

## ENSURING AFFORDABLE AND CLEAN ENERGY: DRIVERS OF SUSTAINABLE DEVELOPMENT AND RESILIENCE WITHIN THE EUROPEAN UNION

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**Abstract.** In the 21st century, the energy system of the European Union is undergoing a structural transformation, the dynamics and scale of which are unprecedented in the continent's modern history. „Affordable and Clean Energy” is the 7th Sustainable Development Goal (SDG 7) established by the United Nations, representing not merely a technological transition, but a redefinition of economic competitiveness and social justice within a geopolitical context where energy has become the primary metric of state resilience. Energy productivity is undoubtedly one of the most critical indicators of the EU economic competitiveness. Over the past decades, the Union has demonstrated continuous improvement in this field: the EU economy now generates nearly 40% more value from the same unit of energy than in the early 2000s, reflecting the expansion of high-value-added services, digitalization, and the technological renewal of industry. Closely linked to this is the explosive growth of clean sources within the power sector, driving the progress of the most visible and perhaps most vital pillar of SDG 7: the share of renewable energy in gross final energy consumption. The proliferation of renewable energy sources has a direct impact on energy import dependency, which currently remains one of the EU's most significant points of vulnerability. However, the transition to clean energy cannot remain solely a macroeconomic or technological issue; social sustainability necessitates the realization of affordability. Without ensuring affordability, social support for the green transition may erode, thereby jeopardizing long-term development goals. In our study, we analyse the indicators associated with the SDG 7 goal for EU countries, presenting the current position of Member States and identifying their medium- and long-term development opportunities.

**Keywords:** Sustainable Development Goals, European Union, energy efficiency, crisis resilience.

### Introduction

In the 21st century, the European Union is undergoing a structural energy transformation, the dynamics and scale of which are unprecedented in the continent's modern history. This transformation represents not merely a technological shift, but a fundamental restructuring of the socio-economic framework. To monitor these changes, numerous global statistical indicator systems provide data; among these, this manuscript utilizes specific indicators associated with the United Nations' Sustainable Development Goal 7 (SDG 7: Affordable and Clean Energy). Within the energy discourse, one of the most critical macroeconomic indicators is energy productivity, defined as the ratio of economic output (GDP) to the units of energy consumed. The European Union achievements in this field are noteworthy, as the EU economy has successfully demonstrated a relative decoupling of economic growth from energy consumption. Consequently, it can be stated that the EU currently generates nearly 40% more value per unit of energy than it did at the turn of the millennium [1; 2].

This improvement is primarily driven by two factors. Firstly, digitalization and expansion of the service sector have reduced primary energy intensity per unit of GDP. Secondly, the technological modernization of the industrial sector – ranging from automation to the application of artificial intelligence – has facilitated the maximization of energy efficiency. Nevertheless, it must be emphasized that improvements in energy productivity alone are insufficient for long-term sustainability if absolute energy consumption does not decrease, or if the energy mix remains fossil-dependent in the long run.

Arguably the most closely monitored element of SDG 7 is the share of renewable energy in gross final energy consumption. This indicator serves not only as an environmental commitment but also as a barometer of technological advancement. The precipitous decline in the cost of solar and wind energy technologies over the last decade has enabled clean sources to become competitive on a market basis. Statistical trends within the EU exhibit a positive yet heterogeneous distribution. While Scandinavian member states have already reached a stage where more than half of their energy mix is derived from renewable sources, the expansion of solar capacities in the Central and Eastern European (CEE) region has only gained significant momentum in the past five years [3; 4].

This trajectory has a direct impact on energy import dependency, which currently represents one of the European Union's primary strategic vulnerabilities. Consequently, it can be asserted that

domestically produced renewable energy mitigates geopolitical exposure, particularly in the post-2022 energy crisis era. However, systemic integration – specifically the challenges of energy storage and grid stability – continues to necessitate technological breakthroughs that require substantial R&D&I (Research, Development, and Innovation) investments. Based on these premises, the green transition is a capital-intensive process, the costs of which are inevitably reflected in consumer prices [5; 6].

From the perspective of the green transition, energy poverty constitutes another critical metric, defined by the percentage of the population in various Member States who are unable to keep their homes adequately warm. Energy poverty, however, is not merely a function of income; it is the resultant of poor building energy performance and a volatile energy market. If significant strata of society are excluded from the benefits of clean energy while bearing its burdens, it may lead to the erosion of the social legitimacy of the green transition. The EU's 'Just Transition Mechanism' is designed to address precisely this issue, recognizing that environmental sustainability is not viable without social sustainability [7; 8].

