ASSESSING REGIONAL DISPARITIES IN THE DIGITAL AND ENERGY TRANSITION: CONSTRUCTION AND ANALYSIS OF THE REGIONAL PREPAREDNESS INDEX IN ROMANIA

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ABSTRACT: *This paper analyses how persistent regional disparities in Romania, as expressed in (SDG 10), reduce progress towards Clean and Affordable Energy (SDG 7) and Climate Action (SDG 13). The analysis highlights the role of Digital Infrastructure (SDG 9) in regional development, showing how digital divides intensify economic and environmental inequalities.*

The study compares SDG indicators 7, 9, 10 and 13 in the eight NUTS 2 regions, by applying an econometric method, through indicators such as energy poverty, broadband internet coverage, GDP per capita and carbon emissions. Correlation Tehe PCA model confirm the theoretical hypothesis that underdeveloped digital infrastructure slows down progress by reducing sustainability indicators and deepening regional inequalities.

The results highlight quite strong correlations between low digital literacy and high energy poverty, low GDP and higher vulnerability to climate change. Based on these findings, the paper proposes policy recommendations that position investments in digitalization as a strategic element for regional cohesion and a successful green transition.

Keywords: *sustainable development, digitalization, regional development, energy poverty, climate*

JEL Classification*: Q01,O33, P25, O13, Q54*

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1. INTRODUCTION

In the idea of the European Green Deal and the sustainable development goals, the transition to an economy with reduced climate pollution strongly intersects with digitalization and social equity. This process is strongly influenced by the persistent economic disparities between the eight NUTS 2 regions of Romania. Optimizing consumption and ensuring access to resources in a country locked in inefficient consumption patterns and climate vulnerability is a difficult and long-term process, requiring specific measures for each region.

This paper analyzes this complex dynamic, proposing a Regional Readiness Index aimed at quantifying the degree to which digital infrastructure and economic performance support or, on the contrary, hinder climate action at the local level. By using the Principal Component Analysis (PCA) method, the analysis provides a complex perspective on how digitalization can be used as a lever for cohesion, demonstrating that the success of the energy transition in Romania fundamentally depends on the balance between technological progress and the social resilience of each region.

The purpose of this paper is to analyze and measure the impact of the energy transition and digital infrastructure on the uneven development of Romania.

The research aims to demonstrate how digitalization (SDG 9) acts as a determinant in reducing economic inequalities (SDG 10) and facilitating access to clean energy (SDG 7), in the context of the challenges generated by climate change (SDG 13). By developing a Regional Readiness Index based on Principal Component Analysis (PCA), the paper aims to identify the gaps in the eight NUTS 2 regions of Romania and to substantiate public policy recommendations that correlate technological development with resilience and environmental objectives.

In this sense, we formulated the hypothesis of this research: H1-Regional economic disparities represent an important determinant of the absorption capacity of digital technologies, which conditions the pace of acceleration of the transition to sustainable energy in the NUTS 2 regions of Romania.

The choice of the time interval between 2015 and 2023 for the analysis of the Regiona l Readiness Index is justified by the fact that 2015 is the year of the adoption of the 2023 Age nda for Sustainable Development by the UN and the signing of the Paris Agreement, represen ting the reference moment for monitoring sustainable development indicators.

The analyzed period covers economic cycles such as the Covid-
19 pandemic crisis and the energy crisis and instability triggered by the war in Ukraine. The p andemic somewhat forced digitalization, further deepening inequalities between the regions o f Romania, especially in education, then the economic recovery after 2021 deepened the ener gy crisis. The year 2023 captures the effects of the energy transition and the implementation o f the first projects financed by the PNRR.

2. LITERATURE REVIEW

In this framework, Romania encounters substantial challenges stemming from significant economic asymmetries across its regions, mainly between urban and rural areas, but also between historical macro-regions. The purpose of this section is to review the relevant academic literature to better understand regional economic performance, emphasizing the specific techniques employed to evaluate regional impact. Furthermore, these works underscore the importance of developmental strategies and examine how particular economic branches can help bridge the gap between varying regions. A number of contemporary works examine the factors driving regional and community-level economic progress in Romania. One paper explores the impact of research and development on the nation's financial expansion,

pointing out that despite a decade and a half of steady growth, regional disparities have actually intensified. Furthermore, their findings indicate that funding for innovation and R&D continues to lag significantly behind the broader European standards (Darie, Badulescu, & Jaganjac, 2023).

