new regime emergence, whereas reducing resolution collapses substantively meaningful distinctions. The baseline K = 5 specification therefore provides a statistically defensible and structurally coherent representation of environmental diversity across LAUs.

5.3. Consumption typology

5.3.1. Analytical framework

The consumption typology was developed using harmonised national food consumption shares aggregated across comparable reference years. Unlike the production and environmental pillars, which capture structural farm and land-use characteristics, the consumption pillar reflects dietary structure and food basket composition.

Clustering was based on normalised gram-based consumption shares grouped into analytically meaningful food categories. These categories were constructed to capture dominant dietary structures rather than product-level granularity. The feature space includes dietary shares of cereals and grains, vegetables, fruits,

dairy, meat, fish and seafood, legumes and nuts, fats and oils, sugar and confectionery, composite dishes, beverages (including coffee/tea and alcohol), and other processed categories, with all shares expressed relative to total intake within the core food basket.

All variables were expressed as shares of total food expenditure, ensuring comparability across countries of different income levels and absolute consumption volumes. Robust scaling was applied prior to dimensionality reduction to mitigate the influence of outliers and skewed category distributions. Principal Component Analysis (PCA) was then used to summarise the structure of dietary variation before clustering.

This framework ensures that the typology captures structural dietary configurations rather than caloric levels or absolute consumption intensity.

5.3.2. Dimensional structure of European consumption patterns

PCA reveals a strongly structured dietary landscape. The first principal component explains approximately 41% of total variance, and the first three components together account for roughly 65% of total variance. The cumulative explained variance surpasses the 85% threshold at six components (Figure C1), indicating that a limited number of latent dietary axes capture most cross-country variation.

The scree profile shows a steep increase between PC1 and PC2, followed by progressively diminishing marginal contributions. This suggests that dietary differentiation is structured around a small number of dominant contrasts rather than diffuse variation across many categories.

Inspection of category loadings (Figure C2) clarifies the interpretation of the principal components. The first component captures a broad gradient between fruit- and vegetable-oriented dietary structures (with positive loadings on fruit, vegetables, and eggs) and alcohol-dominant baskets (strong negative loading). RC1 therefore distinguishes fresh-food-oriented consumption systems from alcohol-intensive patterns. The second component contrasts processed and composite food structures—characterised by high loadings on sugar and confectionery, composite dishes, fish, and dairy—with grain- and egg-based consumption systems, which load negatively. This axis differentiates diversified, processed–dairy baskets from more staple-centred grain structures. The third component reflects a contrast between starchy root and meat-intensive consumption systems (positive loadings on tubers, meat, and eggs) and juice-oriented baskets (strong negative loading on fruit and vegetable juices). RC3 therefore captures variation between solid starchy–protein configurations and beverage-heavy consumption patterns.

Taken together, these axes demonstrate that cross-country dietary variation in Europe is organised along multiple structural contrasts—including fresh-food orientation, processed–staple balance, and starchy–protein intensity—rather than along a single nutritional continuum.

Figure C1 - PCA explained variance

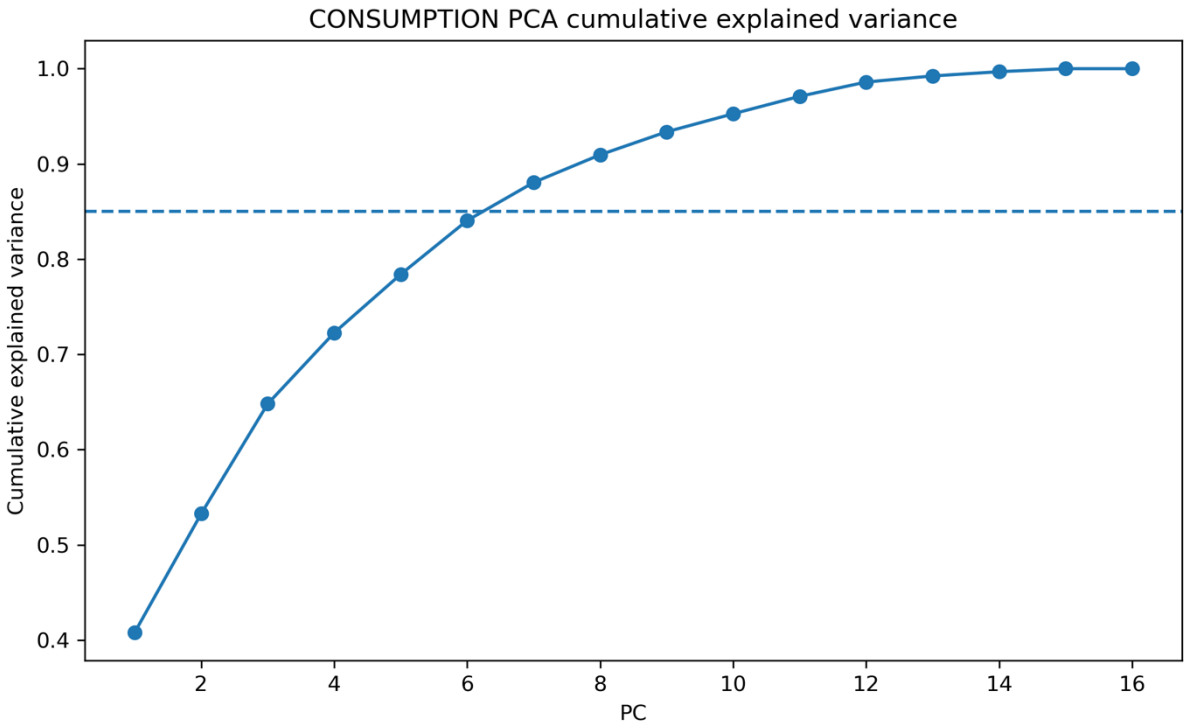
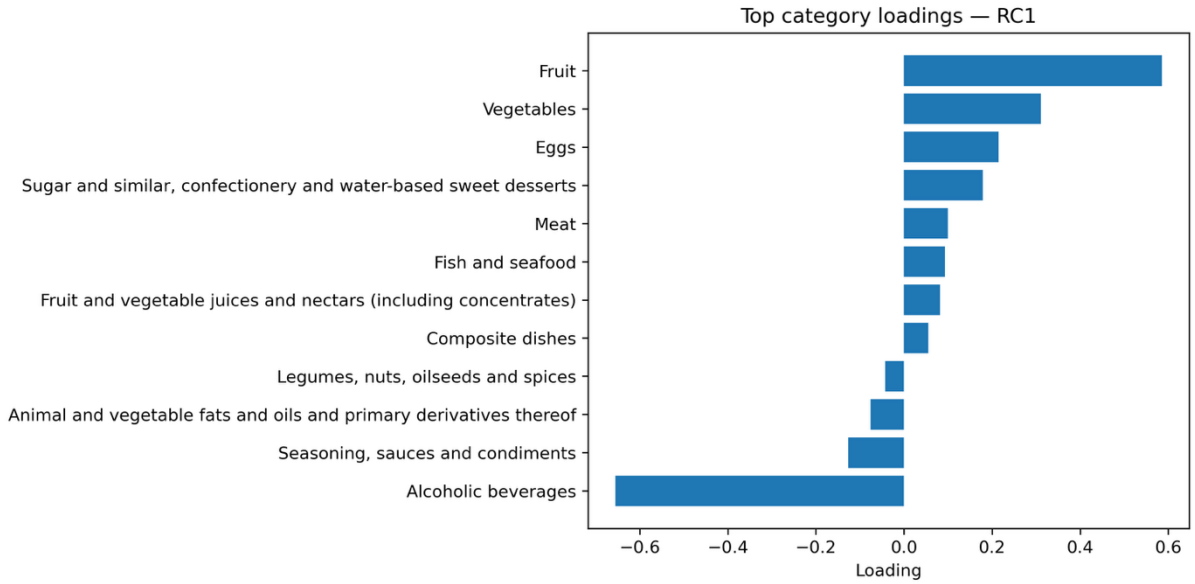
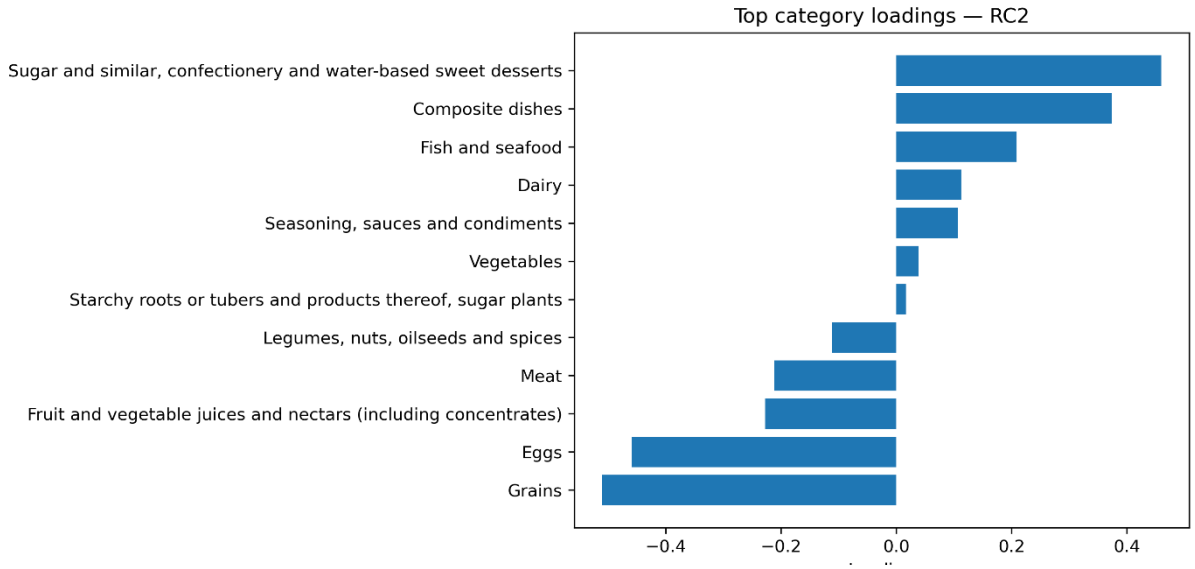
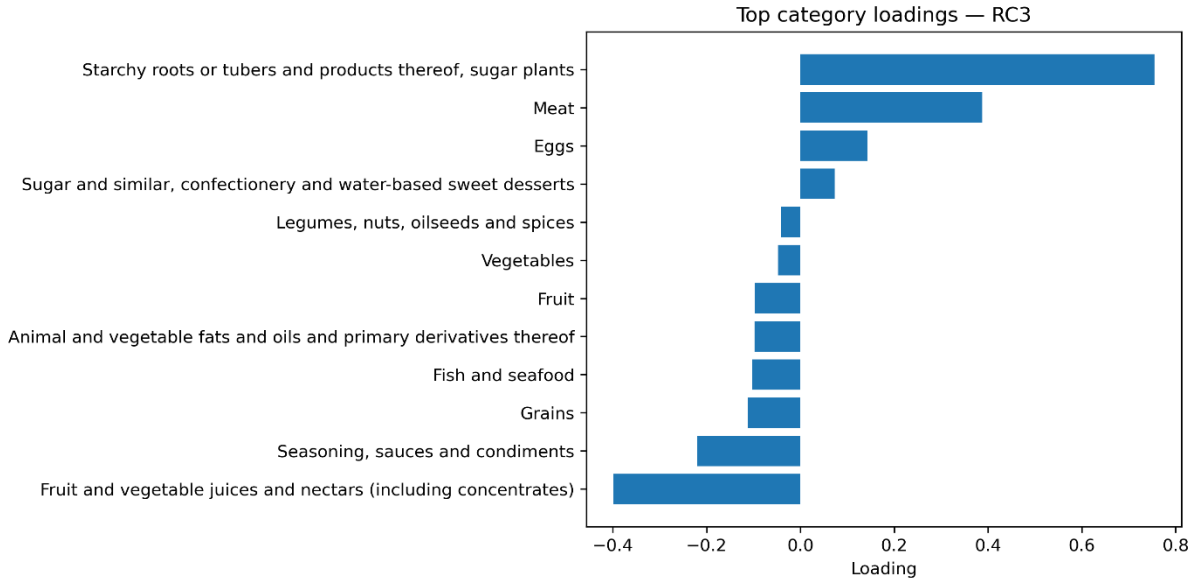


