

Energy Transition in the European Union: A Comparative Analysis of Member States Based on a New Composite Indicator Proposal

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Abstract. *This paper proposes an alternative framework for monitoring the energy transition in the European Union, based exclusively on harmonized Eurostat series for the period 2010-2024. Using classical economic indicators, this article proposes two new complementary indicators - ET-Simple (reflecting a transition status) and ET-Progress Index (dynamic, with base year 2010, reflecting the evolution over time). The indicators aggregate four classical outcomes - RES share in final consumption, electricity generation mix, final energy consumption per capita and GHG emissions per capita - normalized annually by percentiles for robustness to extreme values and adds GDP per capita as proxy for enabling capability. The results show that the EU27 remains in the 'moderate transition' zone both in terms of level and relative progress, despite absolute component improvements. At state level, the overlap between top performers (high status) and top movers (accelerated progress) is limited and the quadrant analysis highlights patterns of maturity versus convergence. In 2024, Sweden and Portugal led in terms of performance, while dynamics were dominated by Denmark, The Netherlands and Luxembourg. A case study on Romania has also been conducted, revealing a relatively good status, but weaker progress. The methodology is transparent, replicable and suitable for regular policy evaluations in the EU area.*

Keywords: energy transition, sustainability, composite indicator, European Union, cross-country benchmark.

Introduction

The path to a zero-carbon world is now clearer than it was decades ago. But although the goal of transitioning all energy-consuming activities from fossil fuels to green or non-polluting energy sources seems achievable, it remains essentially difficult to achieve. The main reason this process faces challenges is that global attention is currently scattered across multiple issues, and the public discourse focuses primarily on the urgent need to secure energy supplies.

So far, the European Union (EU) leads the global effort to address climate change and has started an ambitious energy transformation - being driven by both pressing climate mitigation objectives and the need for energy security (Szép, Pálvolgyi, & Kármán-Tamus, 2022). This transition is also a fundamental element of its ambitious climate and energy policies, and it “involves not only the accelerated growth of renewable generation, but also a reconfiguration of the way power systems are operated and commercially optimized” (Pamfile, 2024), including digitization (Sandu, Ocenic, Vrişcu, & Shakir, 2025) and flexibility solutions designed to manage technical constraints of both conventional and renewable assets (Pamfile, 2024). This shift is further complicated by the diversity of Member States' economic histories, development patterns and energy mixes, which results in significant variation in their routes and progress (Virjan, Popescu, Pop, & Popescu, 2023). In addition, the emergence and need for integration of new technologies, such as energy storage and carbon capture solutions (Pamfile, 2023), or their integration into the concept of smart cities (Tanţău & Şanta, 2021), bring new challenges that require a systematic approach.

These different layers highlight the complexity of achieving a decarbonized economy. To ensure fair and effective implementation, studies suggest that a comprehensive assessment of progress in all Member States is needed (Szép, Pálvölgyi, & Kármán-Tamus, 2022; Renou-Maissant, Abdesselam, & Bonnet, 2022), along with robust frameworks to assess the effectiveness of national strategies and to identify disparities among EU members - in particular given the recognized gap in systematic approaches to sustainability assessment (Ligus & Piotr, 2021). In parallel, it is important to properly assess the status so that policy interventions can be better designed for countries that need more support in this transition process.

There are economists and researchers, such as Giacomo Di Foggia and Massimo Beccarello (2024), who see the transition to a sustainable energy mix as necessary for both climate objectives and economic stability, and recent geopolitical tensions have reinforced the urgency of an accelerated transition that would also serve to increase the EU's energy independence and resilience. To this end, other researchers such as Jarosław Brodny and Magdalena Tutak (2025) argue that the UE has operationalized decarbonization through the 2020 Climate and Energy Package, and subsequently through the European Green Deal enshrined in the European Climate Act, which makes climate neutrality by 2050 a legal objective and sets interim targets for 2030.

Despite the visible progress of the energy transition in the EU, benchmarking often remains fragmented between separate indicators, difficult to interpret in an integrated way and difficult to use in repeated monitoring. A recurrent gap in both applied literature and policy analysis is the absence of a minimalist, easily replicable and communicable tool, built exclusively on official harmonized and comparable data across countries (Eurostat-type), which summarizes performance without completely losing the transparency of the components. Many existing frameworks tend to mix the current level with the dynamics of change, which makes it difficult to assess convergence fairly, because a country may have a good status (high relative position) but a modest rate of improvement, or vice-versa. Therefore, a robust summary score is needed that simultaneously allows (i) cross-country comparisons, (ii) assessment of relative position in a given year, and (iii) explicit separation between status and progress, so that the interpretation is relevant for monitoring and policy evaluation.

In order to address this gap, the present study proposes a comparative assessment of the energy transition performance of the EU Member States over the last 15 years (period 2010-2024), using a composite approach that remains easy to follow at component level. The analysis pursues three research questions: (1) how do EU Member States rank in terms of energy transition over the period under analysis; (2) how each country has evolved and improved its position to adapt to the energy transition; and (3) to what extent is it possible to construct a composite score that ranks countries on the basis of integrated performance in a consistent and replicable way.

Based on the existing literature and the economic logic of the energy transition, the following hypotheses are formulated: 1. There are significant differences between EU Member States in the energy performance (status) of transition. 2. The rate of improvement of energy transition indicators differs significantly between Member States. 3. A composite score constructed on the basis of only few outcome indicators can coherently reflect the relative positioning of countries in the energy transition and support a stable ranking for comparisons.

Within this framework, this paper aims to develop a simple and transparent composite indicator and a progress indicator, to easily compare the performance of Member States, to distinguish between the best-performing countries and those that have made the most progress, and to provide a replicable monitoring tool useful for benchmarking public policies. In order to achieve this, the study relies on classical, quantitative and standardized outcome indicators widely used in

the energy transition literature to evaluate decarbonization, energy efficiency and structural transformation among EU Member States.

Literature review

The energy transition literature frequently starts from ‘classical’ indicators - energy production and consumption, share of renewables, greenhouse gas emissions - which provide a useful but often fragmented picture of the functioning of energy systems. Such fragmented analytical approaches could overlook the connections and compromises (e.g. a country's potential to economically sustain transition), while strong performance in one area does not guarantee overall balance across the entire system – an idea also supported by other researchers (Siksnelyte-Butkiene, Streimikiene, Lekavicius, & Balezentis, 2024). For example, as explained by Mahyar Kamali Saraji and Dalia Streimikiene in a paper in 2024, a high share of renewables signals decarbonization but says little about stability or affordability. Some researchers mention the pressure to have more integrated analytical frameworks, as some measurements may obscure the technological and economic mechanisms that condition the ability to change current indicators (Vîrjan et. al., 2023; Walesiak et al., 2024).

To address the limitations of an analysis based on a single indicator, many studies advocate for using composite indices combining economic, environmental, and social dimensions (Gunnarsdóttir, Davíðsdóttir, Worrell, & Sigurgeirsdóttir, 2021). In this category fall tools widely used in international benchmarking – such as the Energy Transition Index (ETI) and the World Energy Trilemma Index (WETI) – that consolidate indicators related to security, equity, sustainability and readiness, which research find them suitable for providing a comparative synthesis across countries (Manowska, Bluszcz, Chomiak-Orsa, & Wowra, 2024). Recent literature also includes applications with sets of variables, such as energy intensity or energy security proxies, used to construct country rankings and typologies (Li, Liu, & Yuan, 2025).