Another piece of research underlines the major role of industrial and technological ongoing advancement in driving economic expansion. By. Utilizing macroeconomic indicators and empirical data, the study illustrates that countries with a robust industry and a commitment to innovation, secure a more competitive advantage in the global marketplace (Kocsis, 2024). Research, along with technological innovation and development are key drivers for long-term increase in productivity. They are vital elements behind the performance of the world's most developed economies ((Guloglu & Tekin, 2014).

Socioeconomic inequalities are a major concern and have been studied by national and European institutions, as well as research institutes and researches affiliated with universities, aiming to find the drivers of these inequalities, and potential outcomes that could lead to measures that can reduce them (Mihai, Prada, & Simion, 2022).

National research explains regional disparities as an unequal distribution of infrastructure, natural assets, productive resources and technological progress in different regions. (Moussis, 2007). Within the European Union, the reduction of the economic gap is supported by cohesion and resilience policies. (Choi, 2001) In Romania, these disparities arise from the differences in development mainly between urban and rural areas, respectively the unequal economic infrastructure, including the historical legacy of these macro-regions.

Economic policies, both at the European level and, subsequently, at national level, aimed to reduce socio-economic disparities between regions. The priority was to reach a balanced regional development. In Romania, regional disparities deepened considerably since the fall of communism, and again intensified after 2008 recession and the Covid-19 pandemic. Studies warned that developed regions recover faster from crises and this increases regional disparities, unless targeted measures are put in place to counter this trend (Goschin, 2014). Deficient infrastructure, uneven public spending and an uneven economic transition are the main factors of regional disparities. Furthermore, although in recent decades Romania experienced real economic development, NUTS2 regions continue to show major social and economic differences in the quality of life. Existing studies show this trend and emphasize that, while the national economy had a continuous grown, the divide between rich regions and struggling ones continues to increase, mainly due to disparities in industrial development and investments. Other important factors are digital divides and environmental inequalities (Bălan, 2018).

Digital infrastructure, investments in research and development are important factors in short-term economic development and also principles of sustainable and resilient development of the regional economy, as long as they take into account environmental protection and the creation of a sustainable economy that in the long term eliminates the gap between regions and leads to a balanced standard of living in the long term. (Russu, 2014)

Social and economic inequalities point to causes due to structural problems and the lack of socio-economic financing. The distribution of regional inequalities shows a trend that requires the implementation of specific public policies that generate economic growth at the local level. (Bălan, 2018)

Studies shown through statistical data that there is a growing development gap between the different regions of Romania. (Russu, 2014)

Another analysis focuses on regional economic resilience, examining how local economies respond to sudden disruptions, such as the COVID-19 pandemic and the energy crisis triggered by the Russia-Ukraine conflict, can serve as catalysts for fundamental changes within regional economies. These changes can ultimately produce superior outcomes in terms

of social and economic sustainability, opening a more favorable development path than that pursued before the unrest (Trippl, Fastenrath, & Isaksen, 2024)

3. METHODOLOGY

To argue and quantify the complexity of the interactions between regional disparities and the digital-energy transition, a Regional Preparedness Index was developed for the 8 NUTS2 regions of Romania. To provide additional rigor to the research, it was used the principal component analysis (PCA) method. PCA provides a solid statistical basis in order to construct composite indices and confirms that the conceptual dimensions and the economic theory are empirically supported by the data structure. Thus, PCA is also a tool that ensures the consistency and validity of the variables subsequently introduced into the econometric model and strengthens the link between theory and empirical analysis.

To construct the index, the model employed the following variables: GERD by sector of performance and NUTS 2 region; Regional gross domestic product by NUTS 2 region; Individuals regularly using the internet by NUTS 2 region; Rail network by NUTS 2 region; Early leavers from education and training by NUTS 2 region; People at risk of poverty or social exclusion by NUTS 2 region; GWP_100_AR5_GHG by NUTS 2 region for the period 2015-2023. Data were extracted from Eurostat, INS and Emissions Database for Global Atmospheric Research (EDGAR). The use of the PCA (Principal Component Analysis) method in this research is based on the theoretical works of Ian Jolliffe, in order to reduce the complexity of the regional macroeconomic indicators analyzed. (Jolliffe, 1990)

4. RESULTS AND DISCUSSION

The application of the PCA method generated the following results (Figure 1): The first two components together explain about 67% of the phenomenon. This demonstrates that the variables you chose (GDP, GERD, Internet, GHG, etc.) are strongly correlated and that the index you created is a robust tool to measure "regional preparedness".