Figure C2- Principal component loadings







5.3.3. Selection of the cluster solution

Clustering was conducted using Ward's hierarchical agglomerative method on the retained PCA scores. Ward's criterion merges clusters so as to minimise the increase in total within-cluster variance at each fusion step. The resulting dendrogram (Figure C3) illustrates the hierarchical structure of dietary similarity across countries and provides a visual representation of successive fusion levels.

The dendrogram reveals an initial large split separating two broad macro-groups, followed by several secondary merges of comparable magnitude rather than a single dominant three-cluster break. This structure suggests that dietary differentiation is not organised around a simple tripartite division, but instead exhibits multiple layers of internally coherent subgroups.

To complement dendrogram inspection, cluster solutions were evaluated for K values ranging from 2 to 10 using the silhouette coefficient and the Davies–Bouldin index (Figure C4). The silhouette coefficient increases progressively from K = 2 to K = 7, reaching its highest value around K = 7 before declining slightly at higher K. In parallel, the Davies–Bouldin index decreases steadily as K increases, with improvements tapering beyond K = 8–9. This pattern indicates that additional clusters continue to improve compactness and separation up to intermediate K values, although gains become progressively smaller.

At K = 6, both diagnostics indicate a well-balanced solution: the silhouette coefficient is near its upper range, and the Davies–Bouldin index has substantially declined relative to lower K values. Importantly, the transition from K = 5 to K = 6 corresponds to a visible hierarchical separation in the dendrogram, while further increases primarily subdivide existing clusters without introducing qualitatively new structural configurations.

Within the retained PCA space, the first three components already capture the principal dietary contrasts. The six-cluster solution refines these contrasts into distinguishable regime types while avoiding excessive fragmentation observed at higher K.

Given (i) the hierarchical structure observed in the Ward dendrogram, (ii) the favourable diagnostic profile at K = 6, and (iii) the interpretability of six structurally distinct dietary configurations, the six-cluster solution is retained as the baseline specification.

