A COMPARATIVE ANALYSIS OF AGRICULTURAL SUSTAINABILITY AND RURAL MODERNISATION IN ROMANIA AND MOLDOVA, EXAMINING THE CHALLENGES AND POTENTIAL DEVELOPMENT PATHS

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SUMMARY

The study analyses the dynamics of rural sustainability in Romania and Moldova, focusing on the interrelations between the economic, social, and environmental dimensions of agricultural development. Using the Integrated Rural Sustainability Transition Model (IRSTM) and entropy-based composite indices, the research evaluates the evolution of rural systems over the period 2014–2023. The results reveal an asymmetric transition toward sustainability: Romania demonstrates a consolidated trajectory supported by structural modernisation and institutional integration within the European framework, while Moldova displays a more fragmented and vulnerable pattern, constrained by limited resources and structural inefficiencies. The comparative analysis highlights that economic growth alone is insufficient to ensure sustainability without improvements in ecological efficiency and social cohesion. The model's entropy weighting confirms the robustness of the results and the internal balance between the three sustainability pillars. The findings underline the importance of coherent multi-level governance, investment in human capital and infrastructure, and the promotion of territorial innovation to enhance resilience and accelerate the sustainability transition in Eastern European rural regions.

Keywords: *rural resilience, territorial innovation, entropy weighting, composite indicators, sustainability transition*

INTRODUCTION

Agriculture remains a cornerstone of rural economies in Central and Eastern Europe, serving not only as a key source of income and employment but also as a stabilising force for the social and ecological balance of rural territories. In both Romania and Moldova, the agricultural sector fulfils a dual function: it underpins food security and territorial resilience while shaping the ability of these economies to adapt to the transition toward sustainability. Over the last two decades, structural reforms, European integration, and rural development programs have driven profound transformations in the organisation and performance of agriculture in both countries. Nevertheless, marked disparities persist in productivity levels, rural infrastructure modernisation, and the overall sustainability of agricultural systems.

Scholarly interest in rural sustainability has advanced significantly in recent decades, shifting from predominantly economic interpretations of rural development (Ellis, 2000; OECD, 2008) toward holistic frameworks that integrate economic, social, and environmental dimensions (Marsden, 2013; Wilson, 2010; FAO, 2013). Concepts such as *rural resilience* and *territorial innovation* have been introduced to explain how rural societies respond to external pressures—economic, climatic, or demographic—through adaptation and innovation (Darnhofer, 2014; Béné, 2020). Within the Eastern European context, however, the application of these approaches remains limited, as most studies are descriptive or sector-specific and rarely account for the multidimensional nature of sustainability.

Romania and Moldova offer a significant comparative context for analysing the transition toward sustainable rural development. Both maintain strong agricultural profiles characterised by high rural population shares and significant reliance on natural resources, yet they differ in the pace of agricultural modernisation and institutional integration. Romania, as an EU member state, benefits from the Common Agricultural Policy (CAP), which provides regulatory and financial support for the green transition. Moldova, in contrast, while gradually aligning with EU standards, continues to face structural challenges such as fragmented land ownership, small-scale farms, and limited administrative capacity (World Bank, 2022). These contrasts justify a comparative investigation of agricultural sustainability and rural modernisation.

Despite valuable contributions from previous studies, substantial gaps persist in measuring and integrating the economic, social, and environmental components of rural sustainability across Eastern Europe. Most analyses rely on isolated indicators or static descriptions, which limit our understanding of interdependencies and transition dynamics. Consequently, there is a growing need for standardised empirical instruments that allow cross-country comparisons and inform evidence-based rural development policies (OECD, 2020; FAO, 2017).

This paper addresses these gaps by developing an Integrated Rural Sustainability Transition Model (IRSTM) and applying an original empirical methodology based on composite indices representing the economic, social, and environmental dimensions of agriculture in Romania and Moldova. Unlike earlier approaches, this study combines descriptive analysis with a methodological contribution grounded in the OECD (2008) guidelines for constructing composite indicators and employs entropy-based weighting to reflect the relative significance of each indicator within the overall sustainability framework.

The research pursues three main objectives: (i) to compare the economic, social, and environmental performance of agriculture in Romania and Moldova; (ii) to construct a synthetic Rural Sustainability Index (RSI) that traces the long-term evolution of agricultural systems; and (iii) to identify key challenges and policy directions for sustainable rural transition in both countries. The findings are expected to contribute to both academic discourse on sustainable rural development and policy design by providing empirical evidence to guide agricultural modernisation and rural resilience in Eastern Europe.

By integrating the theoretical foundations of the IRSTM with a rigorous empirical strategy, the study offers an original contribution to comparative research on agricultural sustainability. At the same time, it underlines the practical relevance of rural transition processes and the necessity of coordinating economic, social, and environmental policies within a coherent model of sustainable territorial development.

THEORETICAL FRAMEWORK

The concept of rural sustainability can be seen as an evolution of the sustainable development paradigm, reinterpreted for the specific realities of rural territories, where the interlinkages among the economy, society, and the environment determine their long-term viability (Marsden, 2013; Wilson, 2010). Within the academic literature, this concept is not confined to a static balance between human activity and natural resources but is rather perceived as a continuous process of transformation, through which agricultural and institutional systems adapt to both structural and ecological changes (Darnhofer, 2014; Béné, 2020). This process-oriented understanding has encouraged the emergence of complementary concepts such as rural resilience and territorial innovation, which serve as analytical frameworks for exploring how rural areas evolve toward sustainability.

Rural resilience refers to the ability of rural communities and systems to respond to and adapt to external disturbances—whether economic, climatic, demographic, or political—while maintaining their essential socio-economic functions (Darnhofer, 2014; Milestad & Darnhofer, 2008). It does not imply a return to a pre-existing equilibrium but a reorganisation that enhances system stability and encourages innovation (Folke, 2016). In agriculture, resilience is expressed through production diversification, the adoption of sustainable technologies, strengthening rural social networks, and developing short supply chains. Consequently, agriculture is understood as a complex socio-ecological system capable of absorbing shocks and maintaining functionality (Walker & Salt, 2012).

In Romania and Moldova, rural resilience is shaped by several structural constraints, including fragmented land ownership, dependence on imported energy and fertilisers, the ageing of the rural population, and volatility in agricultural markets. Policy interventions can enhance this resilience by promoting infrastructure investment, education, and agricultural research, as well as supporting local cooperatives and community-based initiatives (OECD, 2020).

Territorial innovation frameworks provide a complementary lens for analysing rural sustainability, emphasising collective learning processes, institutional cooperation, and local knowledge generation (Moulaert & Sekia, 2003). These approaches assume that sustainable development depends not only on natural and physical capital but also on cognitive and social resources that drive innovation in agricultural practices, green technologies, and participatory rural governance (Camagni & Capello, 2013). In Eastern Europe, such models are still emerging, yet offer valuable insights into the territorial dynamics of rural modernisation and sustainable agricultural transition.

Building on these theoretical foundations, this paper introduces the Integrated Rural Sustainability Transition Model (IRSTM), which combines rural resilience and territorial innovation within a single analytical structure. The IRSTM conceptualises rural sustainability as the result of dynamic interactions among three interdependent dimensions:

- the economic dimension, reflecting agricultural productivity, public and private investment, gross value added, and resource efficiency;
- the social dimension, addressing human and social capital quality, agricultural employment, income distribution, and lifelong learning; and
- the environmental dimension, capturing pressures on ecosystems through emissions, chemical input use, water efficiency, and organic farming expansion.