EU Member States exhibit disparate levels of development, a divergence that is also reflected in their respective energy indicators. From this perspective, EU Member States can be categorized into three primary developmental trajectories:

1. technological pioneers,
2. catching-up transformers,
3. Southern diversifiers.

This tripartite classification is prevalent in the relevant literature; building upon these foundations, the analytical section of this manuscript proposes a novel approach. The analysis of SDG 7 indicators will demonstrate that increasing the share of clean energy must proceed in tandem with social development. Decarbonization is not an end in itself, but rather a catalyst for fostering a more competitive, secure, and livable Europe. Future research and policy frameworks must concentrate on the synergies between these indicators, specifically exploring how the expansion of renewable energy can be translated into direct reductions in household utility costs and tangible economic advantages, even in disadvantaged regions [9; 10].

Against this backdrop, this study presents a segment of our ongoing research, elucidating the current landscape of European Union Member States through the lens of 'Affordable and Clean Energy'.

## Materials and methods

The methodological framework of this research is based on a quantitative analysis of indicators derived from the United Nations' Sustainable Development Goal 7 (SDG 7) system. Given that the energy transition necessitates not only technological shifts but also social advancements, our methodology focuses on the dichotomy between environmental sustainability and social affordability. The dataset was compiled relying on Eurostat databases, encompassing all EU-27 Member States to facilitate a comprehensive comparative analysis. In alignment with the objectives of this manuscript – pertaining to the year 2023 – two critically significant variables were highlighted [11]:

Share of renewable energy in gross final energy consumption: This indicator serves as the primary metric for decarbonization efforts. Gross final energy consumption accounts for energy utilized in electricity generation, transport, as well as heating and cooling, thereby providing a comprehensive overview of the extent of energy independence across the Member States. Share of the population unable to keep their home adequately warm: This variable is a fundamental indicator of energy poverty. It is pivotal from the perspective of social sustainability, as it reflects the population vulnerability to energy price volatility and income inequalities.

To explore the systemic interrelationships between these two selected indicators, the Member States were examined based on their relative positions. The EU-27 Member States were categorized into three distinct clusters, considering both the level of renewable energy penetration and the degree of energy poverty risk:

1. Energy-efficient system Member States: Countries characterized by a high share of renewable energy, while the proportion of the population unable to heat their homes adequately remains below the EU average.

2. Member States in transition: Countries that have made significant strides toward a clean energy transition, although their progress trails behind that of the EU frontrunners; simultaneously, their populations are considered relatively less socio-economically vulnerable.
3. Energy and social risk-exposed Member States: Countries where a low renewable energy share is coupled with high energy poverty metrics.

For the spatial representation of results and illustration of geographic patterns, QGIS version 3.40.5 (Geographic Information System software) was utilized.

## Results and discussion

In the current decade of the 21st century, the energy system of the European Union is undergoing a complex, multi-level transformation that fundamentally reshapes the continent's socio-economic framework. In this context, the United Nations Sustainable Development Goal 7 (SDG 7) is not merely a set of environmental policy guidelines but serves as a cornerstone of European development strategies. The concept of sustainability here transcends the classical ecological interpretation, defining a framework where technological decarbonization and social welfare emerge as mutually reinforcing processes. This duality is represented by the two indicators at the focus of our research: the share of renewable energy in gross final energy consumption and the proportion of the population unable to keep their home adequately warm. Within this framework, resilience is intrinsically tied to the evolution of these metrics. An increasing share of renewable energy sources enhances systemic resilience by mitigating import dependency. Simultaneously, the social dimension of resilience necessitates that the green transition does not exacerbate energy poverty, as a society can only be considered resilient to the extent that its most vulnerable strata can maintain access to essential energy services [12].

The joint examination of these two indicators highlights the intersection of environmental sustainability and social equity: the success of the European energy transition hinges on whether the tension between technological progress and economic affordability can be resolved within an integrated model that harmonizes climate protection goals with the preservation and enhancement of residential comfort. Our study analyzes the disparities between the Member States along the lines of these interrelationships.