Figure C3- Ward dendrogram

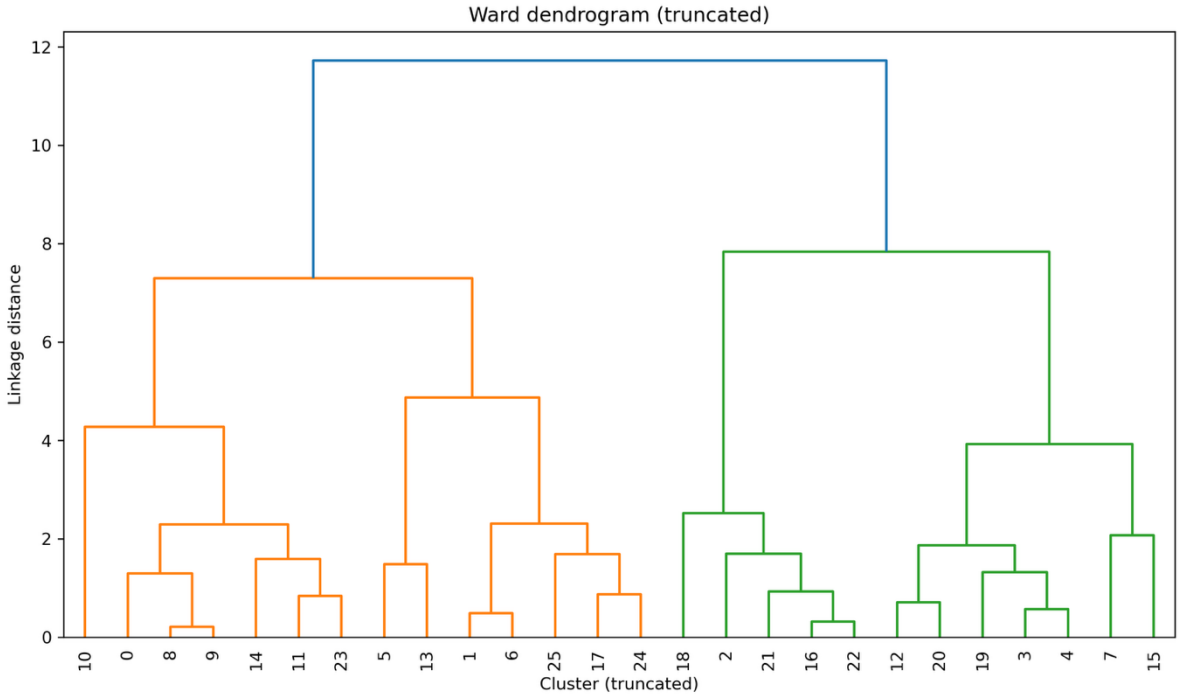
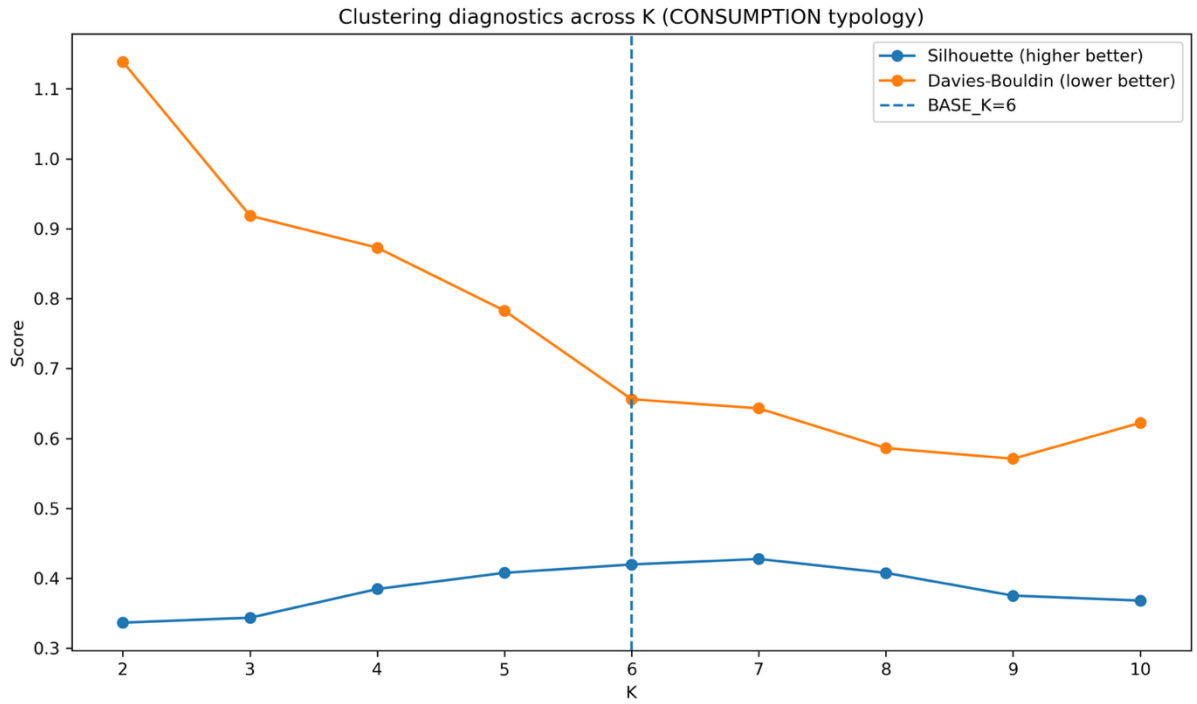


Figure C4 - Clustering diagnostics across k



5.3.4. Structural composition of the six Consumption types

The six-cluster solution reveals that European dietary systems are structured around several distinct consumption logics rather than a single dominant divide (Table C1; Figure C5). Each cluster reflects a coherent combination of staples, animal products, plant foods, beverages, and processed components.

One configuration is clearly staple–animal oriented. The *"*Higher shares of Meat, Grains. Lower share of Vegetables." cluster combines substantial grain (15%) and meat (11%) shares with comparatively lower vegetables (8%). Alcoholic beverages account for a striking 23% of the basket—by far the highest among all clusters—making this regime not only staple-based but also alcohol-intensive relative to the European mean.

A contrasting regime is strongly dairy-centred. The "Higher shares of Dairy. Lower share of Vegetables" cluster displays elevated dairy consumption (19%), alongside composite dishes (9%) and moderate fruit (8%) and grains (14%). Meat (8%) and vegetables (9%) play secondary roles. This structure reflects a dairy-led but otherwise diversified basket.

A third configuration departs from both of these patterns. The *"*Higher shares of Fruit, Grains. Lower share of Vegetables" cluster stands out for its exceptionally high fruit and vegetable juice share (15%)—the single strongest deviation in the centroid heatmap—accompanied by fruit (11%) and grains (15%). Vegetables (6%) and meat (7%) are comparatively lower, indicating a beverage- and fruit-oriented dietary structure rather than one centred on solid plant foods.

The second dairy-oriented regime differs subtly but meaningfully from the first. The *"*Higher shares of Dairy" cluster exhibits the highest dairy share overall (20%) and pairs it with elevated vegetables (14%) and balanced grains (16%). Compared to the first dairy cluster, it places greater weight on fresh plant components and less on composite dishes.

The *"*Higher shares of Grains, Meat. Lower share of Dairy" cluster is defined by the highest cereal share across all regimes (21%). Meat (12%) and vegetables (14%) are also relatively elevated, but cereals clearly anchor the food basket. This configuration represents the most staple-intensive dietary structure within the typology.

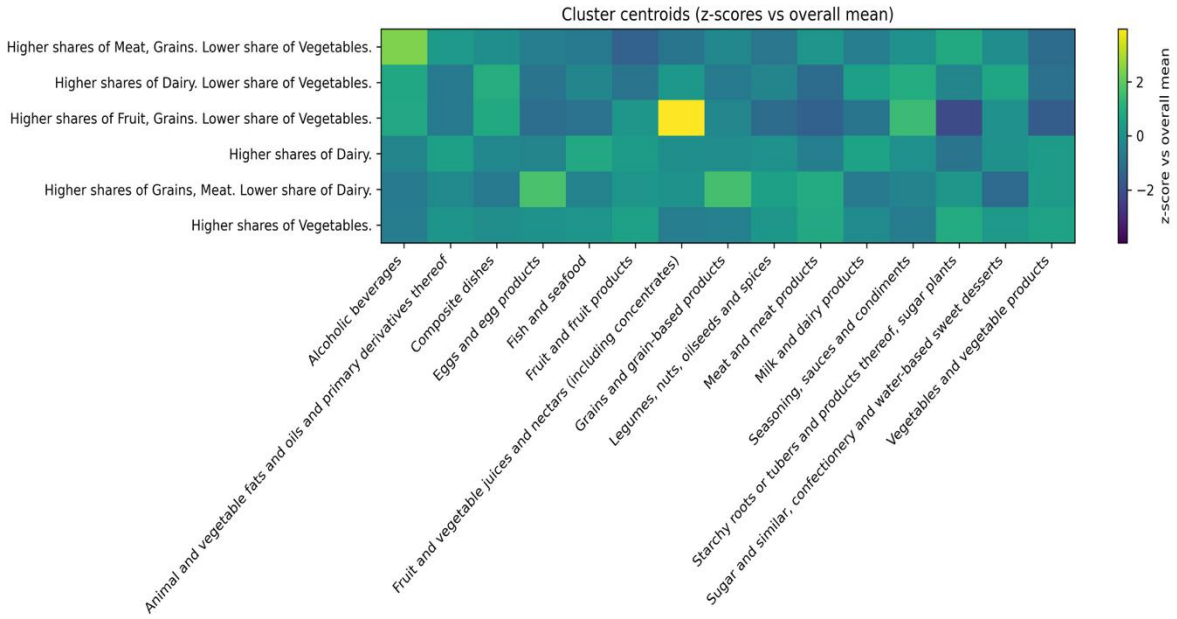
Finally, the *"*Higher shares of Vegetables" cluster combines the highest vegetable share (15%) with strong meat consumption (12%), while maintaining moderate grains (15%) and dairy (16%). This regime reflects a plant-forward yet protein-balanced configuration without a single staple dominating.

Taken together, the evidence from both raw shares and standardised centroids shows that European dietary systems organise into multiple structurally distinct bundles. Differentiation does not follow a simple plant-versus-animal continuum. Instead, regimes vary in their relative reliance on cereals (14–21%), dairy (13–20%), vegetables (6–15%), meat (7–12%), beverages (7–23% alcohol; 3–15% juices), and processed categories. The typology therefore captures patterned diversity in how food baskets are composed, rather than a single nutritional gradient.