In the EU area, there are studies proposing composite indices dedicated to transition assessment, such as the Energy Transition Progress Index (ETPI) for EU countries (Manowska, Bluszcz, Chomiak-Orsa, & Wowra, 2024). Also, other research endeavours formulate composite “sustainable energy transition” indices, highlighting robustness and sensitivity (including uncertainty analysis) to enhance the reliability of interpreting a summary score in policy analysis (Kármán-Tamus, 2025). In terms of methodological standards, the EU holds a collection of datasets created by the Competence Center on Composite Indicators and Dashboards (European Commission, Joint Research Centre (JRC), 2025), however the development and application of composite indicators are thoroughly examined in reference guides that underscore the need for transparency in indicator selection, normalisation, weighting and robustness testing (Nardo, Saisana, Saltelli, Tarantola, & Hoffmann, 2008). At the same time, because these indicators are becoming more and more ambitious, methodological decisions with high impact (normalization, aggregation, weights) are emerging, which can significantly influence their results and interpretation (Gatto & Drago, 2023; Bilbao-Terol, Cañal-Fernández, & González-Pérez, 2023).

Many frameworks use many variables, aggregate and weight them in complex ways, and lack clear documentation, which makes them hard for policymakers to use (Burgass, Halpern, Nicholson, & Milner-Gulland, 2017). Under such conditions, numerous researchers have concluded that it becomes challenging to track the contribution of each component to the final score and, implicitly, hard to identify concrete 'levers' of intervention (Gargalo et al., 2024; Gunnarsdóttir, Davíðsdóttir, & Worrell, 2020). Moreover, high data requirements and reliance on difficult-to-collect indicators may limit systematic applicability (Gebara, 2023), while other studies

suggest that the allocation of weights may represent a separate but extremely important methodological issue, as it may introduce arbitrariness and produce different hierarchies across countries, affecting the final results (Bardazzi, Bortolotti, & Grazia, 2023).

A key analytical distinction - but not always made explicitly - is between a country's current energy-transition status and its progress over time. If you only use current status, countries with good starting conditions are favoured and rapid improvers can be undervalued (Walesiak & Dehnel, 2024). The literature notes that some of the existing indicators tend to confuse high performance at one point in time with actual progress in transition, which may dilute the message about the effectiveness of policies and the pace of convergence (Kettner, Kletzan-Slamanig, Köppl, Littig, & Zielinska, 2019). In terms of policy analysis, the difference between "where you are" and "how fast you are moving" is fundamental for assessing equity, convergence and investment prioritization.

Against this background, the current study proposes a concise and easily replicable synthetic instrument and uses harmonized official data on energy and climate outcomes, with two complementary outputs: a level/status score (ET-Simple) and a progress indicator against a base year, so that cross-country comparison is not confounded with the dynamics of change. This option aims to address the criticisms of opacity and replicability through a clear, simple method, avoiding hard-to-measure indicators and unjustified weights. In this context, the central contribution is the systematic separation of "top performers" (status) from "top movers" (progress), providing a more informative framework for monitoring and for evaluating public policies, including when classical indicators send mixed signals, as suggested by other studies (Usubiaga-Liaño & Ekins, 2022) (Di Foggia & Beccarello, 2024).

Methodology

This section describes the construction of two replicable indicators of energy transition outcomes: an annual composite level indicator – called from now on 'ET-Simple' – and a dynamic index - called 'Progress Index' (or ET-Progress) – relative to a common baseline year. The indicators' name stands for "Energy Transition". The first one serves to capture a country or a region's level/status in the energy transition process, and the second indicator is based on the same components as the first, but it aims to provide a year-over-year assessment of advancement in comparison to a historical baseline.

In terms of methodology, these new indicators are designed to be transparent, resilient to outliers and simple to replicate using openly available and publicly accessible data. As software programs used for processing statistical data, Microsoft Excel was used to store data and collate results, Microsoft Visual Studio Code (VS Code) to run Python codes, with support from artificial intelligence - Microsoft Copilot - in the process of writing and correcting code, doing calculations, testing results and checking indicators. Also, all figures presented in this paper were generated with Python libraries.

Data and indicator selection

As this paper analyses only the European Union area, all data needed to calculate the indicators for the energy transition were found on Eurostat. Annual Eurostat data for the period 2010-2024 (the most recent complete data for all countries) were used and the analytical sample comprises the EU-27 Member States. The data also includes the Eurostat aggregate EU27_2020, which is retained as a benchmark series for comparison purposes, and it is not used to form the cross-country ranking distribution.

Indicators focus on established outcome measures of the energy transition, not policy inputs or institutional readiness. Next, five variables are used, as they provide a comprehensive picture of progress in the energy transition (and the parentheses contain their abbreviation, along with the unit of measurement):

1. Share of renewable energy in gross final energy consumption (RES share, %).
2. Final energy consumption per capita (FEC, toe/capita).
3. Greenhouse gas emissions per capita (GHG, tCO₂ e/capita).
4. Electricity generation mix (PWR; shares of Fossil, Nuclear, Renewables, %).
5. GDP per capita (EUR/capita).

In the Eurostat database, these indicators correspond to the following codes: ‘nrg_ind_ren’ for RES share, filtered by REN (total) and PC (percentage); ‘sdg_07_11’ for FEC, with filter on TOE_HAB (tons of oil equivalent per capita); ‘dsg_13_10’ for GHG emissions, with filter on T_HAB (tons of CO₂ per capita) and TOTXMEMONIA (which represents GHG per total, including land use, land-use change and forestry, aviation etc.); ‘nrg_bal_peh’ for electricity generation mix, with filter on GEP (to distinguish mix by technology); ‘nama_10_pc’ for GDP per capita per year, and filter on CP_EUR_HAB (GDP at market prices, being the standard value) (European Commission, 2026).

The connection between these indicators and the subject of this study is simple. Energy potential is reflected in the RES share and the electricity generation mix, which reflect supply-side decarbonization and structural transformation within the electricity sector. FEC per capita acts as a demand-side indicator of energy efficiency and final-use intensity, and links energy to sustainability. Climate impact measures are then reflected in GHG per capita - which represents the definitive result of climate externalities. While GDP per capita is incorporated solely in an alternate specification to serve as a proxy for enabling capability (e.g., investment and technology adoption potential) without characterizing energy transition performance as economic prosperity. In terms of its role in defining these new indicators, GDP per capita is included only as an enabling factor (capacity), not as an energy-transition outcome.

Normalization of data

The selected indicators are measured in different units, have heterogeneous distributions, and can contain extreme values (e.g., small economies with very high per-capita levels). Hence, to ensure robustness to outliers and a consistent scale across indicators and years, each variable is transformed into a percentile rank (quantile) within the annual cross-section of Member States, a process widely used in studies and supported as effective by the relevant literature.