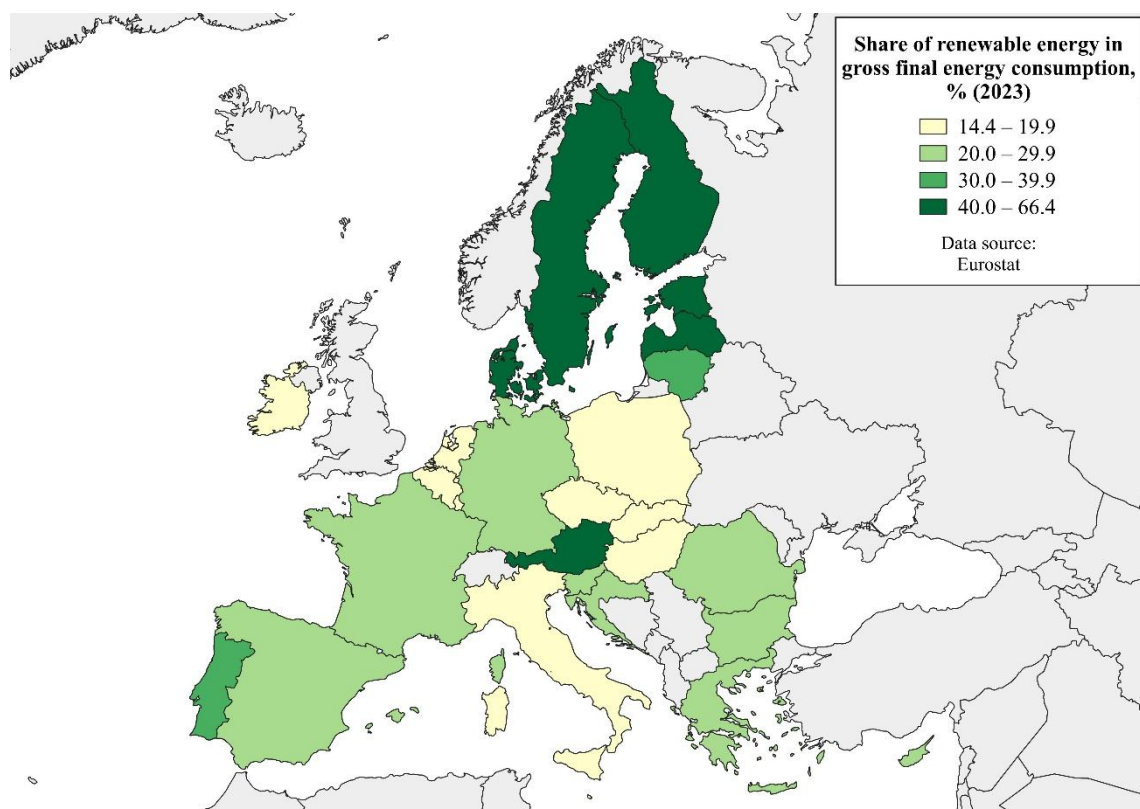


Fig. 1. Share of renewable energy in gross final energy consumption, % (2023)

Fig. 1 illustrates the share of renewable energy in gross final energy consumption across the European Union Member States based on 2023 data. The Fig. clearly delineates both a North-South and a North-Central European dichotomy. The countries exhibiting the highest values (ranging from 40.0% to 66.4%) – namely Sweden, Finland, Denmark, Lithuania, Estonia, and Austria – constitute the decarbonization vanguard. In this zone, the dominance of renewable energy is a result not only of contemporary political will but also of favourable physiographic conditions and decades of infrastructural development. The cohort of countries falling within the 20.0% to 39.9% range is the most heterogeneous, comprising states that have made significant efforts over the past decade to diversify their energy mix. Those with the lowest shares (14.4% to 19.9%) – including Ireland, the Benelux countries, Italy, Poland, the Czech Republic, and Hungary – form the group where renewable energy penetration significantly lags behind the EU average (24.6%).

The map explicitly demonstrates that the attainment of SDG 7 objectives cannot be defined as a uniform process. In 2023 – the first full year following the energy market shock precipitated by the Russo-Ukrainian conflict – Member States recognized that renewable energy is no longer merely an environmental preference but a matter of national security. While the greatest potential for progress is observed in Member States with lower current values, these nations also face the most significant systemic barriers (Fig. 1).