In contrast to conventional assessment methods, the IRSTM integrates these dimensions into a systemic framework where transformations in one sphere influence and are simultaneously influenced by the others. This integrated perspective enables an examination of sustainability transitions rather than static conditions, emphasising adaptation and transformation processes over time.

Each dimension is quantified using a composite index derived from normalised and entropy-weighted indicators (OECD, 2008). These indices are aggregated into a synthetic Rural Sustainability Index (RSI) that captures the overall performance of agricultural systems and enables both temporal and cross-national comparisons between Romania and Moldova.

The proposed model advances existing research by providing a comprehensive and replicable framework for evaluating rural sustainability. It reinterprets rural modernisation as a systemic process combining economic progress, social innovation, ecological balance, and institutional resilience. Moreover, the IRSTM facilitates comparative assessments between countries that share similar agricultural profiles yet follow distinct development trajectories, thus offering a robust empirical foundation for evidence-based rural transition policies. In this respect, the model aligns with current theoretical debates on transformative rural change and territorial sustainability transitions (Marsden, 2013; Béné, 2020; FAO, 2017).

DATA AND METHODS

The empirical analysis is based on the construction of composite indices of agricultural sustainability for Romania and Moldova, following the methodological framework recommended by the Organisation for Economic Co-operation and Development (OECD, 2008) for developing synthetic indicators. The procedure involves a standardised sequence of steps, including indicator selection, data normalisation, weight determination, and aggregation into a final index. In this study, these steps were adapted and integrated into a tailored approach referred to as the Integrated Rural Sustainability Transition Model (IRSTM), which operationalises the three fundamental dimensions of sustainability—economic, social, and environmental—within a unified analytical framework.

The data were collected from official international and national statistical databases: FAOSTAT, Eurostat, the National Institute of Statistics (INS, Romania), and the National Bureau of Statistics (BNS, Republic of Moldova). The analysis spans the period from 2014 to 2023, selected based on the consistent availability of comparable indicators for both countries.

Indicator selection was guided by three main criteria: (i) theoretical relevance, consistent with the literature on rural sustainability (OECD, 2008; FAO, 2013; Marsden, 2013; Talukder et al., 2017; Sinisterra et al., 2024; Zhan et al., 2025); (ii) data; availability and comparability between Romania and Moldova; and (iii) the indicator's capacity to capture structural trends within agricultural systems.

Accordingly, the study selected eight economic indicators, eight social indicators, and five environmental indicators, each representing a distinct dimension of agricultural sustainability. Additionally, four environmental efficiency indicators were computed separately to complement the environmental dimension, but were not included in the main composite index.

All indicators were transformed onto a common scale using the min–max normalisation method, which eliminates unit and scale differences and allows direct comparison across variables. The normalised value (Z_{ij}) of indicator (j) for country (i) was calculated as:

$$Z_{ik} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)}$$

where

Z_{ij} represents the normalized value of indicator j for year i, and iar X_{ij} is the raw value.

For indicators with a negative influence on sustainability (e.g. CO_2 emissions, pesticide use, nutrient losses), the inverse transformation was applied:

$$Z_{ik} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)}$$

Normalisation ensures that all values lie in the range [0,1], where 1 indicates maximum performance and 0 indicates minimum performance in terms of sustainability.

To avoid the arbitrariness of assigning equal weights, the information entropy method (Zeleny, 1982; OECD, 2008) was used, which measures the degree of uncertainty and variability of each indicator. The calculation steps are as follows:

The proportion of each indicator is calculated:

$$p_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{n} Z_{ij}},$$

The entropy of each indicator is determined:

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln(p_{ij}),$$

Where:

$k = \frac{1}{\lg(n)}$, and n is the number of years observed (in this case, 10).

Information diversity is calculated:

$$d_j = 1 - e_j$$

The entropic weight of the indicator is determined:

$$w_j = \frac{d_j}{\sum_j d_j}$$

The weights thus obtained reflect the unique informational contribution of each indicator. Indicators with greater variability between years or between countries receive a higher weight, while stable indicators receive a lower weight. These weights are normalized so that = 1).

For each dimension — economic, social, and ecological — an annual composite index was calculated, using the general formula:

$$I_i = \sum_{j=1}^{m} w_j Z_{jt}$$

where:

I_t represents the composite index of the respective dimension for year *t*, *m* is the number of indicators Z_{ij} included, Z_{ij} are normalized values, and w_j are the entropic weights.

This formula was applied to the following indices: Economic Index (E_t), which measures the productive and investment performance of agriculture; Social Index (S_t, which captures employment conditions, income, and human capital; and Environmental Index (EN_t), which evaluates the ecological impact of agricultural activities.

In parallel, a sensitivity variant with equal weights (1/m) was also calculated to verify the robustness of the results. The differences between the two series are minor, which confirms the methodological stability of the indices.

The three-dimensional indices were integrated into a Global Rural Sustainability Index (RSI), by arithmetic aggregation:

$$RSI_t = \frac{1}{3}\left(E_t + S_t + EN_t\right)$$

This formula provides a balanced representation of rural sustainability, avoiding the dominance of a single dimension. Alternatively, a weighted aggregation can be used if one wishes to emphasize a component (e.g., environmental) in the comparative analysis.

To assess the robustness of the constructed indices, a sensitivity analysis was performed by comparing the results obtained with entropic and equal weights, as well as the correlation between the composite indices and the reference variables (e.g., agricultural productivity and public investment), to verify the internal consistency of the models. The results confirmed a significant positive correlation between the dynamics of the economic index and agricultural performance, which attests to the validity of the empirical construct.

Accordingly, the study selected eight economic indicators, eight social indicators, five environmental indicators, and four efficiency indicators related to environmental aspects.

Table 1 presents the list of selected indicators used to construct the economic dimension of the composite sustainability index. Each indicator was chosen based on its theoretical relevance, data availability, and capacity to reflect structural transformations in agriculture.

Table 1.

Indicators, selection criteria, and sustainability dimensions

Nr	Indicator	Unit	Direction	Relevance	Selection criteria
1	Intermediate consumption	million lei	–	Measures input dependency and efficiency of resource use.	Sensitivity to structural changes; availability and comparability of data.
2	Investments in agriculture	million lei	+	Reflects sectoral modernization and development capacity.	Conceptual and policy relevance (CAP, SDG 2).
3	Government expenditure on agriculture	% of GDP	+	Indicates the level of public support for the agricultural sector.	Policy relevance and cross-country comparability.
4	Gross value added (GVA) in agriculture	million lei	+	Measures the overall economic performance of the agricultural sector.	Data availability and statistical robustness.
5	Efficiency ratio (GVA/IC)	coefficient	+	Indicator of economic efficiency—value added per unit of cost.	Theoretical relevance and interpretability.
6	Crop yield	kg/ha	+	Measures production performance and technological efficiency.	Sensitivity to technological and structural changes.