First, a cross-sectional normalization by year is done. For each year t and indicator X , the normalized score $S_{\{i,t\}}(X)$ for country i is defined as its percentile position within the set of EU Member States j observed in year t , yielding values in $[0,1]$.

$$S_{\{i,t\}}(X) = \text{PercentileRank}(X_{\{i,t\}} | \{X_{\{j,t\}}\}_{j \in C}) \in [0,1]$$

All normalized components are oriented such that higher values indicate better transition outcomes. However, because not all high results have the same meaning, for indicators where lower levels are preferable (FEC per capita, GHG per capita, and fossil electricity share), percentile ranks are computed on the negated values (equivalently, descending ranks).

$$S_{\{i,t\}}^{\downarrow}(X) = \text{PercentileRank}(-X_{\{i,t\}})$$

An important to clarify note is the definition of clean electricity from the total mix, which is relevant for the energy transition, but also sparks debate. In this paper, the low-carbon electricity share in electricity generation is defined as the sum of renewables plus nuclear - as nuclear is accepted as clean energy (Taylor, Bodel, Banford, Butler, & Livens, 2024) and it is associated with decarbonization and sustainability (Fell, Gilbert, Jenkins, & Mildemberger, 2022), including at EU level (European Commission, Joint Research Centre (JRC), 2021):

$$CleanShare_{\{i,t\}} = Renewables_{\{i,t\}} + Nuclear_{\{i,t\}}$$

And therefore the power-mix component uses an explicit penalization of fossil generated from fossil fuels. The main economic and climate rationale for this decision is that decarbonising electricity is central to EU climate objectives and underpins electrification pathways (European Commission, 2025). As a result, penalizing fossil generation aligns the composite indicator with the reduction of carbon-intensive supply and with lower exposure to fossil-fuel price volatility and import dependence (Awerbuch, 2006), which means that the power subscore increases as the fossil share decreases, implemented via the percentile rank of the negated fossil share:

$$S_{\{i,t\}}(PWR) = PercentileRank(-FossilShare_{\{i,t\}})$$

Finally, another relevant point concerns the benchmark handling. ‘EU27_2020’ is treated as a benchmark observation whose percentile position is computed relative to the Member State distribution in each year and it is not included as an observation when computing Member State percentiles, avoiding mechanical effects on rankings.

Construction of the ET-Simple index

Two variants are considered for the construction of this composite indicator: an Outcome-only index based solely on energy and climate outcomes (A); and an Outcome plus Enabler index that incorporates GDP per capita as a capacity proxy (A+B). Both variants are scaled to a 0-100 range.

All normalized scores $S_{\{i,t\}}(RES)$, $S_{\{i,t\}}(PWR)$, $S_{\{i,t\}}(GHG)$, and $S_{\{i,t\}}(FEC)$ denote the annual percentile-rank scores (0-1) for RES share, power mix (with fossil penalization), GHG per capita (where lower is better) and FEC per capita (lower is better) respectively are used to calculate the energy performance of a country. The Outcome component is a weighted linear aggregation:

$$Outcome_{\{i,t\}} = w_{RES} \cdot S_{\{i,t\}}(RES) + w_{PWR} \cdot S_{\{i,t\}}(PWR) + w_{GHG} \cdot S_{\{i,t\}}(GHG) + w_{FEC} \cdot S_{\{i,t\}}(FEC)$$

In the next step, the weights are defined and, following a policy-oriented classical outcomes emphasis, they are set to sum 100: $w_{RES} = 0.30$, $w_{PWR} = 0.30$, $w_{GHG} = 0.25$, and $w_{FEC} = 0.15$. The main reason weights were defined with these values is because they prioritise renewable integration and electricity-sector decarbonisation, while maintaining substantial influence for emissions outcomes and a smaller, yet non-negligible, contribution for final-demand efficiency. As a final step, the Outcome-only ET-Simple score is scaled to a 0-100 metric:

$$ET - Simple^{\{A\}}_{\{i,t\}} = 100 \cdot Outcome_{\{i,t\}}$$

Add the normalized GDP per capita score $S_{\{i,t\}}(GDP)$ as an enabling factor to reflect investment capacity and implementation constraints, while maintaining a results-oriented index. By incorporating GDP, is to also show whether the country under analysis would have the capacity to sustain and accelerate the energy transition - because the process requires capital (for networks development, grid flexibility, investing in new technologies, electrification and renewable

integration). To this end, the A+B variant uses a limited weight of 15% (expressed as 0.15 in the below formula) so that the composite remains primarily driven by energy and climate outcomes (85%):

$$ET - Simple^{A+B}\{i,t\} = 100 \cdot (0.85 \cdot Outcome_{\{i,t\}} + 0.15 \cdot S_{\{i,t\}}(GDP))$$

Construction of the ET Progress Index

The progress is measured based on the results of the ET-Simple index. First, a baseline year t_0 is defined, against which annual differences (or delta) can be compared. Then, progress is measured relative to that common baseline year, which in this paper is 2010 for all countries.

The definition of indicator-specific improvements says that for each country i and year t , raw progress deltas are defined so that positive values represent improvements:

$$\begin{aligned}\Delta RES_{\{i,t\}} &= RES_{\{i,t\}} - RES_{\{i,2010\}} \\ \Delta FEC_{\{i,t\}} &= -(FEC_{\{i,t\}} - FEC_{\{i,2010\}}) \\ \Delta GHG_{\{i,t\}} &= -(GHG_{\{i,t\}} - GHG_{\{i,2010\}}) \\ \Delta PWR_{\{i,t\}} &= CleanShare_{\{i,t\}} - CleanShare_{\{i,2010\}}\end{aligned}$$

These annual differences are also normalized. For each year t , each delta is normalized using the same percentile-rank procedure across Member States, yielding progress percentiles $P_{\{i,t\}}(\cdot)$ in $[0,1]$.

$$P_{\{i,t\}}(\Delta X) = PercentileRank(\Delta X_{\{i,t\}} | \{\Delta X_{\{j,t\}}\}_{j \in C})$$

And in the final step, deltas are aggregated and scaled to calculate the energy transition progress of a country, resulting in the variant A of the progress indicator (focused only on energy and climate activity). The progress outcome component uses the same weights as ET-Simple:

$$\begin{aligned}OutcomeProg_{\{i,t\}} &= 0.30 \cdot P_{\{i,t\}}(\Delta RES) + 0.30 \cdot P_{\{i,t\}}(\Delta PWR) + 0.25 \cdot P_{\{i,t\}}(\Delta GHG) + 0.15 \\ &\cdot P_{\{i,t\}}(\Delta FEC)\end{aligned}$$

$$ET - Progress^A_{\{i,t\}} = 100 \cdot OutcomeProg_{\{i,t\}}$$

For consistency with ET-Simple, GDP per capita also enters as a level enabler (which means the normalized score is used here as well and not a delta) and the resulted A+B variant is expressed as:

$$ET - Progress^{A+B}\{i,t\} = 100 \cdot (0.85 \cdot OutcomeProg_{\{i,t\}} + 0.15 \cdot S_{\{i,t\}}(GDP))$$

From an economic (methodological) interpretation, the ET-Progress Index captures relative improvement since 2010, complementing the ET-Simple level indicator by distinguishing countries that improved rapidly from those that already started from high initial levels.

