

<https://doi.org/10.61308/AQUC2375>

Quantifying Bioeconomy capacity in rural Europe: An index-based comparative analysis

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Citation: Petrov, D. (2026). Quantifying Bioeconomy capacity in rural Europe: An index-based comparative analysis. *Bulgarian Journal of Agricultural Economics and Management*, 71(1), 90-96.

Abstract: This study examines the uneven capacity of EU Member States to implement Bioeconomy policies in rural areas by developing a composite Bioeconomy Policy Implementation Capacity Index (BPICI). Using 2023 data from the World Bank’s World Development Indicators and Worldwide Governance Indicators, the index integrates five dimensions: government effectiveness, regulatory quality, control of corruption, access to credit, and agricultural transformation intensity. The comparative results reveal sharp structural asymmetries: France demonstrates systemic readiness with high institutional effectiveness and market capacity, Bulgaria occupies an intermediate position with partial agrarian transformation but persistent governance deficits, while Romania records the lowest score due to limited institutional quality and economic diversification. The findings highlight the risks of a uniform EU policy model, and underscore the need for context-sensitive strategies that account for institutional and structural conditions. The BPICI contributes methodologically to indicator-based modeling of institutional capacity and offers a tool for strategic planning and policy monitoring.

Keywords: bioeconomy; institutional capacity; rural development; comparative analysis; EU policy

INTRODUCTION

The Bioeconomy has emerged as a key interdisciplinary framework in the ongoing transformation of European agricultural and resource policy, driven by climate challenges, technological change, and the need to diversify rural economic models. Strategic documents such as the Updated EU Bioeconomy Strategy (European Commission, 2018) and the European Green Deal (European Commission, 2019) define the Bioeconomy not as an isolated sector, but as an integrative system that reshapes the extraction, processing, and management of biological resources (Bugge, Hansen and Klitkou, 2016; Schipfer et al., 2024; Srivastav et al., 2024). Despite the existence of a common EU framework, national implementation of Bioeconomy strategies remains highly fragmented. France demonstrates advanced in-

stitutional and market capacity through coordinated policies and regional innovation platforms (Stadler and Chauvet, 2018). In contrast, “new” Member States – particularly Bulgaria and Romania – lag behind due to weaker institutions, limited access to finance, and insufficient administrative capacity (El-Chichakli et al., 2016; Wegener et al., 2011). These asymmetries are especially pronounced in rural areas, which concentrate much of the EU’s biological resources, but remain vulnerable to structural and institutional deficiencies.

To address this gap, the present study develops a composite Bioeconomy Policy Implementation Capacity Index (BPICI), using data from the World Development Indicators and Worldwide Governance Indicators (World Bank, 2023). The index integrates institutional, financial, and

agrarian dimensions to assess the relative capacity of France, Bulgaria, and Romania to implement Bioeconomy policies. Two hypotheses are tested:

- H1: Low levels of institutional effectiveness and regulatory quality act as barriers to Bioeconomy implementation in Bulgaria and Romania, compared with France's more resilient administrative structures.

- H2: Although Bulgaria and Romania possess substantial bioresource potential, this remains underutilized due to limited access to finance and weaker human capital compared with France.

These hypotheses guide the empirical analysis presented later in current study, where their validity is evaluated based on the BPICI results.

Over the past two decades, the Bioeconomy has become central to the EU's vision of transitioning toward a sustainable, low-carbon, and resource-efficient economy. The term "Bioeconomy" lacks a single definition, encompassing instead a multidimensional approach to using renewable biological resources such as crops, forests, and marine ecosystems, for producing food, biomaterials, and bioenergy (Bugge et al., 2016). This multisectoral nature explains both its strategic importance and the challenges of policy implementation. The EU identifies three core goals for the Bioeconomy: (1) sustainable management of natural resources; (2) fostering innovation and employment; and (3) enhancing competitiveness through circular and low-carbon production (European Commission, 2018; 2019). The theoretical evolution of the Bioeconomy has followed several complementary trajectories:

- The biotechnological perspective, focused on scientific and technological innovation (Carus and Dammer, 2018);

- The ecosystem approach, linking Bioeconomy to ecological sustainability (Wegener et al., 2011)

- The circular Bioeconomy, emphasizing recycling and regional biorefineries (D'Amato et al., 2017);

- The resilience perspective, stressing adaptability to climate and market shocks (Proestou et al., 2025);

- The just transition, ensuring inclusion and social cohesion in rural development (Lima, 2022).