Nr	Indicator	Unit	Direction	Relevance	Selection criteria
7	Agricultural GVA per worker	lei/worker	+	An indicator of labor productivity in agriculture.	Theoretical relevance; temporal and territorial comparability.
8	Agricultural GVA per hectare	lei/UAA	+	Reflects land-use efficiency and productivity.	Theoretical relevance; regional sensitivity.

Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

Table 2 presents the set of social indicators included in the IRSTM framework, capturing demographic dynamics, labour structure, and human capital development in rural areas.

Table 2.

Selection of social indicators

Nr	Indicator	Unit	Direction	Relevance	Selection criteria
1	Rural population	number	+	Reflects rural vitality, demographic density, and population stability.	Availability and conceptual relevance.
2	Male rural population	number	±	Indicates demographic structure and labour force composition.	Availability and statistical comparability.
3	Rural employed population	number	+	Measures employment and social integration in rural areas.	Theoretical relevance and social sensitivity.
4	Agricultural employment	number	±	Reflects economic dependency on agriculture and structural vulnerability.	Conceptual relevance; redundancy tested for robustness.
5	Adult participation in lifelong learning	%	+	Indicates human capital investment and adaptability of the rural workforce.	Theoretical relevance (human capital theory); policy relevance (SDG 4).
6	Gross monthly wage in agriculture	lei	+	Reflects economic attractiveness and income level in rural sectors.	Socio-economic relevance and cross-country comparability.
7	Rural immigrants	number	+	Indicates rural revitalisation through positive demographic mobility.	Social relevance; sensitivity to migration policy.
8	Rural emigrants	number	–	Measures the loss of rural human capital and depopulation trends.	Social relevance; cross-country comparability.

Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

Table 3 summarises the set of environmental indicators selected for the IRSTM model. The indicators capture both the pressure of agricultural activities on ecosystems and the efficiency of resource use, in line with the OECD (2008) and FAO (2013) sustainability assessment frameworks.

Table 3.
Selection of Environmental Indicators

	Subgrup	Indicator	Unit	Direction	Relevance	Selection criteria
1	Emissions	Total emissions	%	–	Represents the overall pressure of agriculture on the environment.	Conceptual relevance; temporal data availability.
2		Emissions per capita	t/cap	–	Reflects the intensity of pollution per person.	International comparability and consistency.
3		Emissions per agricultural area	t/ha	–	Indicates ecological pressure on cultivated land.	Sensitivity to environmental efficiency.
4	Pesticides	Pesticide use on cultivated land	kg/ha	–	Measures the chemical intensity of agricultural practices.	Environmental and policy relevance (SDGs 12, 15).
5	Nutrients	Use N per ha	kg/ha	–	Indicates soil and water pollution from nitrogen inputs.	Ecological relevance; data availability.
6		Use P_2O_5 per ha	kg/ha	–	Reflects nutrient runoff and impact on aquatic ecosystems.	Conceptual relevance; sensitivity to eutrophication.
7		Use K_2O per ha	kg/ha	–	Captures nutrient balance and soil fertility.	Ecological relevance and completeness of the nutrient dataset.
8	Irrigation	Area equipped for irrigation	thousand ha	+	Indicates adaptive capacity to climate change.	Policy relevance; temporal comparability.
9		Effectively irrigated area	thousand ha	+	Measures the efficiency of irrigation infrastructure use.	Statistical comparability; data availability.
10	Organic farming	Organic agricultural area	thousand ha	+	Reflects the transition toward sustainable farming practices.	Conceptual and policy relevance (SDGs 2, 15).
11		Organic certified area	thousand ha	+	Indicates compliance with environmental standards.	Policy relevance; cross-country comparability.
12		Organically cultivated area	thousand ha	+	Reflects the expansion of sustainable agricultural production.	Sensitivity to green policy implementation.
13		Certified organic cultivated area	thousand ha	+	Indicates the quality of sustainable agricultural management.	Conceptual and statistical relevance.
14		Organic grasslands	thousand ha	+	Contributes to biodiversity and ecosystem preservation.	Ecological and policy relevance.
15		Organically certified grasslands	thousand ha	+	Confirm the sustainability of ecosystems.	Conceptual relevance and availability.

	Subgrup	Indicator	Unit	Direction	Relevance	Selection criteria
16	Environmental efficiency	Emissions per unit of agricultural production	kg/Int$	–	Reflects the environmental efficiency of agricultural production.	Theoretical and statistical relevance.
17		Pesticide use by production value	g/Int$	–	Measures the intensity of chemical input use.	Ecological relevance; cross-country comparability.
18		N, P, K used by production value	g/Int$	–	Indicates the efficiency of nutrient use in agriculture.	Conceptual relevance; data availability.
19		Water use efficiency in agriculture	USD/m³	+	Measures the economic efficiency of water resources.	Ecological and economic relevance.

Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data.

Research Hypotheses: Grounded in the theoretical foundations and structure of the Integrated Rural Sustainability Transition Model (IRSTM), the study advances the following hypotheses to guide empirical validation:

H1. Economic performance is expected to exert a positive influence on the overall level of rural sustainability. Rationale: Improvements in agricultural productivity, investment intensity, and the efficiency of resource utilisation are anticipated to strengthen both economic resilience and the sustainability of rural systems (OECD, 2020; Marsden, 2013).

H2. Social advancement plays a significant role in the sustainability of rural regions. Rationale: Higher educational attainment, diversified employment, and improved rural income foster adaptability and social cohesion, key drivers of sustainable transformation (Wilson, 2010; Darnhofer, 2014).

H3. Environmental outcomes are negatively affected by intensive farming practices but can be enhanced through efficiency gains and ecological management. Rationale: Decreasing emissions and chemical inputs, together with more efficient irrigation and the expansion of organic farming, are expected to improve ecological performance (FAO, 2013; Folke, 2016).

H4. The three dimensions of sustainability—economic, social, and environmental—are interlinked and exert reciprocal effects. Rationale: Rural sustainability emerges from maintaining a systemic balance between productivity, social inclusion, and ecological integrity (Béné, 2020; OECD, 2008).

H5. Romania's overall sustainability index (RSI) is hypothesised to exceed that of Moldova, owing to institutional convergence and EU policy alignment. Rationale: Integration into the Common Agricultural Policy (CAP) provides Romania with greater financial and regulatory mechanisms for sustainable agricultural transition, whereas Moldova's institutional limitations slow this process (World Bank, 2022).

The hypotheses above summarise the expected relationships among the three sustainability dimensions. They provide the empirical foundation for testing the Integrated Rural Sustainability Transition Model (IRSTM) using composite indices and comparative analysis between Romania and Moldova.

MAIN RESULTS

The subsequent section presents the empirical findings derived from applying the Integrated Rural Sustainability Transition Model (IRSTM) to Romania and Moldova from 2014 to 2023. Following the methodological procedure outlined above, composite indices were developed for each of the three sustainability dimensions—economic, social, and environmental—using normalised indicators and entropy-based weights.

The empirical analysis proceeds in three stages. First, each dimension is examined separately to trace temporal evolution and cross-country variations in performance. Second, the aggregated Rural Sustainability Index (RSI) provides an integrated view of agricultural sustainability across both cases. Finally, a sensitivity assessment tests the robustness of the composite results under alternative weighting assumptions, while a supplementary environmental efficiency index refines the evaluation of ecological outcomes.