Classification and interpretation

Based on the results obtained, a fixed threshold classification can now be created to ensure comparability across years and avoid distribution-dependent reclassification. This step is useful for analysis and reporting, and it is worth noting that the below thresholds and categories have been defined merely as example - depending on specific needs or on the results of future research, they can be changed.

Going forward, both ET-Simple and ET-Progress scores (with values between 0 and 100) for countries are defined using fixed thresholds according to the following categories:

- Leaders: score > 75
- Advanced: $60 \leq \text{score} \leq 75$

- Moderate transition: $45 \leq \text{score} < 60$
- Delayed: $\text{score} \leq 45$

The threshold between ‘Moderate transition’ and ‘Advanced’ was set at 60 to indicate a relative performance well above the median (i.e., above the middle of the distribution), rather than simply above the median. In terms of institutional practices, in the case of composite indicators, this method of categorizing performance by means of distribution thresholds corresponds to other standards - such decisions should be made transparently and subjected to testing, according to the European Commission (European Commission, 2025), whereas percentile thresholds are also used by the World Bank in its composite indicators (World Bank, 2026).

The resulting indices and classifications are designed to support transparent benchmarking and tracking of outcomes across Member States, but the model can also be used on a larger scale - to compare other countries or regions outside EU. While the methodology avoids policy recommendations, it provides a replicable measurement framework based on observable outcomes.

To replicate the results, follow these steps: (i) normalize annual percentile ranks across countries; (ii) penalize fossil fuels and define CleanShare = Renewables + Nuclear; (iii) apply fixed outcome weights (0.30, 0.30, 0.25, 0.15); (iv) optionally include GDP per capita at 15% as an enabler; (v) use 2010 as the baseline for progress deltas; set fixed classification thresholds.

Results and discussions

This section interprets the empirical patterns produced by the ET-Simple (level/status) and ET-Progress (dynamic) indices for EU Member States over 2010-2024 period, with primary emphasis on the A+B variant (which includes energy and climate outcomes + enabler, including GDP per capita). The analysis evaluates outcomes and progress against a common baseline instead of treating rankings as the main goal.

In 2024 the EU27 scores 54.06 (ET-Simple A+B) and 52.02 (ET-Progress A+B), placing it in the 'Moderate transition' band. This shows the EU is mid-range among Member States, not at the frontier or the bottom.

Table 1. ET-Simple score and country's status in 2024
(A = energy and climate outcomes, B = enabler, including GDP per capita)

Country	Score (A)	Status (A)	Score (A+B)	Status (A+B)
Sweden (SE)	86.67	Leaders	85.89	Leaders
Portugal (PT)	84.26	Leaders	76.62	Leaders
Denmark (DK)	69.07	Advanced	72.60	Advanced
Spain (ES)	75.00	Advanced	71.53	Advanced
France (FR)	72.04	Advanced	71.23	Advanced
Austria (AT)	66.94	Advanced	69.68	Advanced
Lithuania (LT)	74.81	Advanced	69.15	Advanced
Romania (RO)	72.41	Advanced	62.66	Advanced
Croatia (HR)	68.24	Advanced	60.78	Advanced
Finland (FI)	58.33	Moderate transition	60.14	Advanced
Latvia (LV)	63.89	Advanced	56.53	Moderate transition
EU27	53.15	Moderate transition	54.06	Moderate transition
Slovenia (SI)	54.63	Moderate transition	53.66	Moderate transition
Slovak Republic (SK)	53.33	Moderate transition	49.78	Moderate transition
Greece (EL)	52.04	Moderate transition	47.56	Moderate transition
Bulgaria (BG)	54.44	Moderate transition	46.83	Moderate transition
Malta (MT)	43.15	Delayed	46.12	Moderate transition

Country	Score (A)	Status (A)	Score (A+B)	Status (A+B)
Italy (IT)	42.59	Delayed	45.09	Moderate transition
Hungary (HU)	49.26	Moderate transition	43.54	Delayed
The Netherlands (NL)	35.28	Delayed	43.32	Delayed
Germany (DE)	34.26	Delayed	40.23	Delayed
Estonia (EE)	39.81	Delayed	39.95	Delayed
Luxembourg (LU)	26.85	Delayed	37.82	Delayed
Belgium (BE)	26.30	Delayed	34.02	Delayed
Cyprus (CY)	30.19	Delayed	33.99	Delayed
Czech Republic (CZ)	25.56	Delayed	28.39	Delayed
Ireland (IE)	14.81	Delayed	27.04	Delayed
Poland (PL)	25.83	Delayed	25.85	Delayed

Source: Author's own research.

Table 2. ET-Progress Index score and status in 2024
(A = energy and climate outcomes, B = enabler, including GDP per capita)

Country	Score (A)	Status (A)	Score (A+B)	Status (A+B)
Denmark (DK)	94.63	Leaders	94.32	Leaders
The Netherlands (NL)	88.70	Leaders	88.73	Leaders
Luxembourg (LU)	85.56	Leaders	87.72	Leaders
Finland (FI)	76.85	Leaders	75.88	Leaders
Ireland (IE)	65.28	Advanced	69.93	Advanced
Estonia (EE)	74.81	Advanced	69.70	Advanced
Greece (EL)	71.67	Advanced	64.25	Advanced
Germany (DE)	58.33	Moderate transition	60.69	Advanced
Belgium (BE)	57.22	Moderate transition	60.31	Advanced
Cyprus (CY)	56.85	Moderate transition	56.66	Moderate transition
Malta (MT)	55.19	Moderate transition	56.35	Moderate transition
Portugal (PT)	56.85	Moderate transition	53.32	Moderate transition
Spain (ES)	53.15	Moderate transition	52.95	Moderate transition
Lithuania (LT)	55.74	Moderate transition	52.94	Moderate transition
EU27	50.74	Moderate transition	52.02	Moderate transition
Austria (AT)	45.74	Moderate transition	51.66	Moderate transition
Sweden (SE)	45.00	Delayed	50.47	Moderate transition
Italy (IT)	44.07	Delayed	46.35	Moderate transition
France (FR)	40.37	Delayed	44.31	Delayed
Czech Republic (CZ)	44.17	Delayed	44.21	Delayed
Slovak Republic (SK)	37.78	Delayed	36.56	Delayed
Hungary (HU)	37.59	Delayed	33.62	Delayed
Poland (PL)	33.33	Delayed	32.22	Delayed
Bulgaria (BG)	35.00	Delayed	30.31	Delayed
Latvia (LV)	32.04	Delayed	29.45	Delayed
Slovenia (SI)	25.00	Delayed	28.47	Delayed
Romania (RO)	21.48	Delayed	19.37	Delayed
Croatia (HR)	7.59	Delayed	9.23	Delayed

Source: Author's own research.

A key interpretive point is that a percentile-based composite can remain 'moderate' even as absolute indicators improve substantially, because the normalization is relative. When most Member States improve together, the EU27 benchmark moves only slightly and the time series oscillates around central values instead of rising steadily.