Table C1 - Share of consumption category per cluster

consumption_cluster	Alcoholic beverages	Animal and vegetable fats and oils and primary derivatives thereof	Composite dishes	Dairy	Eggs	Fish and seafood	Fruit	Fruit and vegetable juices and nectars (including concentrates)	Grains	Legumes, nuts, oilseeds and spices	Meat	Seasoning, sauces and condiments	Starchy roots or tubers and products thereof, sugar plants	Sugar and similar, confectionery and water-based sweet desserts	Vegetables
Higher shares of Meat, Grains. Lower share of Vegetables.	23%	2%	4%	14%	1%	1%	7%	2%	15%	1%	11%	1%	7%	1%	8%
Higher shares of Dairy. Lower share of Vegetables.	14%	1%	9%	19%	1%	2%	8%	5%	14%	1%	8%	2%	5%	2%	9%
Higher shares of Fruit, Grains. Lower share of Vegetables.	15%	1%	8%	13%	1%	1%	11%	15%	15%	1%	7%	2%	2%	1%	6%
Higher shares of Dairy.	8%	2%	2%	20%	1%	3%	11%	5%	16%	1%	9%	1%	4%	1%	14%
Higher shares of Grains, Meat. Lower share of Dairy.	7%	2%	0%	14%	3%	1%	11%	5%	21%	1%	12%	1%	6%	1%	14%
Higher shares of Vegetables.	7%	2%	4%	16%	2%	2%	12%	3%	15%	1%	12%	1%	7%	2%	15%

Figure C5 - Cluster centroids for food categories



5.3.5. Spatial and structural interpretation

The spatial distribution of the six consumption regimes reveals pronounced regional structuring across Europe (Figure C6).

A clear north–south differentiation emerges. The Higher shares of Dairy regime dominates large parts of western and southern Europe, including France, Spain, and Italy, forming a broad contiguous zone. This

cluster reflects dairy-intensive but otherwise diversified consumption systems and appears geographically cohesive rather than scattered.

In contrast, the Higher shares of Dairy. Lower share of Vegetables regime is concentrated in northern Europe, particularly in Scandinavia. Its spatial concentration suggests a distinctive northern dietary configuration characterised by high dairy reliance and comparatively lower vegetable shares.

Central Europe is largely occupied by the Higher shares of Fruit, Grains. Lower share of Vegetable. regime, forming a contiguous belt across Germany and neighbouring countries. This configuration reflects fruit–grain-oriented baskets and appears as a structurally intermediate zone between northern dairy systems and eastern staple–animal regimes.

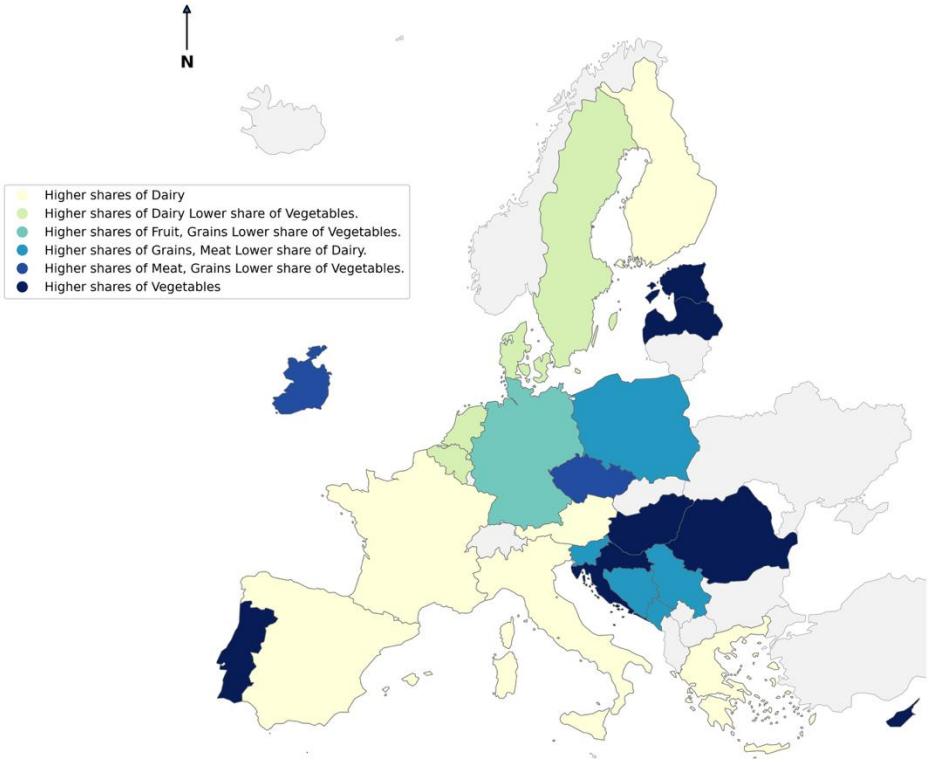
Eastern and south-eastern Europe are predominantly characterised by the Higher shares of Meat, Grains. Lower share of Vegetables regime. The geographic concentration of this pattern across Romania, Bulgaria, and parts of the Baltic region indicates a more staple- and meat-intensive dietary structure relative to western Europe.

The Higher shares of Grains, Meat. Lower share of Dairy configuration appears in a more limited set of central and south-eastern countries, forming a distinct cluster where cereals constitute the structural backbone of the diet while dairy plays a smaller role.

Finally, the Higher shares of Vegetables regime appears in geographically discrete territories, notably Portugal and selected Mediterranean contexts. Its concentration in southern Europe reflects plant-forward dietary traditions that remain structurally distinct within the European landscape.

Overall, the consumption map reveals that European dietary systems organise into geographically coherent macro-regions rather than dispersed country-level anomalies. Dairy-oriented regimes dominate western and northern Europe, grain–meat configurations concentrate in the east and south-east, and vegetable-forward systems appear in southern territories. The spatial coherence of these regimes confirms that the typology captures enduring dietary cultures and regional food traditions rather than statistical artefacts of clustering.

Figure C6 - Spatial distribution of consumption regimes



5.3.6. Robustness and internal consistency

Robustness was assessed by varying the number of clusters around the selected six-cluster baseline while holding preprocessing, scaling, PCA retention (RC1–RC3), and Ward linkage constant. Adjacent cuts at K = 5 and K = 7 were examined to evaluate whether the six-cluster solution represents a stable structural configuration rather than an arbitrary partition.

Partition similarity metrics indicate very high agreement between the six- and five-cluster solutions (ARI = 0.939) and similarly strong agreement between the six- and seven-cluster solutions (ARI = 0.886). Both values reflect strong structural continuity, suggesting that modest changes in K do not reorganize the fundamental dietary landscape.

Inspection of the cross-tabulations clarifies the structural adjustments underlying these ARI values.

Reducing the solution to K = 5 results in a single substantive consolidation. The fruit–grain diversified regime (≈11% fruit, ≈15% grains, ≈6% vegetables, ≈13% dairy) merges with the more dairy-intensive diversified regime (≈20% dairy, ≈14% vegetables, ≈16% grains). These two patterns differ primarily along the fresh-product versus dairy axis, and their merger removes this distinction. All other regimes remain fully intact: the

alcohol- and meat–grain intensive basket (≈23% alcoholic beverages, ≈15% grains, ≈11% meat, ≈8% vegetables), the dairy-dominant low-vegetable regime (≈19% dairy, ≈9% vegetables), the grain–meat intensive regime with low dairy (≈21% grains, ≈12% meat, ≈14% vegetables), and the vegetable-oriented regime (≈15% vegetables, ≈12% meat, ≈15% grains) are preserved without reassignment. Thus, moving to five clusters primarily collapses differentiation within diversified mid-spectrum diets rather than altering the structural poles of European consumption.

Increasing resolution to K = 7 produces even more limited change. Five of the six baseline regimes remain entirely unchanged. The only modification occurs within the vegetable-oriented regime, which subdivides into two internally differentiated subgroups. This split does not generate a qualitatively new dietary configuration; instead, it reflects variation in the intensity of vegetable and grain shares within an already coherent plant-forward pattern. No other regime boundary shifts.

These results demonstrate that the six-cluster specification occupies a locally stable position in the hierarchical structure. Reducing K to five merges two substantively distinct diversified regimes, while increasing K to seven merely refines internal heterogeneity within the vegetable-oriented pattern. The core dietary configurations—alcohol- and meat–grain intensive baskets, dairy-dominant systems, grain–meat intensive low-dairy systems, fruit–grain diversified systems, dairy-intensive diversified systems, and vegetable-oriented regimes—remain structurally stable.

The six-cluster configuration therefore represents a statistically robust and substantively interpretable partition of European consumption structures rather than a fragile statistical artifact.