Together, these results aim to uncover the main structural disparities and transition dynamics that shape rural development in Romania and Moldova, providing quantitative evidence to support subsequent theoretical and policy-oriented discussions.

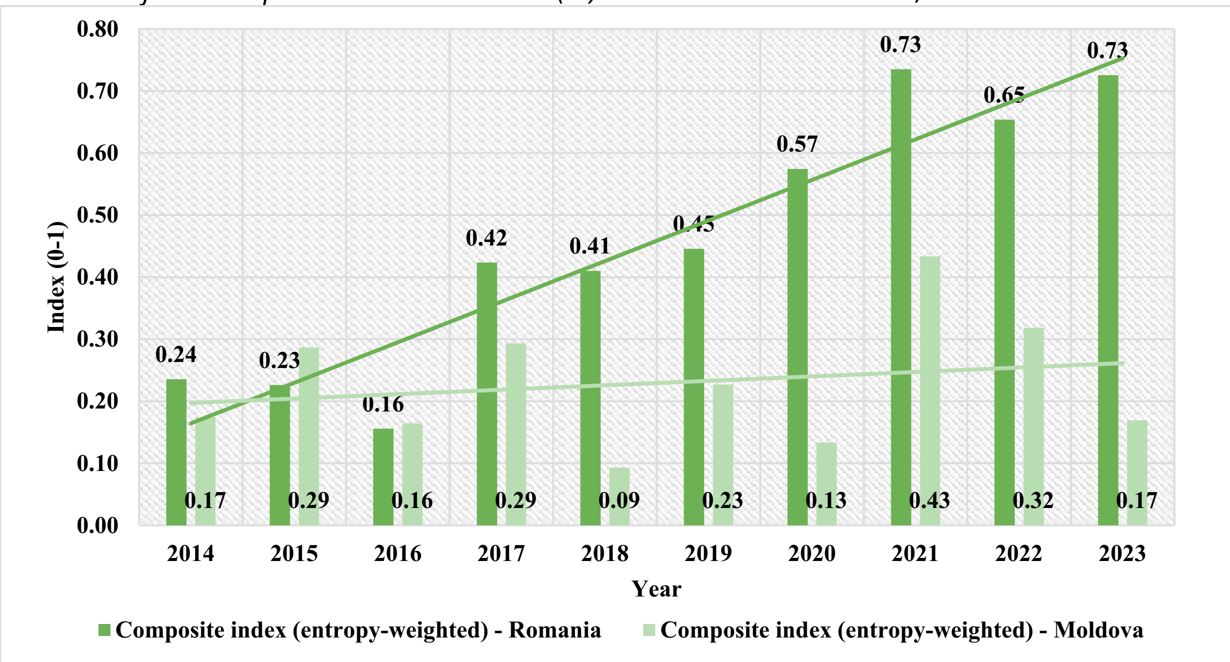
Table 4.
Composite economic index (E_t) – Romania and Moldova, 2014–2023

Year	Composite index (entropy-weighted) - Romania	Composite index (entropy-weighted) - Moldova
2014	0.236	0.174
2015	0.226	0.286
2016	0.156	0.164
2017	0.423	0.293
2018	0.410	0.093
2019	0.446	0.227
2020	0.574	0.133
2021	0.735	0.433
2022	0.654	0.318
2023	0.726	0.169

Note: Composite economic index (Et) was calculated based on eight indicators: E1 - intermediate consumption, E2 - agricultural investment, E3 - government expenditure on agriculture, E4 - gross value added, (E5 = GVA/CI) - resource efficiency crop, E6) – yield, E7 - agricultural GVA per worker, and E8 - agricultural GVA per hectare. The weights were determined using the information entropy method (OECD, 2008).

Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

Figure 1.
Evolution of the composite economic index (Et) - Romania and Moldova, 2014–2023



Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

The results presented in Table 4 and Figure 1 indicate a positive trend in the economic composite index in Romania, which increased from 0.236 in 2014 to 0.726 in 2023. This upward trend reflects the intensification of both public and private investments in agriculture, the growth of gross value added, and improvements in resource-use efficiency.

In Moldova, the economic index displays a more fluctuating pattern, remaining at lower levels (between 0.13 and 0.43) throughout the analysed period. These dynamics suggest the persistence of structural constraints such as land fragmentation, limited capital accumulation, and restricted access to external financing.

The consistent gap between the two countries confirms the economic modernisation divide, yet the upward trajectories in both cases indicate a partial convergence toward a more productive and sustainable agricultural model, particularly after 2020, when public investment and policy alignment became more evident.

While economic indicators reveal gradual convergence, the social dimension provides further insights into disparities in human capital, labour dynamics, and rural demographic stability.

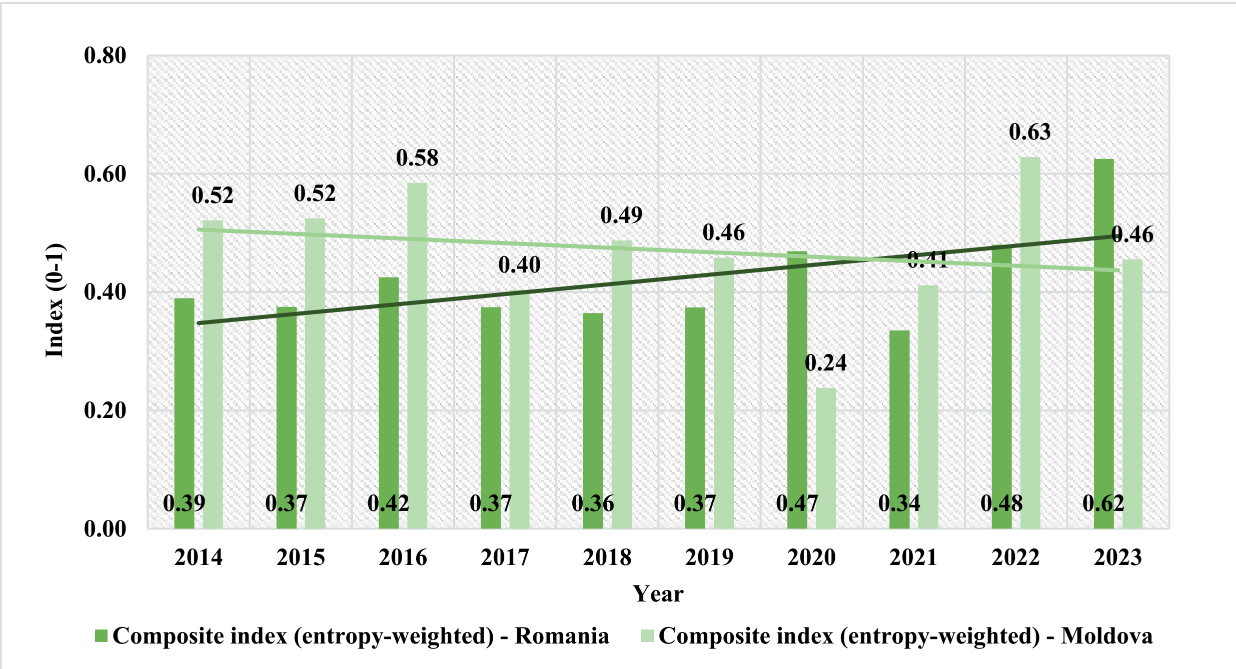
Table 5.
Composite social index (S_t) – Romania and Moldova, 2014–2023

Year	Composite index (entropy-weighted) - Romania	Composite index (entropy-weighted) - Moldova
2014	0.390	0.521
2015	0.375	0.525
2016	0.425	0.585
2017	0.374	0.404
2018	0.364	0.487
2019	0.374	0.458
2020	0.469	0.238
2021	0.335	0.412
2022	0.480	0.628
2023	0.625	0.455

Note: The composite social index (S_t) was calculated based on eight indicators: S1 - Rural population; S2 - Rural male population; S3 - Employed rural population; S4 - Agricultural employment; S5 - Adult participation in lifelong learning; S6 -Average monthly wage in agriculture; S7 - Rural immigrants; S8 - Rural emigrants. The weights were determined using the information entropy method (OECD, 2008).