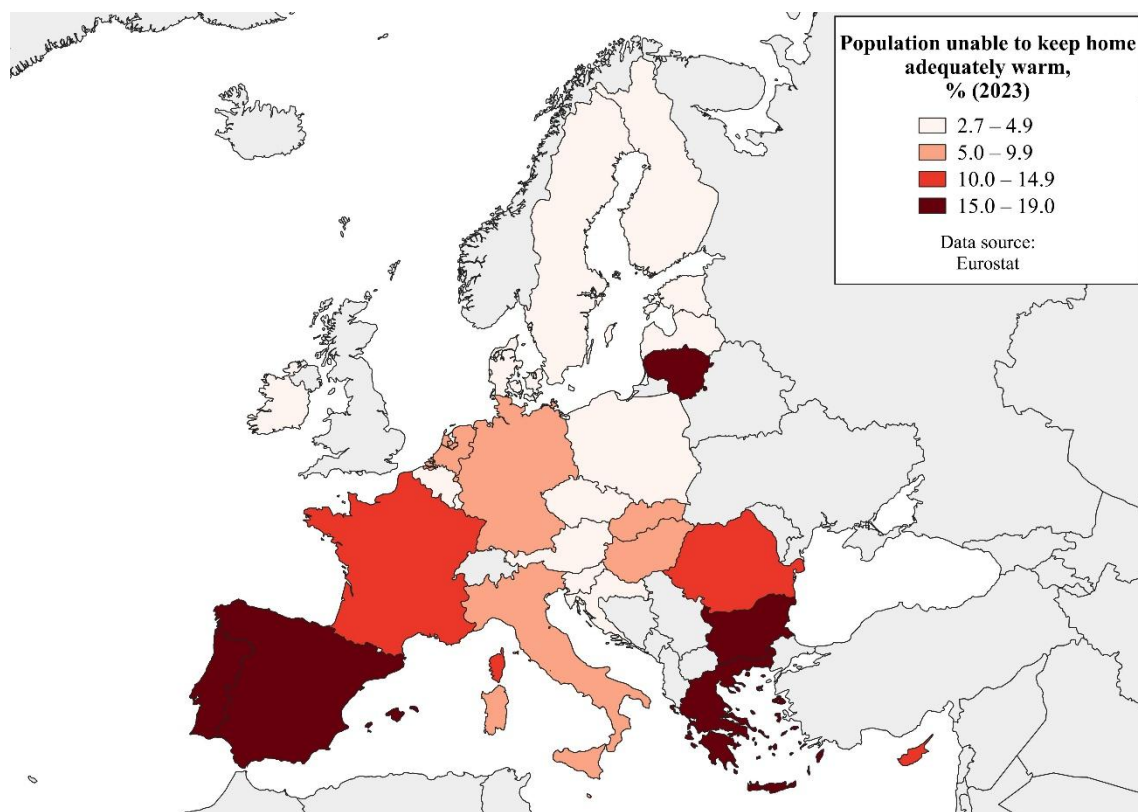
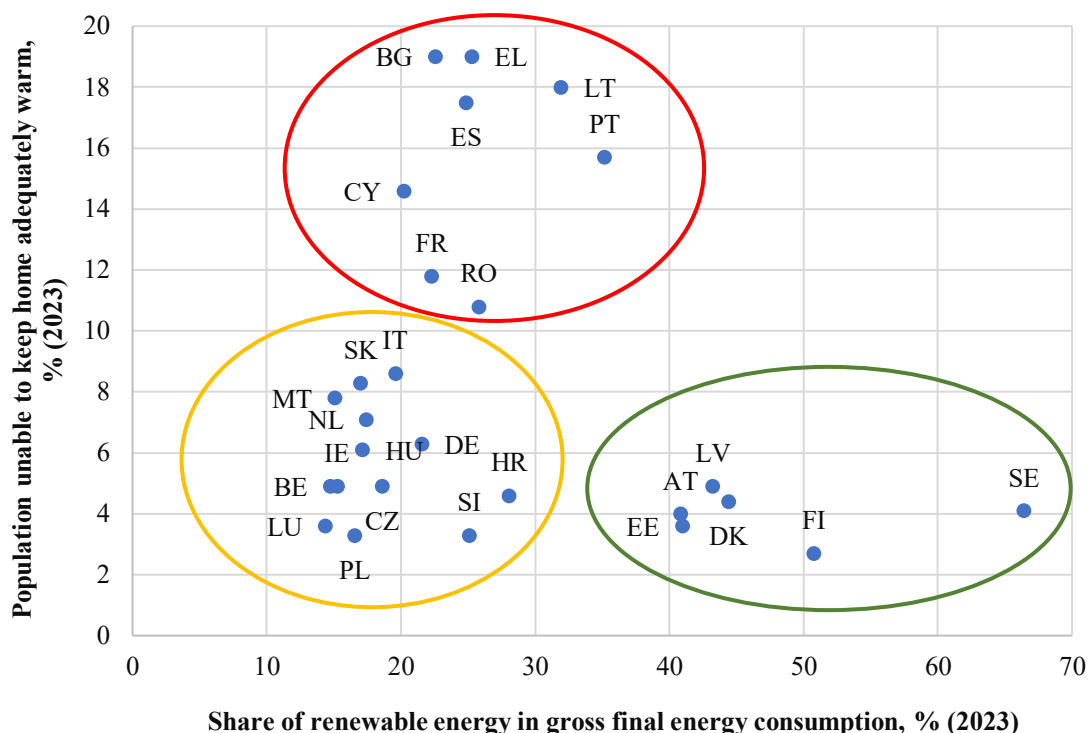