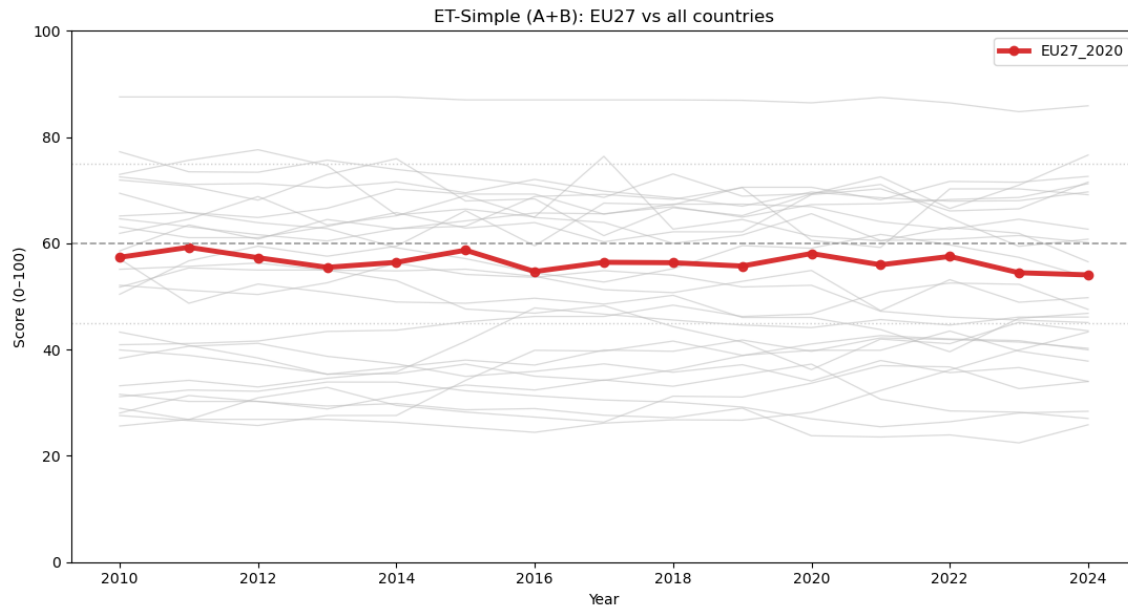


Figure 1. EU27 energy transition status by year (ET-Simple) compared to all Member States

Source: Author's own research.

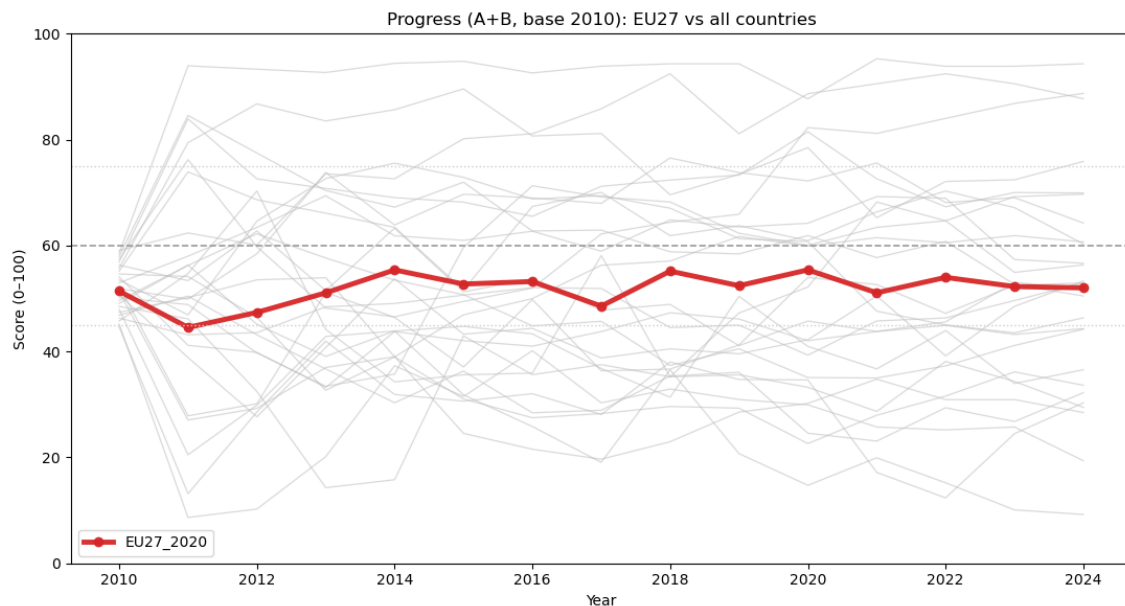


Figure 2. EU27 annual progress of energy transition (ET-Progress Index, base 2010) compared to all Member States

Source: Author's own research.

Separating level from progress is therefore analytically valuable at the EU aggregate because the two perspectives answer different policy-evaluation questions and should not be confused. As proposed at the beginning of this paper, ET-Simple captures where the EU benchmark stands in a given year relative to cross-country outcomes (a status snapshot), while ET-Progress captures how the EU benchmark's improvements since 2010 compare with distributions of improvements (reflecting the dynamics of the transition).

Cross-country comparison

The results can be interpreted in many ways and one way to conduct a cross-country benchmark and highlight the best results is to classify the countries within a performance quadran. The highest scores in ET-Simple are labelled as ‘top performers’, while the highest scores in ET-Progress are labelled as ‘top movers’. Thus, in 2024, the ET-Simple top performers are led by Sweden and Portugal, followed by Denmark, Spain and France, while by contrast the ET-Progress top movers are led by Denmark, The Netherlands and Luxembourg, followed by Finland and Ireland. The complete list of all Member States and their performance classification is provided below (in Table 3).

**Table 3. Cross-country benchmark based on level and progress
(A+B = energy and climate outcomes, including GDP per capita)**

Country	ET-Simple score	ET-Progress score	Performance quadran
Sweden (SE)	85.89	50.47	High status / Low progress
Portugal (PT)	76.62	53.32	High status / Low progress
Denmark (DK)	72.60	94.32	High status / High progress
Spain (ES)	71.53	52.95	High status / Low progress
France (FR)	71.23	44.31	High status / Low progress
Austria (AT)	69.68	51.66	High status / Low progress
Lithuania (LT)	69.15	52.94	High status / Low progress
Romania (RO)	62.66	19.37	High status / Low progress
Croatia (HR)	60.78	9.23	High status / Low progress
Finland (FI)	60.14	75.88	High status / High progress
Latvia (LV)	56.53	29.45	Low status / Low progress
Slovenia (SI)	53.66	28.47	Low status / Low progress
Slovak Republic (SK)	49.78	36.56	Low status / Low progress
Greece (EL)	47.56	64.25	Low status / High progress
Bulgaria (BG)	46.83	30.31	Low status / Low progress
Malta (MT)	46.12	56.35	Low status / Low progress
Italy (IT)	45.09	46.35	Low status / Low progress
Hungary (HU)	43.54	33.62	Low status / Low progress
The Netherlands (NL)	43.32	88.73	Low status / High progress
Germany (DE)	40.23	60.69	Low status / High progress
Estonia (EE)	39.95	69.70	Low status / High progress
Luxembourg (LU)	37.82	87.72	Low status / High progress
Belgium (BE)	34.02	60.31	Low status / High progress
Cyprus (CY)	33.99	56.66	Low status / Low progress
Czech Republic (CZ)	28.39	44.21	Low status / Low progress
Ireland (IE)	27.04	69.93	Low status / High progress
Poland (PL)	25.85	32.22	Low status / Low progress

Source: Author’s own research.