5.4. Trade typology

5.4.1. Analytical framework

The trade typology captures the external food-system orientation of European countries through bilateral trade balances and dependency structure. Unlike the production and environmental pillars, which classify structural agricultural regimes, and the consumption pillar, which captures dietary configuration, the trade pillar isolates how national food systems are positioned within international markets.

The analytical framework combines two structural dimensions. The first dimension measures import dependency, defined as imports divided by total trade (imports plus exports), averaged over a rolling multi-year window. This indicator captures the degree to which domestic food supply relies on external sourcing. The second dimension captures net trade direction, defined as net exports per capita (exports minus imports). This separates structurally exporting systems from structurally importing systems.

Trade quantities are harmonised in kilograms and averaged over a three-year window (baseline: 2022–2024). Population in the reference year is used to compute per-capita metrics, ensuring comparability across countries of different size. Dependency levels are operationalised using quantile-based thresholds. In the baseline specification, the lower and upper terciles of the empirical dependency distribution define “low,” “medium,” and “high” dependency regimes.

This framework yields a regime typology defined by the interaction between trade direction (importing vs exporting) and dependency level (low, medium, high), producing structurally interpretable trade-system categories.

5.4.2. Distributional structure of European Trade systems

The distribution of import dependency in the baseline specification (W3, Q33–67) reveals a broad but continuous spread across countries (Figure T1). The empirically estimated dependency cut-points are 0.443 (low threshold) and 0.599 (high threshold), dividing the distribution into three balanced segments based on the observed data rather than externally imposed benchmarks. Most countries cluster around intermediate dependency values, with fewer cases occupying the extremes of very low or very high import reliance.

The distribution of net trade per capita (Figure T2) is centred around zero, indicating the coexistence of structurally exporting and structurally importing systems within Europe. The spread of values is moderate rather than polarised, suggesting that most countries do not operate at extreme surplus or deficit positions. Together, these two distributions establish the empirical axes along which the trade typology is constructed: sourcing intensity (dependency) and balance orientation (net trade).

Taken independently, neither indicator exhibits strong bimodality or structural discontinuity. Instead, both display gradual variation across countries, implying that regime differentiation emerges from the interaction of the two dimensions rather than from discrete breaks in either variable alone.

Figure T1- Import Dependency Distribution

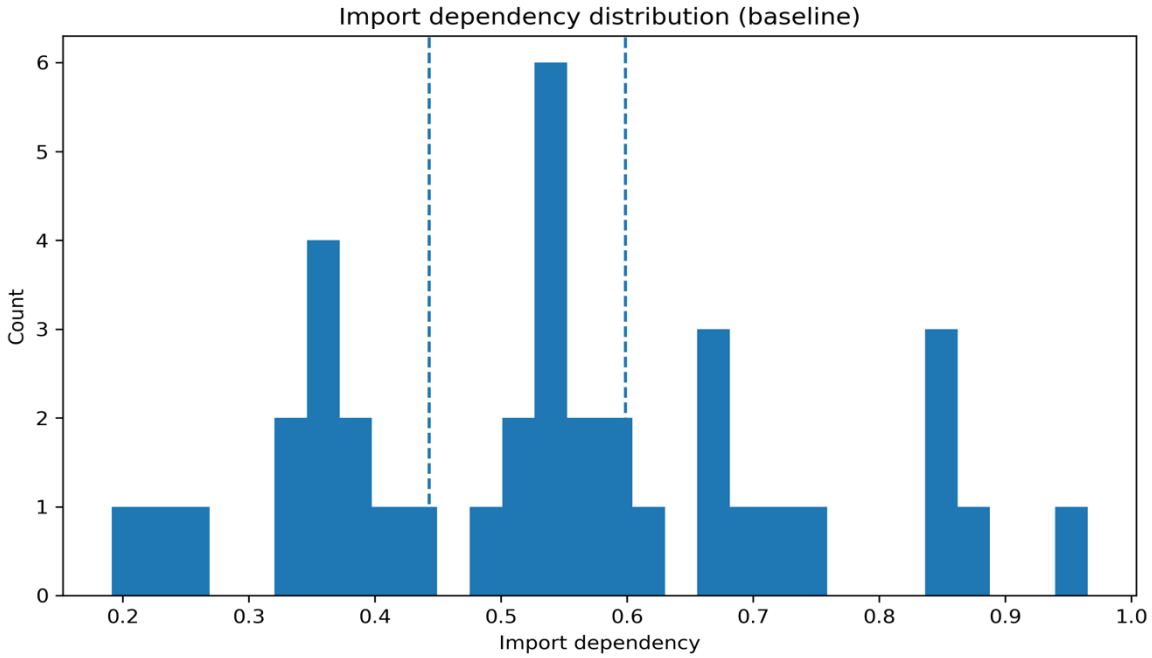
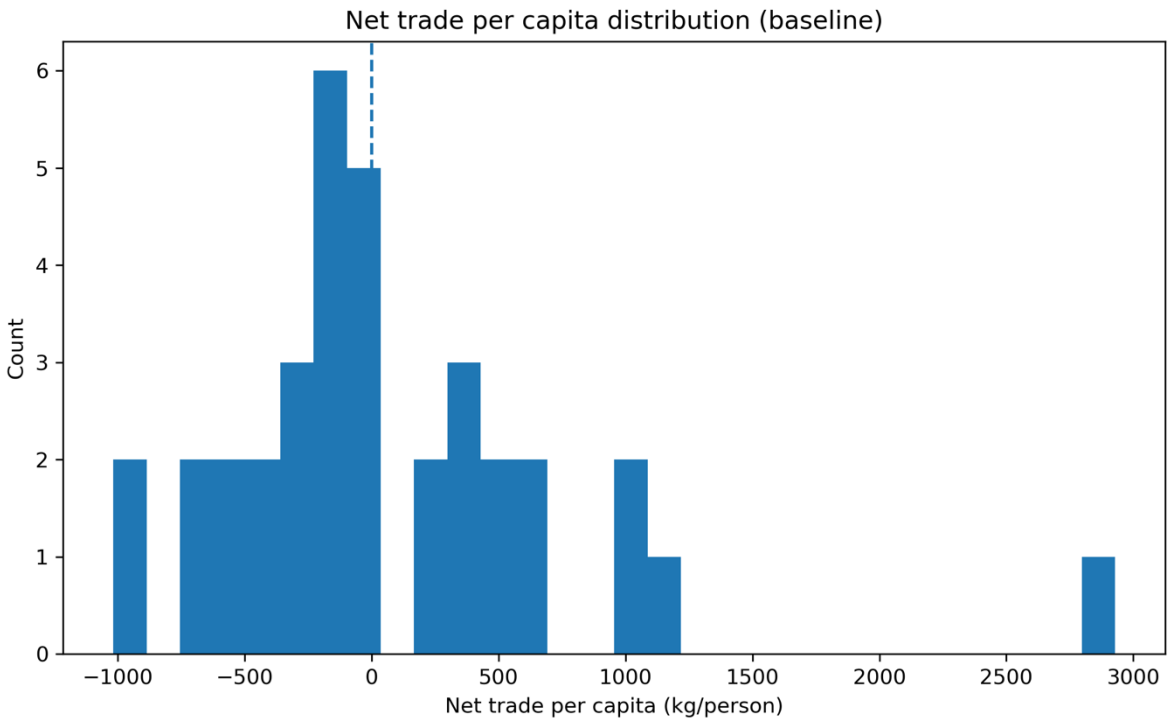


Figure T2 - Net Trade Per Capita Distribution



5.4.3. Structural composition of Trade regimes

The interaction between import dependency and net trade balance produces a two-dimensional regime architecture (Figure T3). The vertical threshold bands separate low, medium, and high dependency regimes, while the horizontal zero line distinguishes exporting from importing systems. The scatter confirms that dependency and trade balance are analytically distinct dimensions rather than mechanically coupled indicators. Exporting countries are not uniformly low in dependency, and importing countries are not uniformly high; instead, countries populate multiple quadrants of the dependency–direction space.