Rural regions are central to the Bioeconomy, as they host key resources such as arable land, forests, water, and biomass, that form the foundation of bio-based systems (Knickel et al., 2018; European Commission, 2023). However, in Eastern Europe these assets remain underutilized due to infrastructural gaps and weak institutional frameworks (Srivastav et al., 2024). World Bank data show that Bulgaria and Romania have low tertiary education attainment and limited credit access, constraining rural innovation capacity (World Bank, 2023). Meanwhile, France performs significantly better on human capital, governance, and financial inclusion indicators (Schipfer et al., 2024). These contrasts underline that bioresource potential alone is insufficient for successful transformation – strong institutional and investment capacity are equally essential. Research in agricultural economics further stresses the need for a territorial approach that integrates resource endowments with socio-economic structures (Dax and Fischer, 2018; Lima, 2022). Weak knowledge transfer systems and limited local institutional capacity hinder rural innovation ecosystems in many Member States (European Commission, 2023).

Furthermore, small and medium-sized farms often lack the capacity to join innovation networks or access EU modernization funds. In low-governance contexts, such as Bulgaria and Romania, these limitations result in fragmented and unsustainable Bioeconomy initiatives. As previous studies emphasize (Stadler and Chauvet, 2018; El-Chichakli et al., 2016), successful Bioeconomy strategies require not only resource availability, but also governance alignment across policy levels and institutions. The comparison among France, Bulgaria, and Romania thus provides a relevant framework for assessing the institutional and economic preconditions for Bioeconomy transition. While France serves as a benchmark with a mature and territorially integrated Bioeconomy, Bulgaria and Romania display mixed capacities, combining strong bio-

resource bases with persistent governance and financing constraints. Accordingly, this study develops a quantitative analytical framework to measure and compare the institutional and economic capacity for Bioeconomy implementation. The BPICI uses comparable World Bank indicators – Government Effectiveness, Regulatory Quality, Control of Corruption, Domestic Credit to the Private Sector, and Employment in Agriculture, to construct a normalized cross-country index. The analysis is based on the latest available data (2023), providing an empirical foundation for assessing relative capacity rather than policy outcomes.

The research aims to quantify and compare the institutional and economic capacity of selected EU Member States (France, Bulgaria, and Romania) to implement Bioeconomy policies in rural areas through the construction of the BPICI. The results seek to reveal structural asymmetries and to inform EU policy design for territorially balanced and context-sensitive Bioeconomy development.

MATERIAL AND METHODS

The BPICI is grounded in the understanding that a country's capacity to implement EU Bioeconomy strategies in its rural territories is not a one-dimensional variable, but reflects a complex system of institutional quality, economic infrastructure, and agrarian structure. For this reason, the indicator set is structured around three analytical pillars:

- Institutional effectiveness, measured through:
 - Government Effectiveness – assessment of administrative capacity to formulate and implement policies;
 - Regulatory Quality – assessment of the quality of the regulatory framework;
 - Control of Corruption – perception-based measure of the misuse of public power.
- Financial and infrastructural support, represented by:
 - Domestic Credit to the Private Sector (% of GDP) – level of access to private capital for economic agents, including agro-based entities.

• Agrarian transformation intensity, measured by:

- Employment in Agriculture (% of total employment) – interpreted inversely, since a high share of agricultural employment typically signals weak diversification of rural economies and limited innovation capacity.

The analysis uses 2023 data to ensure temporal comparability. All selected indicators are available simultaneously for the three countries, and are standardized within the publicly accessible WGI and WDI databases. The normalization is conducted within the sample of the three countries (France, Bulgaria, and Romania), which makes the 0 – 1 scale relative to this dataset.