According to the Kaiser criterion, we retain the components that have an eigenvalue greater than 1.

$$PC\ 1 = 3.35 > 1$$
$$PC\ 2 = 1.34 > 1$$

According to the cumulative variance criterion, there are retained enough components to be able to explain a large proportion of the total variance. The first two components PC1 and PC2 together explain 67.07% of the total variance.

The Regional Preparedness Index will thus be a bidimensional index formed by PC1 and PC2.

The Principal Component PC1– explains 47.89% of the variance.

Table 1. Variance of Principal Components

Eigenvalues: (Sum = 7, Average = 1)

Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	3.352118	2.009218	0.4789	3.352118	0.4789
2	1.342900	0.448719	0.1918	4.695018	0.6707
3	0.894181	0.143463	0.1277	5.589200	0.7985
4	0.750718	0.360273	0.1072	6.339918	0.9057
5	0.390445	0.210198	0.0558	6.730363	0.9615
6	0.180247	0.090857	0.0257	6.910610	0.9872
7	0.089390	---	0.0128	7.000000	1.0000

Source: Eviews output

Principal Component 2 (PC 2) – explains 19.18% of the variance. PC 2 appears to be a balancing component for innovation/digitalization and transport.

A high score on PC 2 is associated with high digital usage and good rail infrastructure, but relatively low R&D expenditure. This could indicate regions that have adopted digital technology and have a logistics base, but are not major innovation and research centers.

Table 2. Correlation coefficients between the original variables and the principal components

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
EARLY_LEAVER...	0.330752	0.056311	0.782822	0.195713	0.215283	-0.435550	0.016398
GERD_BY_SECT...	-0.240352	-0.668738	-0.055812	-0.339073	0.504718	-0.263535	0.229659
GWP_100_AR5_...	0.388971	-0.001256	-0.518977	0.530702	0.121785	-0.322973	0.422582
INDIVIDUALS_RE...	-0.353210	0.496692	-0.099535	0.193119	0.732134	0.058043	-0.204811
RAIL_NETWORK...	0.348282	0.441754	-0.011502	-0.628095	0.162584	0.117823	0.498599
PEOPLE_AT_RIS...	0.450894	-0.327681	0.102578	0.188451	0.328322	0.728950	-0.064190
REGIONAL_GRO...	-0.481843	0.019795	0.306883	0.312680	-0.117607	0.296504	0.688290

Source: Eviews output

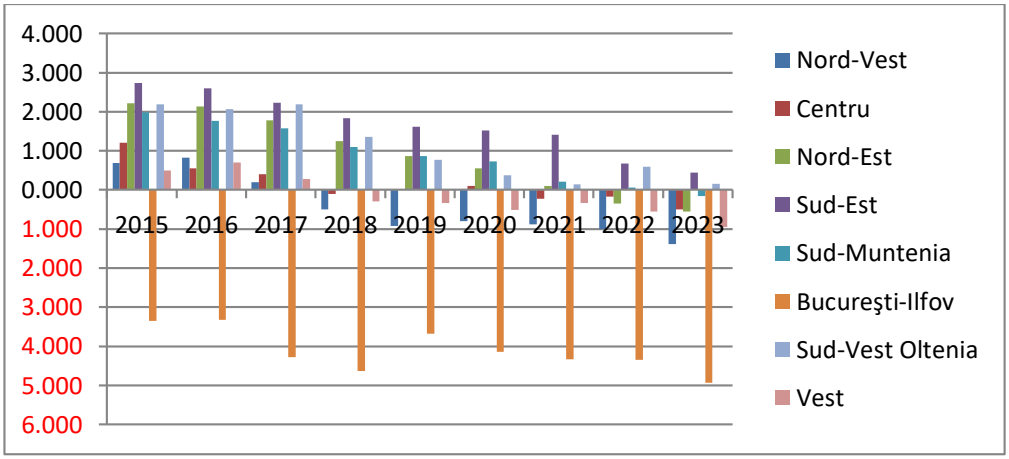
PC1 seems to reflect a mix of social exclusion and infrastructure, with high positive loadings for: People at risk of poverty or social exclusion by NUTS 2 region, with a score of 0.450894; Higher CO2 emissions- GWP_100_AR5_GHG- with a score of 0.388971

Early leavers from education and training by NUTS 2 region with a score of 0.330752; and negative values for: Regional gross domestic product by NUTS 2 region with a score of -0.481843; Individuals regularly using the internet by NUTS 2 region with a score of -0.353210

This component can be interpreted as a composite indicator of regional disadvantage, where high scores indicate social vulnerability and poor infrastructure.