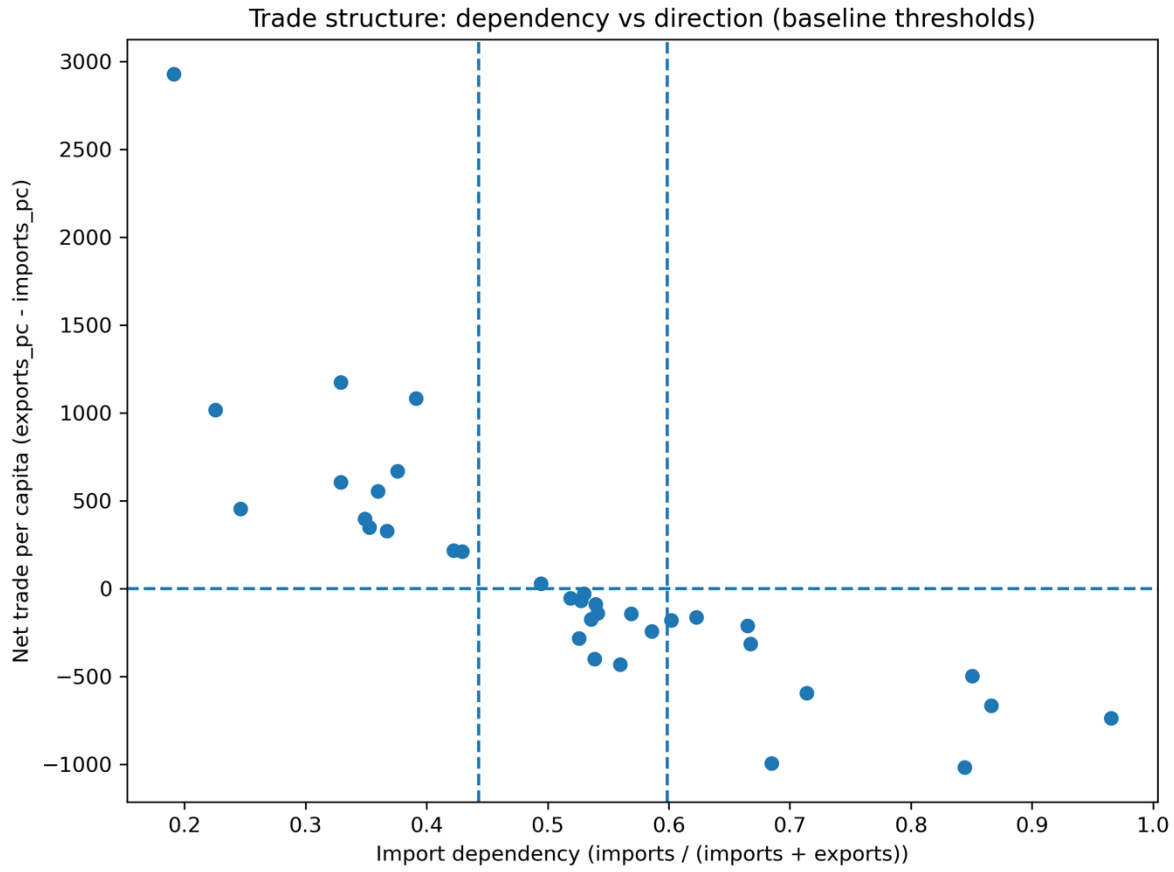
Baseline regime counts indicate an asymmetric but interpretable structure. Low-dependency exporting systems form the largest group (n = 13), suggesting that a substantial share of exporting countries combine positive trade balances with relatively limited reliance on imports within their total trade bundle. Medium-dependency importing systems (n = 11) and high-dependency importing systems (n = 10) together account for a large proportion of European countries, indicating heterogeneity among net importers in the degree to which imports dominate total trade flows. In contrast, medium-dependency exporting systems are rare (n = 1), implying that exporting countries typically fall below the low-dependency cut-point rather than clustering at intermediate dependency levels.

Structurally, low-dependency exporting systems represent the most outward-facing and relatively autonomous configurations, combining net surplus positions with limited import reliance. High-dependency importing systems represent structurally embedded regimes in which domestic food supply is strongly

integrated into global sourcing networks. Medium-dependency importing systems occupy an intermediate position, indicating partial external reliance without extreme structural dependence.

The typology therefore captures a genuinely two-dimensional external orientation landscape defined by sourcing intensity and trade balance, rather than a single linear gradient of import intensity. The empirical distribution demonstrates that Europe's food trade structure is not polarised between pure exporters and pure importers, but instead organised around differentiated combinations of dependency and direction.

Figure T3 - Trade Structure



5.4.4. Spatial distribution across Europe

The spatial distribution of trade regimes reveals a pronounced west–east differentiation rather than a simple north–south polarity (Figure T4).

Western and northern Europe are predominantly characterised by importing systems, though with varying dependency intensity. Scandinavia shows a split pattern: Sweden and Finland are importer, medium dependency, mix of animals and crops, while Norway and Iceland are importer, high dependency, variety of crops. The United Kingdom is also classified as importer, high dependency, variety of crops, reinforcing the concentration of high-dependency importing regimes along Europe's north-western periphery.

In continental western Europe, the dominant pattern is importer, medium dependency, variety of crops, visible in Germany, Belgium, Luxembourg, the Netherlands, Austria, and Spain. Italy and Greece, by contrast, are classified as importer, medium dependency, mix of animals and crops, indicating a slightly different commodity composition within similarly moderate dependency structures. Portugal stands out as importer, high dependency, variety of crops, marking one of the clearer high-dependency cases in southern Europe.

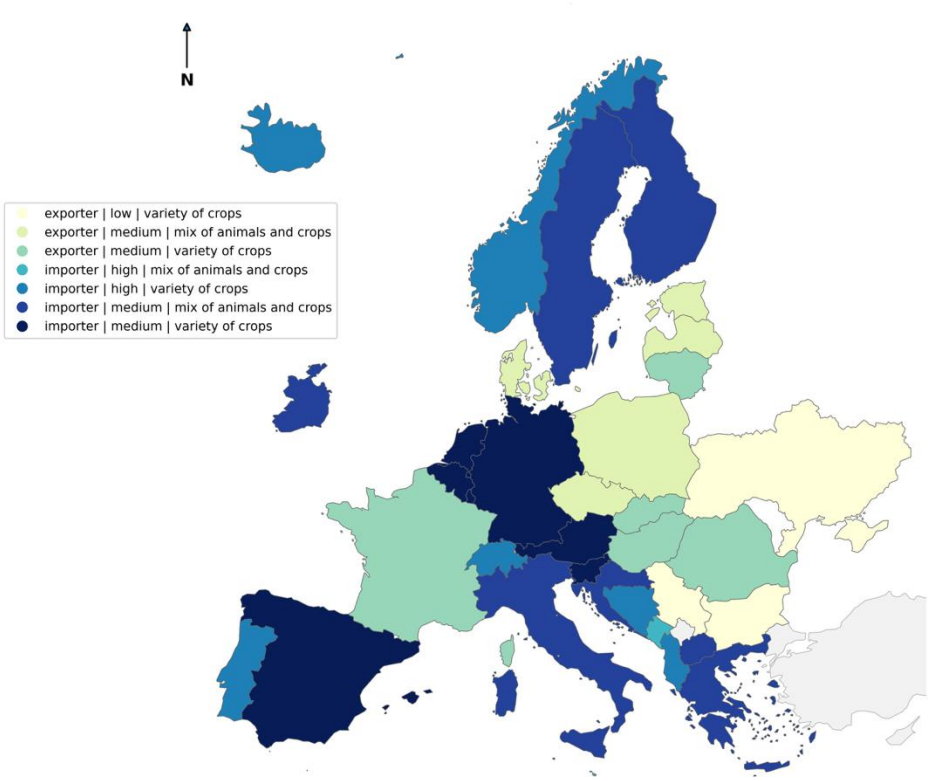
Eastern Europe presents a structurally different configuration, with exporter regimes dominating large parts of the region. Ukraine, the Russian Federation, Serbia, Bulgaria, and the Republic of Moldova are classified as exporter, low dependency, variety of crops, forming a coherent low-dependency exporting corridor across eastern Europe. Several neighbouring countries — including Poland, Czechia, Estonia, Latvia, Belarus, and Denmark — fall into exporter, medium dependency, mix of animals and crops, indicating outward-facing systems with more balanced commodity structures.

Central-eastern countries such as Hungary, Romania, Slovakia, and Lithuania are classified as exporter, medium dependency, variety of crops, reinforcing the broader pattern of export orientation across eastern Europe.

High-dependency importing systems are geographically limited but clearly concentrated. In addition to Portugal, Norway, Iceland, and the United Kingdom, several smaller states — including Malta, Montenegro, Albania, and Bosnia and Herzegovina — fall into high-dependency importer categories, reflecting structural reliance on external sourcing.