To ensure comparability between indicators with different scales and directions of influence, all values are normalized to the [0,1] interval using linear rescaling:

$$X_i^{norm} = \frac{x_i - \min(X)}{\max(X) - \min(X)} \quad (1)$$

where: X_i is the value of the indicator for country i , and $\min(X)$ and $\max(X)$ are the minimum and maximum values of the indicator across all countries. For indicators with an inverse interpretation (e.g., Employment in agriculture), inversion is applied after normalization:

$$X_i^{inv} = 1 - X_i^{norm} \quad (2)$$

Thus, all indicators achieve interpretative unidirectionality: higher values reflect a higher capacity for policy implementation. The final index is calculated as the simple arithmetic mean of the normalized values of the five indicators:

$$BPICI_i = \frac{1}{n} \sum_{k=1}^n X_{i,k}^{norm} \quad (3)$$

where: $BPICI_i$ is the index value for country i , n is the number of indicators (here $n = 6$), $X_{i,k}^{norm}$ is the normalized value of indicator k for country. Equal weighting across all indicators is deliberately applied, as in the absence of consensus on the relative importance of each variable, this approach minimizes analytical bias (Nardo et al., 2005). After calculating the BPICI for each country, the following secondary analytical techniques are employed:

- Z-score classification:

$$Z_i = \frac{BPICI_i - \mu}{\sigma} \quad (4)$$

which allows identification of deviations from the sample mean.

- Percentile classification:

Ranking by quintiles or terciles to distribute countries by relative capacity.

- Pairwise comparative analysis, including:

Absolute difference: $\Delta_{ij} = BPICI_i - BPICI_j$

Proportional difference: $R_{ij} = \frac{BPICI_i}{BPICI_j}$

Percentage gap: $G_{ij} = \left(\frac{BPICI_i - BPICI_j}{BPICI_j} \right) \cdot 100\%$

To identify systemic relationships between the component indicators, Pearson's correlation coefficient (r) is calculated for all pairs of normalized values:

$$r_{XY} = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^n (X_i - \bar{X})^2} \cdot \sqrt{\sum_{i=1}^n (Y_i - \bar{Y})^2}} \quad (5)$$

The correlation analysis aims to test the hypothesis that countries with stronger institutional frameworks also tend to exhibit higher infrastructural readiness for implementing Bioeconomy policies.

RESULTS AND DISCUSSION

The purpose of this section is to present, interpret, and discuss the results of the empirical application of the BPICI to Bulgaria, Romania, and France. Table 1 reports the normalized values for each indicator as well as the computed composite BPICI score. Normalization was conducted through linear rescaling, where the highest value

for each indicator is assigned a score of 1 and the lowest a score of 0. The indicator employment in agriculture is inversely interpreted, as lower values signal a more advanced agrarian transformation and, consequently, a higher potential for Bioeconomy development.

The results in Table 1 reveal pronounced structural contrasts among the three countries. France achieves the maximum value across all indicators, reflecting a stable institutional framework, a well-functioning market economy, and a modernized agrarian structure. This establishes France as a benchmark for assessing the capacity to implement Bioeconomy-related policies. Bulgaria occupies an intermediate position with a BPICI score of 0.252. While far from the French benchmark, Bulgaria demonstrates a degree of structural diversification in its rural economy, as reflected in the normalized score of 0.794 for employment in agriculture. This indicates partial agrarian transformation and potential for further development. However, institutional indicators – particularly Control of Corruption – remain at the lowest levels, creating significant barriers to effective policy implementation. Romania ranks lowest, with a BPICI score of only 0.027. This reflects a combination of weak institutional quality, limited access to finance, and a high dependence on traditional agriculture. The lack of regulatory effectiveness and insufficient private sector engagement in innovation processes represent critical obstacles in meeting the goals of the European Green Deal and the EU Bioeconomy Strategy.

For a more detailed quantitative interpretation of the differences across countries, a classification analysis based on the standard score (Z-score) is presented in Table 2.

Table 1. Normalized values of component indicators and composite BPICI (2023)

Country	Government Effectiveness	Regulatory Quality	Control of Corruption	Domestic Credit	Employment in Agriculture (inv.)	BPICI
France	1.000	1.000	1.000	1.000	1.000	1.000
Bulgaria	0.113	0.107	0.000	0.148	0.794	0.252
Romania	0.000	0.000	0.135	0.108	0.000	0.027

Source: Authors' calculations.