Source: own calculations based on SNI data, Tempo online (Romania), NBS (Moldova).

Figure 2.
Evolution of the composite social index (S_t) - Romania and Moldova, 2014–2023



Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

The results presented in Table 5 and Figure 2 reveal a complex dynamic of the social dimension of rural sustainability in Romania and Moldova. During the period 2014–2016, Moldova recorded higher values of the social index (0.52–0.58), mainly driven by labour mobility, external remittances, and a higher share of the rural employed population. In contrast, Romania exhibited a slower but more stable trajectory, reflecting a gradual transition toward human capital consolidation and increasing agricultural wages.

After 2019, the trend reversed: Moldova's social index declined sharply in 2020 (0.24) due to pandemic-related restrictions and labour reallocation, while Romania experienced a steady increase—from 0.37 in 2018 to 0.62 in 2023. This evolution reflects improved employment conditions, rising income levels, and greater participation in continuing vocational training.

Overall, the values of the social index indicate a partial convergence between the two countries, although structural disparities persist, particularly in areas such as rural emigration and access to lifelong learning opportunities. Romania appears to be moving toward a faster and more sustainable social transition, supported by European cohesion policies and increased investment in human resources.

While social indicators highlight gradual progress and partial convergence, the environmental dimension presents a more heterogeneous picture, reflecting the divergent ecological trajectories of the two countries.

Table 6.

Composite environmental index (EN_t) – Romania and Moldova, 2014–2023

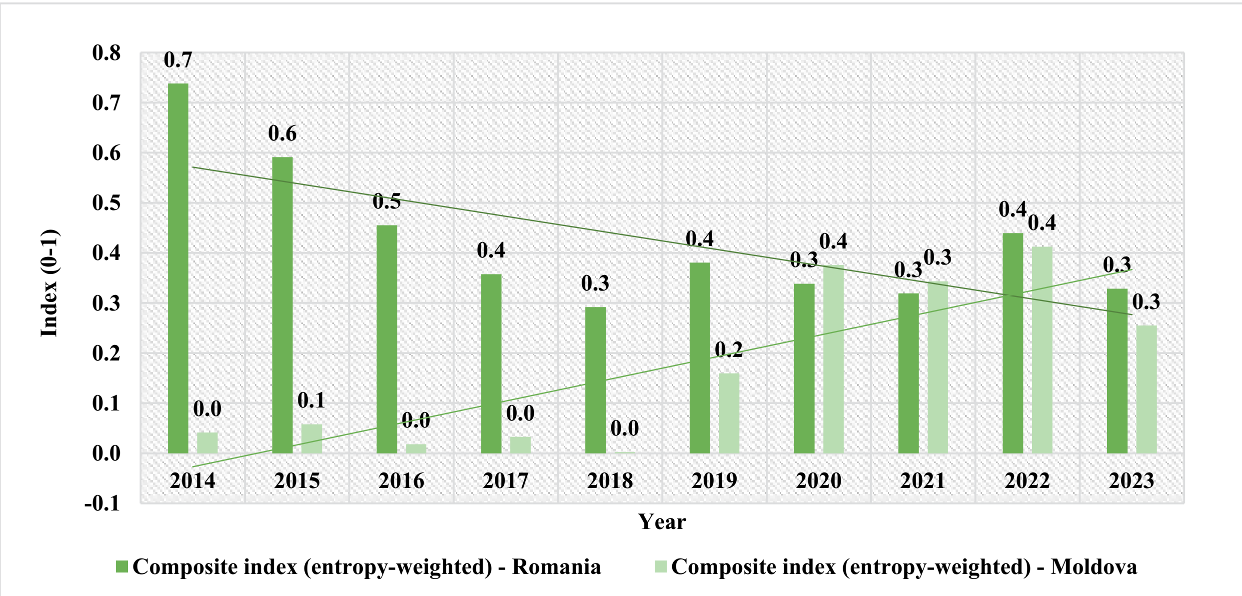
Year	Composite index (entropy-weighted) - Romania	Composite index (entropy-weighted) - Moldova
2014	0.738	0.041
2015	0.591	0.058
2016	0.455	0.018
2017	0.357	0.033
2018	0.292	0.002
2019	0.381	0.160
2020	0.338	0.376
2021	0.319	0.343
2022	0.440	0.412
2023	0.328	0.255

Note: The composite environmental index (ENt) was calculated based on 5 indicators: EN_1 - Emissions (Emissions Share (CO2eq) (AR5); Emissions per capita; Emissions per area of agricultural land); EN2 - Pesticide use per cultivated area; EN3 – Nutrients (Nitrogen use per ha; Phosphorus use per ha; Potassium use per ha); EN4 – Water (Land area equipped for irrigation; Agriculture area actually irrigated); EN5 – Organic agriculture (Agriculture area under organic agric; Agriculture area certified organic; Cropland area under organic agric.; Cropland area certified organic; Perm. meadows & pastures area under organic agric.; Perm. meadows & pastures area certified organic). The weights were determined by the information entropy method (OECD, 2008).

Source: own calculations based on FAOSTAT data

Figure 3.

Evolution of the composite environmental index (EN) - Romania and Moldova, 2014-2023



Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

The results presented in Table 6 and Figure 3 illustrate the contrasting evolution of the environmental dimension of agricultural sustainability in Romania and Moldova. During the period 2014–2016, Romania recorded relatively high environmental index values (0.74–0.45), reflecting more efficient resource use and the gradual expansion of certified organic agricultural areas. However, after 2016, a steady downward trend was observed, driven by production intensification, increased use of chemical inputs, and declining ecological efficiency within the agricultural sector.

In contrast, Moldova started from a very low level (0.04 in 2014) but registered a slow and steady increase up to 2022 (0.41). This evolution can be attributed to a reduction in the use of pesticides and fertilisers, the expansion of organic farming, and a decline in agricultural emissions per unit of land area. Nevertheless, the overall level of environmental sustainability remains below that of Romania, despite the positive trajectory.

Trend-line analysis indicates a partial ecological convergence between the two countries, generated not by simultaneous improvement but by the decline in Romania's environmental performance and the gradual improvement in Moldova's indicators. This pattern underscores the need for more robust environmental policies that focus on reducing emissions and promoting organic agriculture in both states.

To complement the assessment of ecological sustainability, a series of derived indicators was computed to evaluate the efficiency of environmental resource use in agriculture. These indicators relate emissions, pesticide use, and nutrient consumption to the value of agricultural production (Int$), providing a measure of the ecological intensity of agricultural output.