Overall, the map demonstrates that Europe’s external food-system orientation is geographically structured along a broad west–east divide. Western and northern Europe are predominantly net importers with medium to high dependency levels, while eastern Europe forms a contiguous exporter zone characterised by lower import reliance. The spatial coherence of these regimes indicates persistent structural trade orientations linked to agricultural surplus capacity, market integration, and regional production specialisation rather than short-term trade fluctuations.

Figure T4 - Spatial distribution of trade regimes



5.4.5. Robustness and internal consistency

Robustness was evaluated by varying two design parameters while holding the full preprocessing pipeline constant: (i) the temporal averaging window and (ii) the dependency threshold definition. The baseline specification uses a three-year window (W3) and tercile thresholds (Q33–67).

5.4.5.1. Sensitivity to averaging window

To test whether regime assignments depend on short-term fluctuations, the averaging window was varied to one year (W1) and five years (W5), holding dep endency thresholds constant.

Relative to the baseline, 1.89% of countries change trade label under the one-year window, while no countries (0.00%) change under the five-year window. The absence of any reclassification under W5 indicates that the baseline regime structure reflects stable trade patterns rather than short-run volatility. The very small change under W1 suggests that only a marginal number of countries lie near classification boundaries. The typology is therefore highly robust to temporal aggregation choice.

5.4.5.2. Sensitivity to dependency thresholds

Dependency cut-points were re-estimated using a stricter quantile specification (Q25–75) while maintaining the three-year window. Under this alternative threshold definition, 11.32% of countries change trade label relative to the baseline.

This higher switch rate reflects boundary sensitivity: tightening the tails necessarily reassigns borderline medium-dependency cases into high or low categories. Importantly, the underlying distribution of import dependency remains unchanged; only the categorical interpretation shifts. No structural reorganisation of the dependency–direction landscape occurs. The regime architecture therefore remains intact.

5.5. Farmland ownership and land tenure dynamics

In addition to the four typological pillars, complementary project evidence on farmland ownership provides an institutional perspective on European food-system structure. While the production, environment, consumption, and trade typologies describe functional configurations of food systems, land-tenure dynamics help identify who controls the agricultural land base through which production systems operate and transformation pathways may be implemented. This evidence is therefore not treated as a fifth typology, but as an additional layer for interpreting structural capacity, local control, and resilience.

The land-tenure analysis shows that family farms, classified as Natural Persons, remain the dominant form of farmland ownership in Europe. However, their relative share declined between 2016 and 2020, from approximately 72% to 67% of farmland. This indicates that family-based ownership continues to form the core of European farmland control, but that ownership structures are gradually shifting toward more institutionalised ownership forms, including Legal Persons and Group Holdings.

Figure L1 illustrates this institutional geography through the Land Ownership Index. The map distinguishes regions where farmland ownership is dominated by Natural Persons from those where Legal Persons are more prominent, while Group Holding ownership is shown separately because of its lower overall share and uneven reporting. The figure demonstrates that farmland ownership is not randomly distributed across Europe. Instead, ownership structure follows clear territorial patterns, with many regions remaining strongly family-farm oriented, while others show a stronger presence of corporate, cooperative, or association-based ownership. This spatial differentiation matters because ownership structure influences who has decision-making authority over land, investment, production organisation, and long-term adaptation pathways.

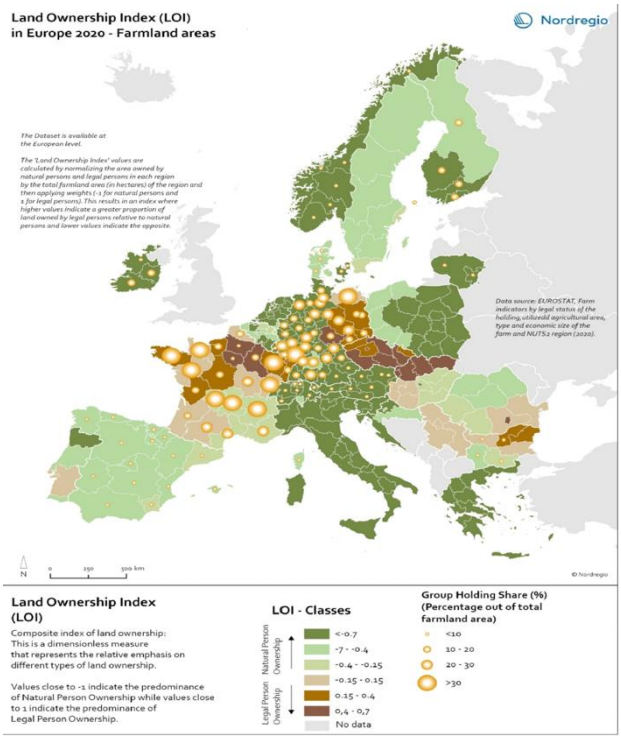
These ownership patterns are also dynamic. Between 2016 and 2020, land-tenure change varied across countries and regions, indicating that farmland ownership is not evolving according to a single European trajectory. Some regions experienced declining Natural Person ownership alongside increasing Legal Person ownership, while others showed the opposite pattern. This uneven geography suggests that ownership change is shaped by regional production structures, national land-market conditions, and broader institutional contexts rather than by a uniform process of farmland concentration.

The analysis also examined the relationship between increasing Legal Person ownership and farm economic performance. Across 118 regions in 20 European countries where Legal Person ownership increased between 2016 and 2020, 84.7% showed positive economic performance associated with the expansion of Legal Person-owned farmland, while 12.7% showed negative economic performance. This indicates that the growth of Legal Person ownership can coincide with economic strengthening in many regions, potentially reflecting investment capacity, larger operational scale, or greater access to capital.

However, the relationship between ownership type and economic performance is not deterministic. Negative outcomes were also observed, and the results show substantial regional variation. This suggests that ownership structure alone does not explain farm economic performance. Instead, the effects of ownership change are mediated by local policy frameworks, infrastructure, market conditions, production systems, and environmental constraints. Legal Person ownership may therefore support economic performance in some contexts, while creating risks or weaker outcomes in others.

Overall, the land-tenure evidence complements the typological results by showing that European food-system differentiation is not only functional, but also institutional. Production regimes, environmental regimes, dietary structures, and trade positions describe how food systems operate, while land tenure helps explain who controls the resources through which these systems can adapt or transform. This distinction is important for interpreting resilience and policy capacity: regions with similar production or trade profiles may face different transformation pathways depending on whether farmland control remains primarily family-based, corporate, collective, or mixed.

Figure L1 - Land Ownership Index



6. Discussion

Food systems appear as sets of overlapping geographies and not as one uniform territorial object. The production and environmental results showcase a visible spatial organisation. The dominant production regime is a moderate-input arable system, while the environmental baseline is a diversified mixed-farming regime with moderate livestock pressure. The environmental typology includes local areas with high organic shares, reduced crop diversity, or very high livestock density that cannot be inferred from the broad production classification. This matters because agricultural specialisation increasingly separates crop and livestock functions across farms and regions. This separation is linked to externalised manure and feed flows, nutrient surpluses, biodiversity loss, and dependence on mineral inputs. The deliverable's two typologies identify the territorial structure in which these processes occur: a broad production regime may contain local environmental hotspots, and environmental conditions may reflect relationships extending beyond the boundaries of the producing locality.

The trade results explain how these separated functions remain connected. Countries with positive or balanced net trade can still rely on imported products or inputs that are essential to domestic production. Most countries occupy intermediate positions, which is consistent with the EU's combination of aggregate agricultural export strength and dependence on selected feed materials, oilseeds, fertilisers, and other commodities. The relevant relationship is therefore between production structure and the composition of external flows. An exporting country with high livestock density may depend on imported feed, while an arable exporter may depend on imported energy or fertiliser inputs. Net trade balance alone cannot reveal these relationships.

The consumption typology completes this picture by showing that production and demand are principally connected through national markets. The six dietary profiles follow recognisable macro-regional patterns, including dairy-oriented, grain–meat, fruit–grain, juice-oriented, and vegetable-oriented configurations. These profiles do not align directly with the FADN production regimes. The mismatch is useful: it indicates that the food consumed within a country is assembled through trade, processing, retail, and cultural practice, with production often located elsewhere. Research on regional self-sufficiency reaches a similar conclusion, showing that only a minority of EU regions are self-sufficient across livestock products, cropland products, and the primary biomass required to produce them, while many livestock systems are disconnected from the land supplying their feed (Kaufmann et al., 2022). The consumption and trade results should therefore be read as evidence of spatial decoupling between food demand and agricultural production.