The overlap between the two lists is limited (notably Denmark and Finland appear in both groups), indicating that being good now is not the same as improving most since a reference historical year. This difference is due to border effects and it means that early achievers can face diminishing returns, while latecomers can show large relative gains during catch-up. Hence, across all EU Member States the overall pattern is as follows (in Table 4):

Table 4. Energy transition performance at EU level

Performance quadrant	Number of countries
Low status / Low progress	10
High status / Low progress	8
Low status / High progress	7
High status / High progress	2

Source: Author's own research.

Analysing results by using a quadrant framework (ET-Simple on the x- axis, ET-Progress on the y-axis) clarifies these patterns by distinguishes four archetypes based on performance. For 2024, most countries fall into mixed quadrants rather than the extremes, and only two countries are in 'High status / High progress'.

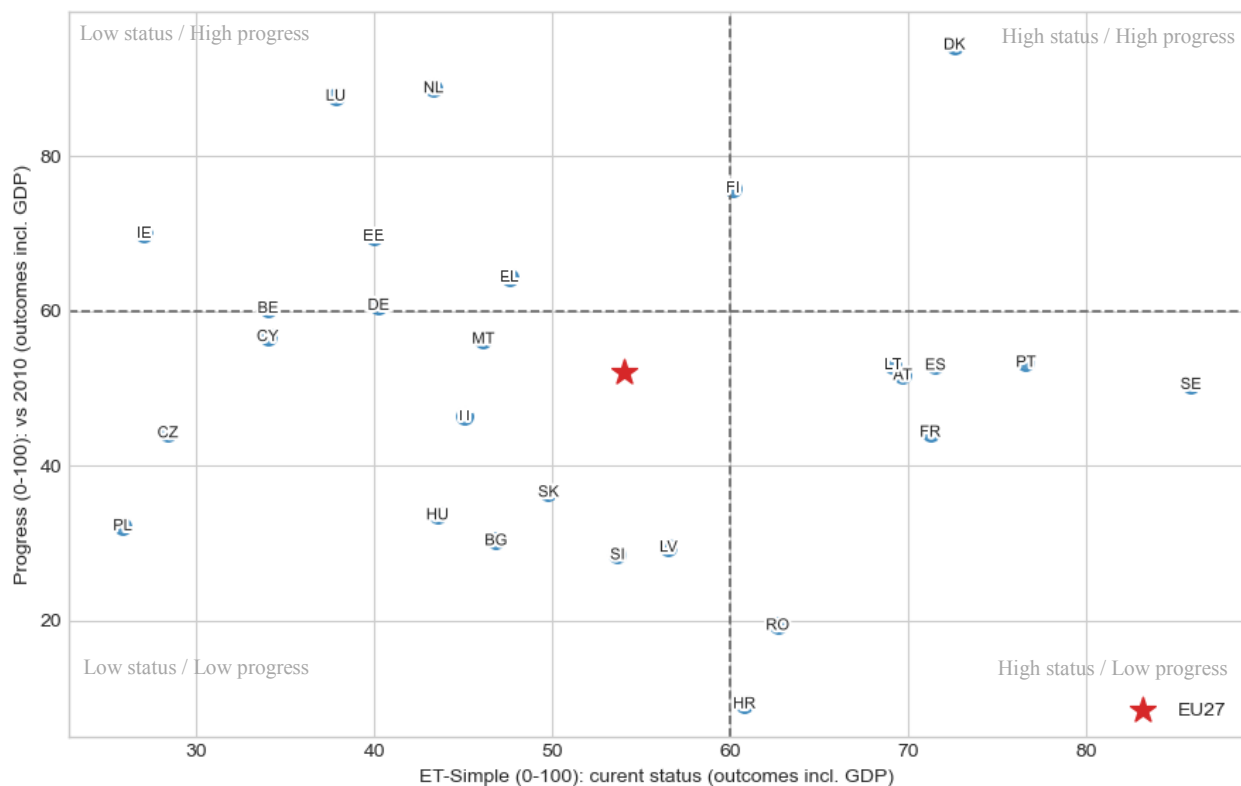


Figure 3. Energy transition status (ET-Simple) and progress (ET-Progress Index) among all EU Member States in 2024

Source: Author's own research.

Figure 3 above shows very well this separation between Member States' status and progress. From a fairness and convergence perspective, 'High level / Low progress' countries can be interpreted as mature transition economies that already achieved favourable outcomes and therefore now grow more slowly, while 'Low level / High progress' countries can be considered as late starters, but they are catching up quickly. Both issues are policy-relevant, as the first group highlights the growing difficulty of incremental progress near the frontier, while the second group highlights momentum and potential for convergence, even when current status remains below the EU leaders.

To verify the two indicators proposed in this paper, Spearman's and Pearson's correlations were used, as they are standard statistical methods for measuring the linear association between two variables, as well as for ranking comparisons (Hauke & Kossowski, 2011). The weak and even slightly negative association between ET-Simple and ET-Progress (Spearman ≈ -0.17) reinforces that level and progress capture distinct dimensions, as can be seen in Table 5. In the end, simultaneous reporting of both indices is justified for monitoring and evaluation.

Table 5. Spearman and Pearson correlation results between energy transition status and progress

Year	Spearman coefficient	Pearson coefficient
2010	-0.260	-0.199
2011	-0.318	-0.229
2012	-0.080	-0.042
2013	-0.071	-0.034
2014	0.079	0.123
2015	-0.118	-0.002
2016	-0.096	-0.039
2017	-0.085	-0.032
2018	-0.132	-0.121
2019	-0.237	-0.187
2020	-0.067	-0.106
2021	-0.180	-0.108
2022	-0.031	-0.072
2023	-0.114	-0.079
2024	-0.172	-0.088

Source: Author's own research.

These results also support the earlier statement that some countries have good status but less progress, while others have still modest status but have made great progress, and some concrete examples are Belgium, Romania and France:

- Belgium: ET-Simple ≈ 34.0 (Late starters), but Progress ≈ 60.3 (Advanced), indicating notable progress vs. 2010, but current level (especially on current mix/performance) remains relatively low in cross-country comparison.
- Romania: ET-Simple ≈ 62.7 (Advanced), but Progress ≈ 19.4 (Lagging behind), indicating that current level looks relatively good in the EU, but improvement vs. 2010 is lower compared to other countries.

- France: ET-Simple ≈ 71.2 (Advanced), and Progress ≈ 44.3 (Lagging behind), indicating a good status, relatively less progress compared to others.

Composite indicator versus classical indicators

Member States often perform asymmetrically across renewables, demand, emissions and power system when simple comparisons based on single indicators are used, and this can generally yield mixed signals. Therefore, the composite indicator provides clearer cross-country comparisons by combining normalized results, making cross-country benchmarking more transparent and preserving each component's percentile scores to show the drivers. For example, a country may have low GHG per capita and low final energy consumption per capita yet only moderate RES shares or a still-fossil-heavy power mix. The composite thus summarizes the overall balance while the component percentiles explain the drivers.