The results indicate a general improvement in environmental efficiency in both countries, albeit at varying rates. In Romania, the decline in emissions and pesticide use per unit of agricultural output suggests a relative decoupling between economic growth and environmental pressure, although absolute emission levels remain high. In Moldova, environmental efficiency exhibits greater variability, influenced by fluctuations in agricultural output and structural constraints, including limited irrigation infrastructure and low adoption of eco-friendly practices.

Overall, these findings support the argument that environmental efficiency represents a cross-cutting dimension of rural sustainability, essential for understanding the transition toward low-emission, resource-efficient agriculture. After assessing the three individual dimensions, the next step aggregates them into a comprehensive measure — the Rural Sustainability Index (RSI) — capturing the overall dynamics of sustainable transition in both countries.

Table 7.
Compozit environmental efficiency index (EEN_t) – România and Moldova, 2014–2023

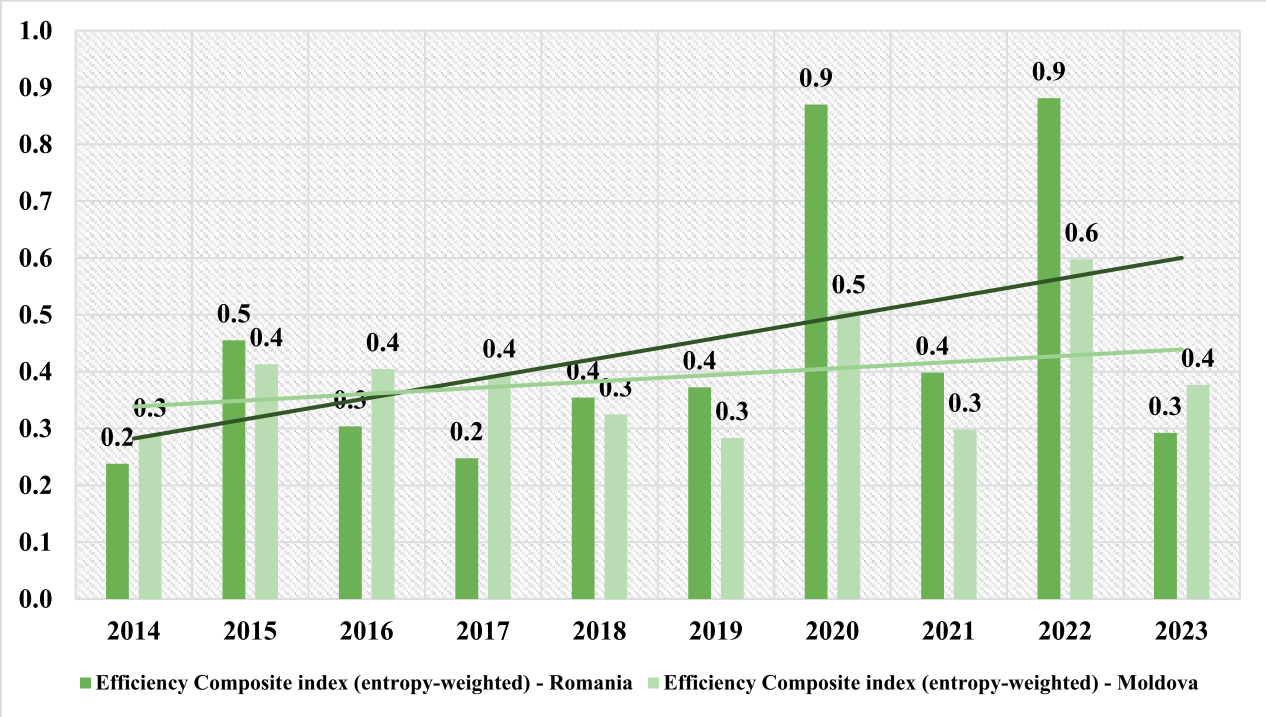
Year	Composite index (entropy-weighted) - Romania	Composite index (entropy-weighted) - Moldova
2014	0.238	0.289
2015	0.455	0.413
2016	0.304	0.404
2017	0.248	0.393
2018	0.355	0.325
2019	0.372	0.283
2020	0.870	0.506
2021	0.398	0.298
2022	0.881	0.598
2023	0.292	0.377

Note: The composite environmental efficiency index (EEN_t) was calculated based on four indicators: EEN_1 – Emissions related to the value of agricultural production; EEN_2 – Pesticide use related to the value of agricultural production; EEN_3 – Nutrient use (N, P_2O_5, K_2O) related to the value of agricultural production; EEN_4 – Water use efficiency in agriculture. The weights were determined using the information entropy method (OECD, 2008).

Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

Figure 4.

Evolution of the composite environmental efficiency index (EEN_t), Romania and Moldova, 2014-2023



Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

The results presented in Table 7 and Figure 4 reveal a mixed evolution of environmental efficiency in Romania and Moldova over the period from 2014 to 2023. In the early years (2014–2016), both countries recorded moderate levels of efficiency, ranging between 0.25 and 0.40. Moldova displayed slightly higher values, mainly due to the extensive nature of its agriculture and the lower use of chemical inputs, particularly pesticides and fertilisers.

After 2019, a significant increase in environmental efficiency was observed in Romania, reaching peaks of 0.87–0.88 in 2020 and 2022. This trend can be explained by the modernisation of agricultural infrastructure, the adoption of precision farming technologies, the digitalisation of production processes, and the implementation of conservation agriculture practices. The high index values suggest a partial decoupling between economic growth and environmental pressure, indicating progress toward a more sustainable agricultural model. Meanwhile, Moldova recorded a positive but slower evolution, rising from 0.29 in 2014 to 0.60 in 2022, followed by a moderate decline in 2023. This pattern reflects improvements in rational water use and reductions in emissions per unit of output, while also highlighting the structural vulnerabilities of Moldovan agriculture, which remains dependent on climatic conditions and limited technological investment.

Trend-line analysis points to a general improvement in environmental efficiency in both countries, although Romania exhibits greater variability, typical of transitional processes toward high-performance technologies. Overall, the results suggest that environmental efficiency represents a transversal dimension of rural sustainability, complementing absolute ecological indicators with a relative perspective that relates environmental pressure to economic performance.

Although the efficiency index was not included in the computation of the Integrated Rural Sustainability Index (RSI), it provides valuable supplementary information regarding the quality of the ecological transition. In the medium term, integrating environmental efficiency into the global analytical framework could enhance the precision of rural resilience assessments and the evaluation of the decoupling of agricultural growth from environmental impact (Ding et al., 2016; FAO, 2019).

To assess the overall sustainability level of rural agriculture, the Integrated Rural Sustainability Index (RSI) was calculated, aggregating the three fundamental dimensions — economic (E), social (S), and environmental (M). This approach provides a comprehensive overview of rural performance and enables a comparative analysis between Romania and Moldova during the period 2014–2023. The model adheres to the OECD (2008) methodological framework for composite index construction, ensuring a balanced weighting of the three core dimensions of sustainable development.

Table 8.