The Z-score analysis confirms France’s statistically higher capacity to implement Bioeconomy policies. Bulgaria ranks below the mean but remains within one standard deviation, while Romania deviates by more than 1.5 standard deviations below the average. These results validate Hypothesis 1 (H1) – which low levels of institutional effectiveness and regulatory quality significantly constrain Bioeconomy implementation in Bulgaria and Romania compared to France.

The comparative analysis highlights a clear hierarchy of capacity. France significantly outperforms both Bulgaria and Romania. The nearly 900% percentage gap between Bulgaria and Romania demonstrates the heterogeneity within Eastern Europe – often incorrectly perceived as a homogeneous policy group in EU discourse. These results also confirm Hypothesis 2 (H2), indicating that despite considerable bioresource potential, Bulgaria and Romania underperform due to insufficient access to finance and underdeveloped human capital. Beyond the quantitative outcomes, the findings suggest important political

and structural mechanisms driving these disparities. France’s success stems from the alignment between national and EU policy frameworks, strong administrative coordination, and targeted innovation investments in rural areas. Conversely, the weaker results of Bulgaria and Romania reflect fragmented governance, low administrative professionalism, and underdeveloped financial intermediation in rural economies. These institutional constraints limit the ability to integrate local bioresources into higher value-added bio-based value chains. The strong correlation between governance indicators and financial access supports the theoretical assumption that institutional quality is a prerequisite for sustainable bioeconomic transformation. This relationship illustrates that structural change cannot be achieved solely through resource endowment or European funding – it requires functioning public institutions capable of translating policy objectives into effective territorial action.

CONCLUSIONS

The analysis demonstrates profound structural and institutional disparities in the capacity for Bioeconomy transformation between “old” and “new” EU Member States. France, with the highest BPICI score, exhibits systemic readiness characterized by an effective regulatory environment, low corruption, and a developed private sector capable of supporting innovation and green investment. Bulgaria holds an intermediate position – its progress in agrarian restructuring signals development potential, though governance weaknesses continue to impede progress. Romania remains at the lowest level, constrained by insufficient institutional quality and economic diversification.

These findings carry several implications. From a policy perspective, they emphasize the need for a differentiated, context-sensitive approach in implementing the European Green Deal and related Bioeconomy strategies. Applying a uniform EU policy model risks amplifying pre-existing disparities among Member States.

Table 2. Country classification by Z-score (BPICI)

Country	BPICI	Z-score	Capacity category
France	1.000	+1.11	High
Bulgaria	0.252	-0.34	Medium/low
Romania	0.027	-1.55	Very low

Source: Authors’ calculations.

Table 3. Comparative analysis of BPICI differences between countries

Country pair	Absolute difference (Δ)	Relative ratio (R)	Percentage gap (G, %)
France – Bulgaria	0.748	3.97	296.8%
France – Romania	0.973	37.13	3607.4%
Bulgaria – Romania	0.225	9.36	892.6%

Source: Authors’ calculations.

Targeted investment in institutional capacity, human capital, and rural infrastructure is therefore essential for achieving a more balanced Bioeconomy transition. From an academic perspective, the BPICI represents a valuable methodological contribution to indicator-based modeling of institutional and economic readiness. It demonstrates that composite indices can capture not only the outcomes, but also the systemic preconditions for policy implementation. The results provide a foundation for future research, including dynamic time-series analysis and subnational applications that explore regional variations within countries. The study's limitations stem from its focus on a restricted set of indicators and the use of cross-sectional data for 2023. Future extensions could incorporate innovation capacity, stakeholder participation, and qualitative assessments of governance effectiveness.

In conclusion, the results confirm both hypotheses and reinforce the argument that successful implementation of the EU Bioeconomy Strategy depends on pre-existing institutional and financial structures. Quantitative tools such as the BPICI can thus serve as practical instruments for strategic planning, monitoring, and promoting territorially balanced, innovation-driven rural development in Europe.

ACKNOWLEDGEMENTS

This research was carried out with the support of the scientific project "Agricultural land, green transformation, energy transition, digital environment", Contract No KII-06-H96/2 from 9.12.2025. We gratefully acknowledge the financial and institutional assistance provided, which enabled the successful completion of this study.

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Постъпила – 30 септември 2025 г.; Одобрена – 17 декември 2025 г.; Публикувана – март 2026 г.