Fig. 2. Population unable to keep home adequately warm, % (2023)

Fig. 2 illustrates the proportion of the population unable to keep their home adequately warm across the European Union Member States, based on 2023 data. The Fig. clearly delineates the critical situation within the Mediterranean region and certain Baltic states. Among the Member States exhibiting the highest values (ranging from 15.0% to 19.0%), we find – inter alia – Portugal, Spain, Greece, and Bulgaria. This highlights an apparent paradox: in the Southern states with relatively milder climates, a larger share of the population faces heating difficulties compared to the significantly colder Northern regions. Specific attention should be paid to the figures for Lithuania, which is the only country in the Baltic region categorized within the highest-risk group, while its neighbours, Estonia and Latvia, report substantially more favourable values. This apparent contradiction underscores that energy poverty is not merely a geographical or climatic issue. The map explicitly demonstrates that Europe is struggling with a ‘socio-energy gap’. While heating is technically and financially resolved in Northern countries, energy

poverty has become a barrier to social integration in the peripheries. The data corroborate the necessity of a just transition, confirming that increasing the share of renewable energy is insufficient if the population remains unable to afford heating services. The transition to a low-carbon economy can only be sustainable if social safety net enhancements precede or, at the very least, accompany the market-based restructuring of energy prices (Fig. 2).



Note (1): Abbreviations of country names: BE: Belgium, BG: Bulgaria, CZ: Czechia, DK: Denmark, DE: Germany, EE: Estonia, IE: Ireland, EL: Greece, ES: Spain, FR: France, HR: Croatia, IT: Italy, CY: Cyprus, LV: Latvia, LT: Lithuania, LU: Luxembourg, HU: Hungary, MT: Malta, NL: Netherlands, AT: Austria, PL: Poland, PT: Portugal, RO: Romania, SI: Slovenia, SK: Slovakia, FI: Finland, SE: Sweden

Fig. 3. Correlation between the share of renewable energy in gross final energy consumption and the population unable to keep home adequately warm (2023)

Fig. 3 illustrates the correlations between the two indicators previously mapped, presenting the three identified clusters. The lower-right quadrant of the diagram comprises those countries that have successfully integrated decarbonization with social inclusion.

The prominent positions of Sweden and Finland demonstrate that a high share of renewables (exceeding 50%) does not inherently entail an increase in the burden on households. In these states, the synergy between cleanliness and affordability is founded upon high levels of building energy efficiency and robust welfare systems. Within this cluster, renewable energy serves as a tool for systemic stability and lower operational costs. A critical situation is observed among the countries situated in the upper range of the diagram. As anticipated by our prior spatial analysis, these nations have made significant strides in deploying renewable capacities – primarily wind and solar energy (20.2-35.2%); however, relative to the EU average, a substantial portion of their population (over 10%) remains unable to heat their homes adequately. The lower-left quadrant clusters those countries where the share of renewable energy remains low (below 30%), yet energy poverty metrics are favourable (below 10%). The case of these nations highlights a transitory energy strategy: in this cluster, maintaining household affordability is often achieved through fossil-based or nuclear sources, or via significant state price interventions. Although this group appears stable from a social perspective, the lower level of sustainability indicators suggests that this model may prove vulnerable in the long term, necessitating targeted developmental interventions (Fig. 3).

## Conclusions

1. The Northern model demonstrates that a high renewable energy share and low energy poverty are simultaneously achievable, resulting from the combined effect of superior building energy efficiency and robust welfare systems. This region serves as the European benchmark for aligning decarbonization with social resilience.
2. The Mediterranean case highlights that the expansion of renewable capacities alone does not eliminate energy poverty if the energy efficiency of the residential building stock remains substandard.
3. The Central European region's low energy poverty metrics are currently predicated on fossil fuel dependency or state-mandated price interventions, both of which hinder the shift toward decarbonization. To ensure long-term sustainability, it is imperative to increase the share of renewable sources without jeopardizing current levels of social security.
4. Based on the analysis, it can be concluded that there is no linear correlation between the proliferation of renewable energy and the reduction of energy poverty. Instead, an 'L-shaped' trend emerges: above a specific renewable threshold (approximately 40%), energy poverty is suppressed to low levels almost universally.

## Author contributions

Conceptualization, B.L., T.Cs. and J.K.; Data collection and Methodology, B.L.; Formal analysis, T.Cs. and J.K.; Investigation, B.L. and J.K.; Writing-review and editing, T.Cs. and J.K.; Visualization, B.L. All authors have read and agreed to the published version of the manuscript.

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