Although the original name is the Regional Preparedness Index (RPI), the PCA analysis shows that: high scores on the principal component (PC1) are associated with: high school dropout rates; risk of poverty; high gas emissions; poor railway infrastructure and low internet use. The high values reflect the accumulation of structural vulnerabilities, which suggests that the index works more like a Regional Preparedness Index. Thus, the NUTS 2 regions of Romania are, for the most part, in a disadvantageous position in relation to the requirements of the digital, energy and social transition.

Figure 1. Multiannual graph of the NUTS2 Regional Readiness Index



Source: Generated after the index obtained in Eviews

Most regions oscillate between positive and negative values, but Bucharest-Ilfov (orange bars) stands out with constant negative values in all the years analyzed. The North-West, Center, West and South-Muntenia regions seem to have moderate variations, with episodes of increase and decrease, but without extreme deviations. South-West Oltenia and North-East show wider variations, suggesting structural instability or vulnerability.

Bucharest-Ilfov is a special case where constant negative values may indicate: ecological deficits (e.g. GHG emissions, pollution), hidden social exclusion (e.g. high cost of living, inequality) or a calculation methodology that penalizes urban concentration. It is possible that the region is disadvantaged in the preparedness index, despite its gross economic performance, or requires the analysis of some variables specific to the metropolis. Although the Bucharest-Ilfov region is a national growth pole, it is unprepared in terms of sustainability in terms of equity, infrastructure and environment. The Oltenia N-E, S-E, S-V regions tend to have lower values, which confirms the PCA conclusions regarding regional unpreparedness. Overall, the PCA model suggests persistent disparities at the level of NUTS2 regions.

Table 3. Regional Preparedness Index

	2015	2016	2017	2018	2019	2020	2021	2022	2023
Nord-Vest	0.691	0.821	0.197	0.502	0.923	0.801	0.877	1.001	1.389
Centru	1.207	0.555	0.395	0.100	0.012	0.095	0.232	0.172	0.501
Nord-Est	2.223	2.133	1.778	1.246	0.872	0.558	0.103	0.343	0.551
Sud-Est	2.739	2.605	2.228	1.837	1.614	1.517	1.405	0.674	0.440
Sud-Muntenia	1.979	1.761	1.576	1.102	0.869	0.731	0.205	0.057	0.154
Bucureşti-Ilfov	3.356	3.327	4.281	4.640	3.678	4.143	4.339	4.345	4.939
Sud-Vest Oltenia	2.192	2.073	2.184	1.356	0.777	0.368	0.143	0.598	0.160
Vest	0.502	0.698	0.279	0.295	0.337	0.508	0.331	0.558	0.943

Source: generated by the author after the results obtained in Eviews

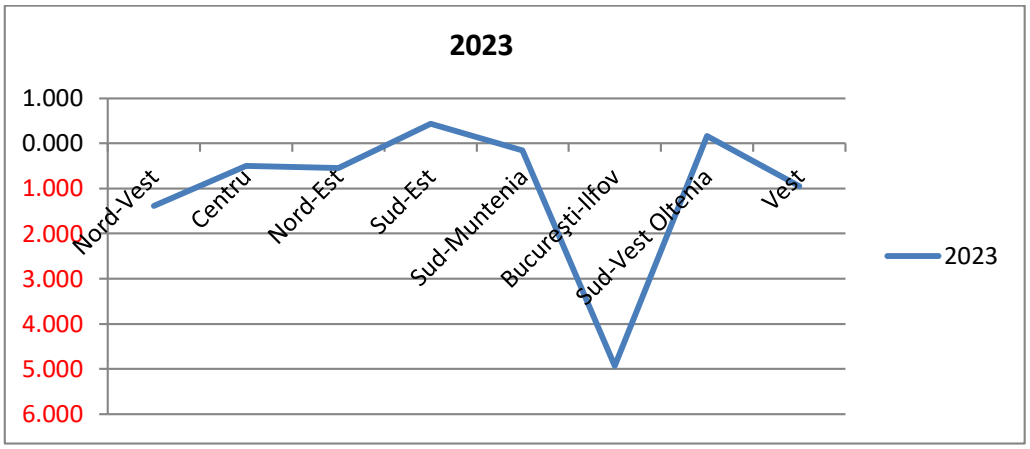
The fact that many values (in red) are negative, turn the interpretation of the Regional Readiness Index into a concern for certain areas and suggests that factors such as the risk of poverty, school dropout or greenhouse gas emissions have outweighed the benefits brought by GDP or digitalization.