However, a drawback is that granularity and sector specificity might suffer. The use of a single composite score hide which factor is driving success by the power sector, demand-side outcomes or structural reasons. Moreover, linear aggregation lets different pillars make up for each other, which may be inconsistent with non-compensatory policy aims in some areas. These limitations argue for the use the composite mostly for screening and monitoring, and give each component a closer look.

Then, the use of the final A+B variant, which includes the GDP per capita as enabler, adds interpretive value by separating outcomes from enabling capacity, as countries with high GDP per capita can receive a positive adjustment relative to their outcome-only position, while countries with strong outcomes but lower GDP per capita can receive a negative adjustment. For example, this is seen in the 2024 disparities between A and A+B scores, in Table 3, where Luxembourg and The Netherlands experience gains, but Romania and Bulgaria incur losses - demonstrating how the enabler influences cross-country comparability without altering outcomes.

The composite indicator should be taken as a handy tool for tracking energy and climate results, not a full measure of well-being. Although it has limitations, the methodology is well suited for ongoing policy evaluation as uses standard economic data sets, incorporates outlier-resistant percentile scaling, and yields transparent results (scores, categories, and component diagnostics).

On another note, a comparison with the WEF's ETI ranking (2024, 2025) for EU member states was made to test the proposed composite indicator ET-Simple and the result suggests a moderate alignment between them. Spearman's $\rho \approx 0.48$ (2024) and $\rho \approx 0.62$ (2025) indicate moderate positive rank correlation: ET-Simple partly agrees with the WEF ETI, but differs because ET-Simple measures outcomes only (e.g., emissions intensity, renewable share, energy productivity) while the ETI also includes policy and institutional indicators.

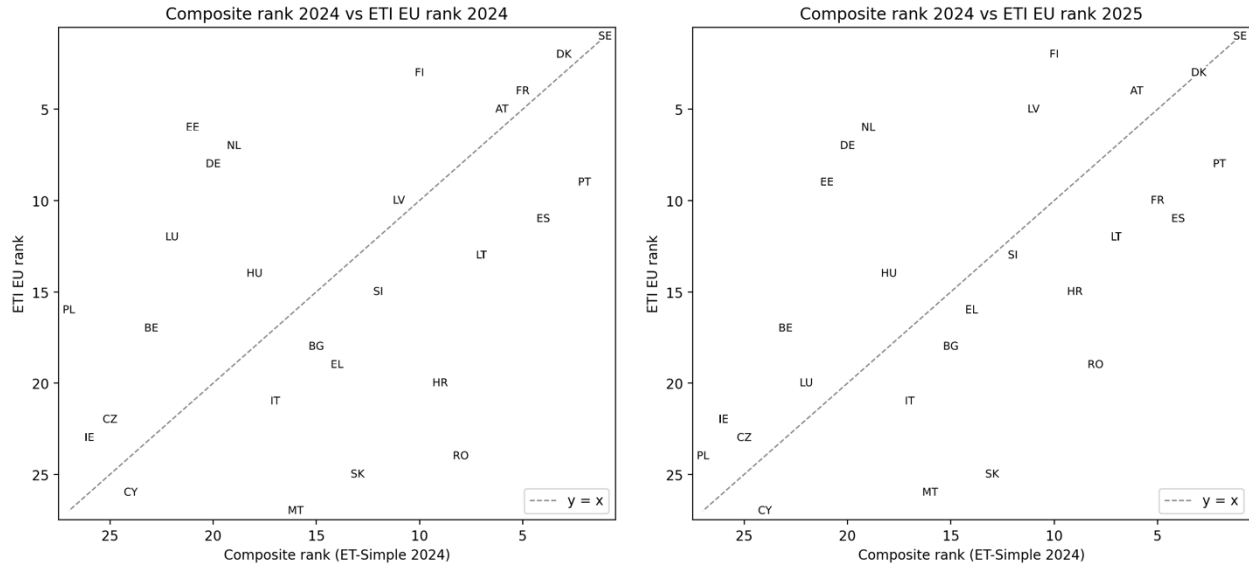


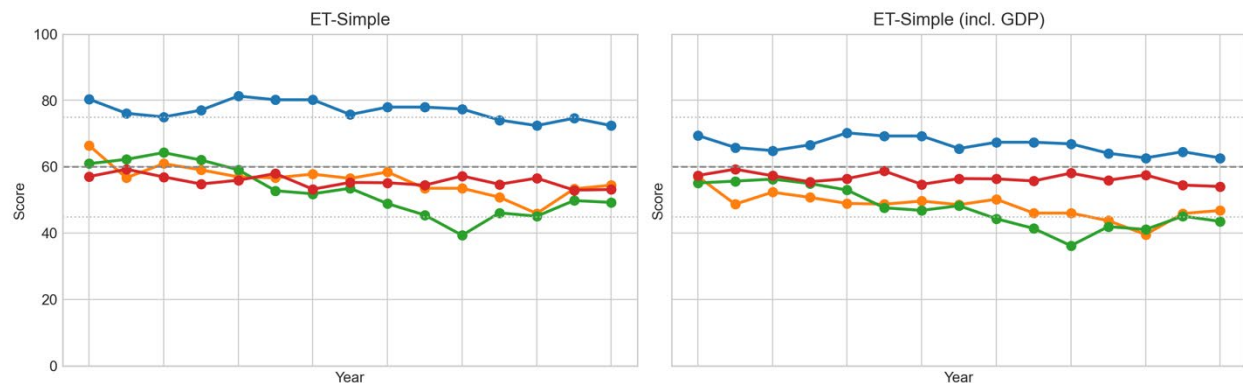
Figure 6. Comparison between the rank of EU Member States using the composite index (ET-Simple) in 2024 and the WEF index (ETI) in 2024 and 2025

Source: Author's own research.

Case study on Romania

Countries such as Romania illustrate the analytical value of differentiating status from progress, as well as why the financial capacity to support the energy transition is important. In the Outcome-only perspective (A) from in Table 1, Romania's 2024 ET-Simple score is 'Ad vanced' and exceeds the EU27 benchmark and regional peers (like Bulgaria and Hungary), which is reflecting a strong outcomes profile in particular on GHG per capita and final energy consumption per capita, if we were to look specifically at these simple indicators.

However, the country's progress score in 2024, as seen in Table 2, is significantly diminished and it is designated as 'Delayed', signifying limited progress since 2010 compared with other EU countries, especially in renewable energy and clean electricity share. This contrast highlights again that a positive current outcome does not necessarily indicate robust transition momentum.