Integrated Rural Sustainability Index (RSI) – Romania and Moldova, 2014–2023

Country	Year	ECONOMIC (E)	SOCIAL (S)	ENVIRONMENT (EN)	RSI_t
RO	2014	0.236	0.390	0.738	0.454
RO	2015	0.226	0.375	0.591	0.397
RO	2016	0.156	0.425	0.455	0.345
RO	2017	0.423	0.374	0.357	0.385
RO	2018	0.410	0.364	0.292	0.355
RO	2019	0.446	0.374	0.381	0.400
RO	2020	0.574	0.469	0.338	0.461
RO	2021	0.735	0.335	0.319	0.463
RO	2022	0.654	0.480	0.440	0.524
RO	2023	0.726	0.625	0.328	0.560
MD	2014	0.174	0.521	0.041	0.246
MD	2015	0.286	0.525	0.058	0.290
MD	2016	0.164	0.585	0.018	0.256
MD	2017	0.293	0.404	0.033	0.243
MD	2018	0.093	0.487	0.002	0.194
MD	2019	0.227	0.458	0.160	0.282
MD	2020	0.133	0.238	0.376	0.249
MD	2021	0.433	0.412	0.343	0.396
MD	2022	0.318	0.628	0.412	0.453
MD	2023	0.169	0.455	0.255	0.293

Note: The RSI was calculated as the arithmetic mean of the three dimensions (economic, social and environmental), using composite indices normalised and weighted by the information entropy method (OECD, 2008).

Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

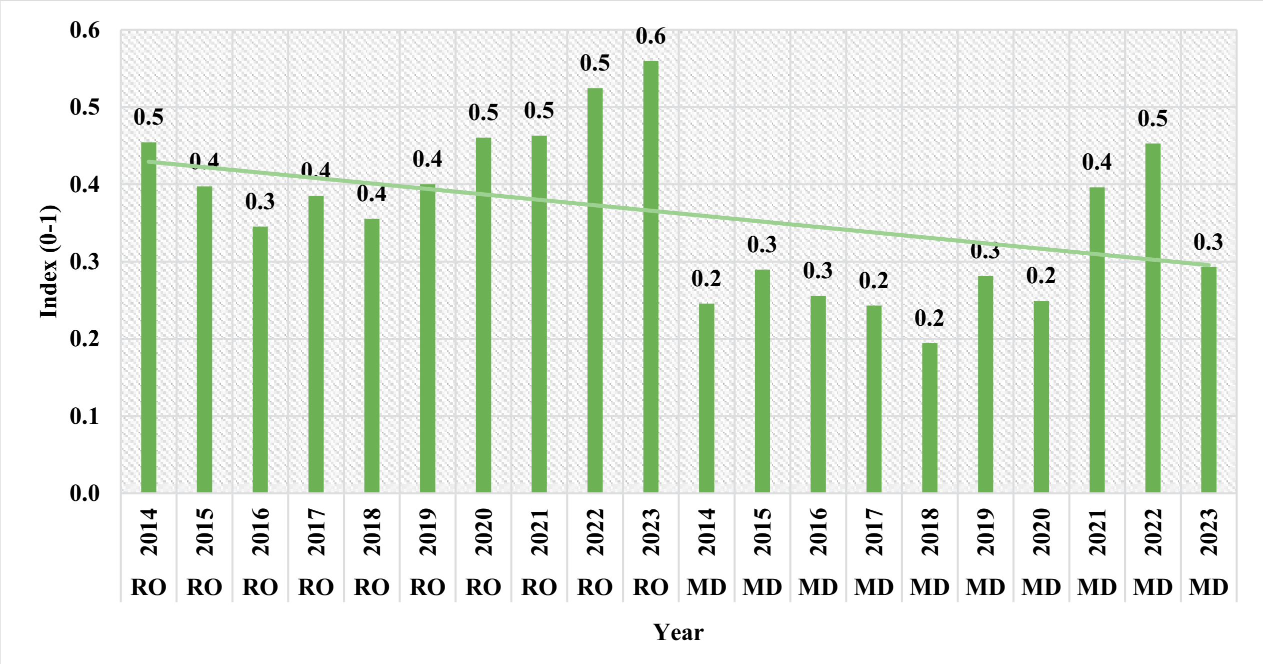
The results presented in Table 8 and Figure 5 highlight significant differences between the two countries, both in terms of the average level of rural sustainability and its temporal dynamics. In Romania, RSI values fluctuated between 0.34 and 0.56, showing a general upward trend after 2019. During the first part of the period (2014–2018), sustainability levels were moderate (RSI ≈ 0.35–0.40), reflecting an agricultural economy still undergoing structural modernisation, accompanied by high environmental pressures. After 2020, Romania experienced a steady increase in the integrated index, reaching a value of 0.56 in 2023, the highest recorded during the decade. This positive trajectory results from the combined effect of economic advancement, improved rural social conditions, and, to a lesser extent, stabilised ecological performance.

In Moldova, RSI values ranged between 0.19 and 0.45, remaining consistently below Romania's levels throughout the entire period. Between 2014 and 2018, the index registered very low values (0.19–0.29), indicating limited sustainability, which was largely determined by structural vulnerabilities in the agricultural economy and a pronounced environmental impact. After 2019, Moldova exhibited a slight recovery, reaching 0.45 in 2022, followed by a moderate decline to 0.29 in 2023. This pattern reflects the dependence on climatic conditions, the volatility of public investment, and institutional constraints in implementing environmental policies.

From a comparative perspective, Romania exhibits an upward trajectory of rural sustainability, whereas Moldova displays a fluctuating trend, albeit with gradual improvements in certain years. The trend-line analysis (Figure 5) reveals a slow convergence, though a structural gap persists: Romania's RSI values consistently exceed Moldova's by 0.15–0.20 points. This finding confirms the hypothesis of an asymmetric transition toward sustainability between the two states — Romania moving toward a modernised rural model anchored in EU agricultural and environmental policies (CAP, Green Deal), while Moldova continues to face challenges related to agricultural infrastructure and rural social cohesion.

From a policy perspective, the results suggest the need for an integrated rural development strategy in Moldova, focusing on public investment, agricultural digitalisation, expansion of organic farming, and vocational training programs for rural populations. In Romania's case, maintaining the current progress requires redirecting policies toward reducing environmental pressure and strengthening rural resilience.

Figure 5.
Evolution of the Integrated Rural Sustainability Index (RSI) – Romania and Moldova, 2014–2023



Source: Own calculations based on FAOSTAT, INS data – Tempo online, Statistics of Moldova, and Eurostat data

Romania, with an RSI value above 0.5 after 2020, demonstrates a stable tendency toward rural sustainability, supported by agricultural economic growth and the strengthening of rural social capital. Moldova, with RSI values below 0.35 in most years, exhibits a fragile sustainability pattern, characterised by an imbalance between relatively good social performance and weak environmental efficiency. Structurally, the average RSI for 2014–2023 was 0.44 for Romania and 0.29 for Moldova. The overall trend is positive but slow, and the sustainability gap persists, largely due to disparities in investment levels, infrastructure development, and institutional integration.

To assess the stability and robustness of the results, a sensitivity analysis of the Integrated Rural Sustainability Index (IRSI) was conducted, following the methodological recommendations of the OECD (2008). The purpose of this analysis is to examine the extent to which the final RSI values are affected by changes in the weighting scheme applied to the three fundamental dimensions: economic (E), social (S), and environmental (EN).