The analysis indicates a paradox of regional development in Romania: the regions with the highest GDP and the highest rate of digitalization (Bucharest-Ilfov, North-West) record the worst regional readiness scores (negative values). This suggests that environmental pressure (GHG emissions), the degradation of the railway infrastructure and social risks cancel out the economic advantages. In contrast, the less economically developed regions maintain a positive but fragile index, being on a downward trend of underdevelopment.

The graph highlights a sharp polarization of regional resilience, where the collapse of the index in the Bucharest-Ilfov growth pole signals that the accelerated economic expansion has exceeded the supporting capacity of the infrastructure and the environment, transforming the capital from a development engine into a critical point of structural vulnerability.

From an economic and digital point of view (GDP, internet users) the Center region is active, the negative value of -0.501 suggests that the benefits of development are partially cancelled out by pressure indicators (such as gas emissions or the risk of social exclusion), pulling the index below the equilibrium line. From the point of view of the Regional Readiness Index, the Centre region occupies a position of fragile equilibrium, being located between the positive pole of resilience and the negative pole of vulnerability.

Figure 2. Regional Preparedness Index Graph – 2023



Source: Generated by the author based on data from table 1- year 2023

5. CONCLUSIONS

In Romania, most NUTS2 regions are not sufficiently prepared for the digital transition and its implications for socio-economic development, thus regional disparities are recorded.

The PCA analysis led to the construction of a Regional Readiness Index (RPI), intended to synthesize the degree of readiness of NUTS 2 regions in Romania for the digital, energy and social transition. However, the distribution of scores and the orientation of the variables indicate an interpretative reversal: high scores reflect the accumulation of vulnerabilities, such as educational exclusion, risk of poverty, high emissions and poor infrastructure.

The results reflect a multitude of intuitive vulnerabilities such as educational exclusion, poverty risk, high emissions and poor infrastructure.

Thus, the constructed index, IPR functions as an Index of Regional Unpreparedness, summarizing the structural gaps that limit the capacity of regions to respond effectively to current economic challenges. The regions of Romania are predominantly positioned in the risk zone (negative indicators) and require specific interventions in order to reduce disparities and develop adaptive capacity. We ask ourselves the question: do we develop the regions while maintaining and protecting the environment or do we sacrifice the environment in favor of development?

Although NUTS 2 regions provide a useful overview, this division can mask huge dis parities within the same region (for example, the discrepancy between a university center like Iași and the neighboring rural counties in the North- East region).

Using data at county level (NUTS 3) would have provided greater precision, but repor ting of SDG indicators at this level is often incomplete in international databases.

Principal Components Analysis is sensitive to extreme variations (outliers). The case of the Bucharest-Ilfov region, witch statistically dominates the rest of the country, can exert a disproportionate influence on the weights of the principal components, causing pressure indicators (such GHG emissions) to be over-weighted relative to social development indicators.

Public policy recommendations

To reverse the negative values in the performing regions (such as Bucharest-Ilfov or N-V), it is necessary to implement subsidies conditional on the carbon footprint for large companies. Instead of stimulating only the growth of turnover, the state should offer tax incentives exclusively to entities that invest in technologies with low greenhouse gas (GHG)

emissions. Such a policy would force a transition from quantitative development, which "settles" the environment to a qualitative one, where the regional readiness index returns to the positive zone by reducing pollution and modernizing railway networks.

The data indicates a major fragility in regions such as Sud-Muntenia or North-East where, although the index is still positive, the trend is downward. Here, the public policy should focus on creating special economic zones with a focus on human capital retention. This would involve mentoring programs and technical scholarships financed through public-private partnerships, aimed to reduce the rate of early leavers and integrating the population at risk of poverty into high value-added sectors (such as R&D or Digital). Only by securing the human factor, these regions can prevent the index from collapsing towards the negative values observed in overpopulated urban centers.

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