Farmland ownership adds the institutional dimension to these material relationships. The production typology describes the organisation of farming, while the ownership analysis indicates how farmland is legally organised across NUTS-2 regions. A region may have a similar production profile to another region while differing in the prevalence of Natural Persons, Legal Persons, or Group Holdings. Such differences may affect farm continuity, access to capital, land mobility, and the ability of local actors to influence changes in land use. Land-property research treats ownership and access arrangements as underlying drivers of the material form of food systems and of the possibilities for alternative or agroecological development. The present ownership data cannot establish these mechanisms because they do not measure tenure security,

leasing, land concentration, or effective control (Calo et al, 2021). They nevertheless identify where those questions should be investigated.

The main limitations of this study concern data resolution, indicator coverage, and the simplification introduced by typological classification. While production, consumption, and trade indicators are generally available at regional or national levels, harmonised environmental data include a limited set of consistently comparable variables. As a consequence, local production diversity, sub-national dietary variation, and regional trade specialisation are only partially captured. The selected indicators represent measurable structural dimensions of food systems, while aspects such as processing, affordability, governance, supply-chain organisation, and detailed labour relations remain outside the analytical framework. The PCA and clustering results therefore reflect the variance contained in the available indicators, and additional variables could modify component structures or regime boundaries. Since the underlying characteristics vary continuously, assigning territories to discrete regimes also simplifies gradual differences and leaves heterogeneity within clusters and around cluster boundaries. The typologies should therefore be interpreted as comparative maps of dominant structural configurations, with improved harmonised LAU-level and sub-national datasets offering scope for greater territorial precision.

7. Conclusion

This deliverable presents a multi-dimensional assessment of European food systems through four separately typologies covering production, environmental conditions, consumption, and trade. Farmland ownership is examined as an institutional layer. The main contribution of the deliverable is relational. It shows how different parts of the food system can be connected while remaining spatially and institutionally separated. Arable production, livestock concentration, imported feed, national dietary demand, and changing ownership structures may belong to one food system even when they occur in different regions and are recorded in different datasets. This perspective changes how the typology should be used. The individual regime labels are useful entry points, but the more important analytical task is to examine combinations such as production with environmental regimes, production regime with ownership structure, or consumption profile with trade orientation. These combinations could reveal whether particular territorial configurations are associated with greater dependence on external inputs, stronger environmental pressure, or more limited room for local adaptation. The robustness analysis supports this use as a baseline. The main production, environmental, and consumption structures remain recognisable under adjacent cluster solutions, while trade classifications are most sensitive for countries close to the dependency thresholds. This confirms stability within the tested specifications. It does not establish that the regimes persist through time or that they respond similarly to future shocks. The results remain dependent on indicator selection, data coverage, spatial resolution, imputation, PCA-based representation, and clustering choices. To conclude, value of the typologies lies in making spatial disconnections and institutional differences visible: where production is separated from livestock demand, where environmental pressures are concentrated, where national diets depend on external flows, and where ownership structures may condition land-use change. Further work could go further in connecting these profiles through explicit spatial overlays, cross-tabulations, temporal analysis, and more detailed evidence on tenure and governance. This would allow to move from describing separate territorial patterns to testing how they combine in concrete food-system configurations.

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9. Appendix 1

Table A1 – Indicator inventory

Indicator	Data source	Year or reference period	Spatial resolution	Measurement or category	Pillar
Arable land share	FADN	2021-2023	FADN region	Share of utilised agricultural area	Production
Grassland share	FADN	2021-2023	FADN region	Share of utilised agricultural area	Production
Permanent-crop share	FADN	2021-2023	FADN region	Share of utilised agricultural area	Production
Crop output orientation	FADN	2021-2023	FADN region	Relative contribution of crop output to total agricultural output	Production
Livestock output orientation	FADN	2021-2023	FADN region	Relative contribution of livestock output to total agricultural output	Production
Livestock stocking density	FADN	2021-2023	FADN region	Livestock units per hectare of agricultural land	Production
Specific costs	FADN	2021-2023	FADN region	Expenditure per hectare; log-transformed where applicable	Production
Energy costs	FADN	2021-2023	FADN region	Expenditure per hectare; log-transformed where applicable	Production
Fertiliser costs	FADN	2021-2023	FADN region	Expenditure per hectare; log-transformed where applicable	Production
Veterinary costs	FADN	2021-2023	FADN region	Expenditure associated with livestock production	Production
Paid labour share	FADN	2021-2023	FADN region	Share of labour provided by hired workers	Production
Unpaid labour share	FADN	2021-2023	FADN region	Share of labour provided by family or other unpaid workers	Production
Machinery value	FADN	2021-2023	FADN region	Farm capital indicator	Production
Buildings value	FADN	2021-2023	FADN region	Farm capital indicator	Production
Fixed assets	FADN	2021-2023	FADN region	Farm capital indicator	Production
Output per hectare	FADN	2021-2023	FADN region	Agricultural output per hectare	Production

Indicator	Data source	Year or reference period	Spatial resolution	Measurement or category	Pillar
Crop emissions intensity	Eucropmap (JRC)	2022	LAU	tCO_2-equivalent per hectare of utilised agricultural area	Environmental
Livestock emissions intensity	FAOSTAT	2022	LAU	tCO_2-equivalent per hectare of utilised agricultural area	Environmental
Crop diversification	Eucropmap (JRC)	2022	LAU	Diversification Simpson index	Environmental
Livestock diversification	EUROSTAT	2020	LAU	Diversification Simpson index	Environmental
Organic agricultural land share	EUROSTAT	2020	LAU	Share of agricultural land under organic management	Environmental
Livestock density	EUROSTAT	2020	LAU	Livestock units (LSU) per hectare of utilised agricultural area	Environmental
Economic output per hectare	EUROSTAT	2020	LAU	Agricultural economic output per hectare	Environmental
Cereals and grains	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Vegetables	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Fruit	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Meat	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Fish and seafood	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Milk and dairy products	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Eggs	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Legumes, nuts, oilseeds and spices	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Fats and oils	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Sugar and confectionery	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption

Indicator	Data source	Year or reference period	Spatial resolution	Measurement or category	Pillar
Composite dishes	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Fruit and vegetable juices	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Alcoholic beverages	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Other retained food categories	EFSA food consumption database	1997-2021	Country	Share of the defined core food basket	Consumption
Food imports by item	FAO country-by-item trade data	2022–2024	Country	Quantity, harmonised to a common physical unit	Trade
Food exports by item	FAO country-by-item trade data	2022–2024	Country	Quantity, harmonised to a common physical unit	Trade
Total food imports	FAO country-by-item trade data	2022–2024	Country	Sum of item-level import quantities	Trade
Total food exports	FAO country-by-item trade data	2022–2024	Country	Sum of item-level export quantities	Trade
Population	Population dataset used with FAO trade data	2022–2024	Country	Population used for per-capita calculations	Trade
Import dependency	Derived from FAO trade data	2022–2024	Country	Imports divided by imports plus exports	Trade
Net trade per capita	Derived from FAO trade and population data	2022–2024	Country	Exports minus imports, divided by population	Trade
Net trade direction	Derived from FAO trade data	2022–2024	Country	Net importer or net exporter	Trade
Net-flow composition	Derived from FAO trade data	2022–2024	Country	Animal-based, crop-based, mixed, or other categories	Trade
Net-flow concentration	Derived from FAO trade data	2022–2024	Country	Dominance share, concentration index, and diversity measures	Trade
Import and export diversification	Derived from FAO trade data	2022–2024	Country	Top-item shares and concentration statistics	Trade
Natural Person ownership share	Eurostat farm-structure data	2016 and 2020	NUTS-2	Share of farmland associated with Natural Persons	Land-ownership
Legal Person ownership share	Eurostat farm-structure data	2016 and 2020	NUTS-2	Share of farmland associated with Legal Persons	Land-ownership

Indicator	Data source	Year or reference period	Spatial resolution	Measurement or category	Pillar
Group Holdings share	Eurostat farm-structure data	2016 and 2020	NUTS-2	Share of farmland associated with Group Holdings	Land-ownership
Change in ownership composition	Eurostat farm-structure data	2016–2020	NUTS-2	Change in the share of each ownership category	Land-ownership
Farm economic performance	Eurostat/FADN farm-structure or accountancy data	2016 and 2020,	NUTS-2	Economic performance measure used in association analysis	Land-ownership