The baseline model employs entropy-based weights, determined through the internal informational distribution of each indicator set. For verification, the RSI was recalculated using equal weights (1/3 for each dimension), and the comparative results are presented below:

$$RSI_{t\_Romania}^{entropie} = \frac{1}{3}\,(E_t + S_t + EN_t) = \frac{1}{3}(0{,}459 + 0{,}421 + 0{,}424) = 0{,}435$$

$$RSI_{t\_Romania}^{egal} = \frac{1}{3}\,(E_t + S_t + EN_t) = \frac{1}{3}(0{,}480 + 0{,}488 + 0{,}456) = 0{,}475$$

$$RSI_{t\_Moldova}^{entropie} = \frac{1}{3}\,(E_t + S_t + EN_t) = \frac{1}{3}(0{,}229 + 0{,}471 + 0{,}170) = 0{,}290$$

$$RSI_{t\_Moldova}^{egal} = \frac{1}{3}\,(E_t + S_t + EN_t) = \frac{1}{3}(0{,}270 + 0{,}488 + 0{,}261) = 0{,}340$$

The results show that the differences between the two weighting scenarios are minor: for Romania, RSI values range from 0.435 (entropy weighting) to 0.475 (equal weighting), while for Moldova, they vary from 0.290 to 0.340. These small deviations (below ±0.05 points) confirm the robustness of the model and the internal stability of the index.

Therefore, it can be concluded that the entropy-based method provides a balanced distribution of indicator influence without significantly altering the comparative results. The obtained values confirm that the internal structure of the RSI is both coherent and reliable, and that the conclusions regarding the relative performance of Romania and Moldova remain valid regardless of the weighting scheme applied.

This methodological consistency supports the use of entropy-weighted composite indices as robust tools for comparative rural sustainability analysis (OECD, 2008; Mo & Li, 2025).

DISCUSSIONS

The comparative analysis reveals notable structural disparities between Romania and Moldova in their respective pathways toward rural sustainability and agricultural modernisation. The Integrated Rural Sustainability Index (IRSI) supports the hypothesis of an asymmetric transition: Romania has reached a more consolidated stage of rural transformation, whereas Moldova follows a more fragmented trajectory, shaped by contextual and institutional constraints.

In Romania, the consistent improvement of economic and social indicators after 2018 reflects the influence of public and EU-funded agricultural investments, the modernisation of rural infrastructure, and the strengthening of institutional capacities for implementing development policies. These advances are closely tied to the country's participation in the Common Agricultural Policy (CAP) and its alignment with the European Green Deal, both of which have enhanced productive efficiency and stimulated rural diversification. Nonetheless, the environmental pillar of sustainability remains fragile, as it is affected by pressures on soil and water resources, persistent pesticide use, and elevated levels of agricultural emissions.

In Moldova, the RSI profile reveals a reversal of priorities, with the social component performing relatively better, indicating the adaptability of rural communities and lower inequality, while the economic and environmental dimensions remain considerably weaker. This pattern reflects an extensive agricultural model that is highly exposed to external shocks, market volatility, and climatic fluctuations—factors that undermine both income stability and environmental performance.

Viewed through the framework of rural resilience (Wilson, 2010; Darnhofer, 2014), Romania appears to be advancing toward an adaptive form of resilience characterised by technological innovation, diversification of rural functions (including agrotourism, bioeconomy, and renewable energy), and enhanced institutional coordination. Conversely, Moldova remains in a phase of reactive resilience, focused on maintaining social stability but constrained in its capacity for structural transformation.

From the perspective of territorial innovation models (Camagni & Capello, 2013; Moulaert & Sekia, 2003), Romania is converging toward a decentralised pattern of territorial innovation, supported by regional networks and European financing instruments. In contrast, Moldova continues to rely on a centralised and sector-oriented governance model, marked by limited local participation and weak integration into European value chains.

The comparative behaviour of the composite indices indicates a co-evolution between the economic and social dimensions, but a relative decoupling from the environmental dimension—a phenomenon observed in both countries. This divergence suggests that progress toward sustainability is driven less by resource endowments and more by governance quality and policy coherence (Marsden, 2013).

From a strategic perspective, the findings provide several theoretical and policy implications. They confirm the integrated model of rural transition based on the interdependence among the three sustainability pillars, and they demonstrate the empirical strength of entropy-based composite indices for cross-country agricultural analysis. Furthermore, they indicate that sustainable rural modernisation relies not only on economic performance but also on achieving a balanced interaction among competitiveness, social inclusion, and environmental protection. The results also underline the importance of multi-level policy strategies—spanning local, regional, and transnational levels—to promote territorial cooperation and encourage rural innovation.

Ultimately, the study reaffirms that rural sustainability is a dynamic, non-linear process shaped by the interplay between economic, institutional, and ecological subsystems. The transition toward sustainability should thus be viewed as an adaptive and co-evolutionary process in which resilience, territorial innovation, and social equity become the central mechanisms for reinforcing rural development across Eastern Europe.

CONCLUSIONS

The comparative assessment of rural sustainability in Romania and Moldova underscores the asymmetric nature of their transition toward sustainable agricultural and rural development. Romania has entered a phase of consolidation, defined by structural modernisation, institutional maturity, and gradual alignment with the objectives of the European Green Deal. Conversely, Moldova remains at an earlier and more uneven stage of transition, constrained by agricultural fragmentation, limited financial and technological capacity, and the incomplete development of policy instruments supporting sustainability.

The findings demonstrate that economic growth and rural modernisation do not inherently lead to sustainability unless accompanied by enhanced ecological efficiency and stronger social cohesion. Romania's higher RSI values after 2020 confirm the positive impact of integrated rural and agricultural policies, yet persistent environmental vulnerabilities highlight the need to reinforce ecological governance. In Moldova, the more substantial contribution of the social dimension reflects the adaptability of rural communities but also exposes the dependency of the rural economy on external drivers such as remittances, climatic fluctuations, and cross-border market dynamics.

From a theoretical standpoint, the research validates the Integrated Rural Sustainability Transition Model (IRSTM) as a comprehensive framework for assessing the multidimensional structure of sustainability. By integrating economic, social, and environmental indicators through an entropy-based composite approach, the model provides a robust and comparable analytical instrument that captures both convergence and divergence among countries sharing similar agricultural profiles but differing institutional trajectories.

The main limitations of this study stem from data availability and comparability, particularly regarding environmental indicators, where inconsistencies in frequency and measurement persist between the two countries. The absence of detailed longitudinal or micro-level data limits the ability to identify local variations and causal linkages between policies and sustainability outcomes. Moreover, the national scale of analysis may obscure regional disparities and differences in territorial resilience.

Future research should extend the application of the IRSTM to regional and local contexts, employ spatial and panel data methods to identify sustainability determinants, and develop predictive models linking public investment, human capital, and ecological performance. Another promising direction is to evaluate the effects of European agricultural and environmental policies on rural convergence processes across Eastern Europe.

From an applied perspective, the study emphasises that sustainable rural modernisation requires coherent governance, balanced investment in infrastructure, human capital, and environmental protection, as well as strengthened cross-border cooperation between Romania and Moldova. Enhancing institutional convergence and fostering innovation-oriented policies could accelerate the transition toward resilient, inclusive, and environmentally responsible rural systems throughout the region.

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