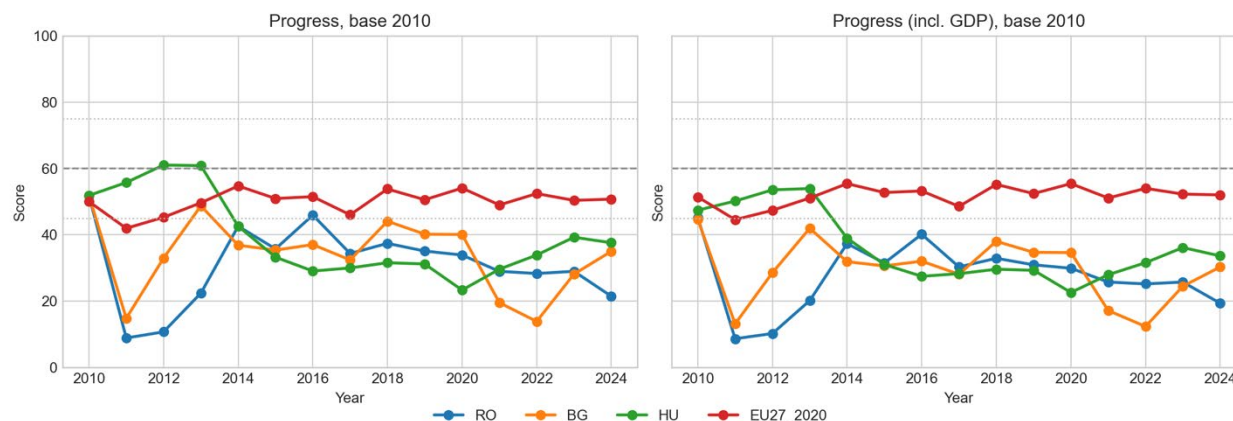
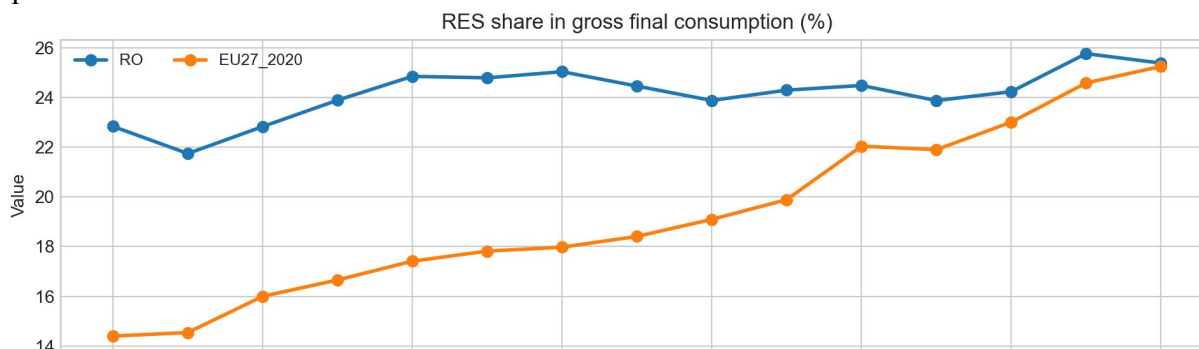


Figure 4. Evolution of Romania's energy transition score (0-100) compared to Bulgaria, Hungary and the EU average

Source: Author's own research.

Moving from the simple outcome variant to the one with enabler (with GDP) significantly changes Romania's position, as shown in Figure 4. In 2024, Romania's A+B level score is notably below its Outcome-only score, whereas higher-income countries tend to receive a positive adjustment, therefore demonstrating how the addition of the GDP per capita as enabler can improve fairness of interpretation when comparing countries with different capacity to finance and absorb transition investments, while keeping outcomes as the dominant component.

We can also look at the simple Eurostat indicators taken into account when creating the composite indicators to analyse Romania's situation in detail and understand the results of the two proposed ET indices:



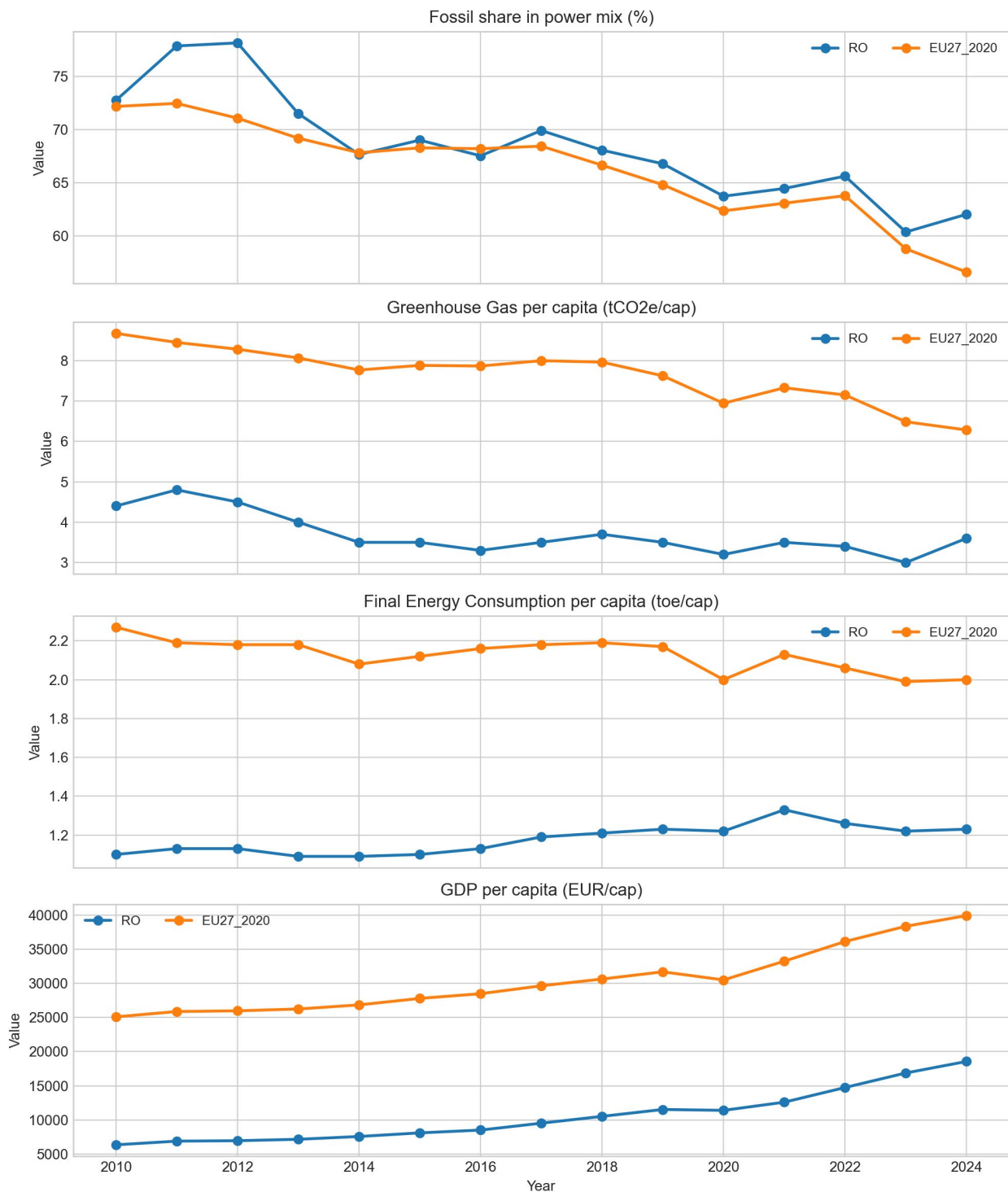


Figure 5. Romania vs. EU27 - evolution of gross indicators (2010-2024)

Source: Eurostat.

Peer and benchmark comparisons thus reinforce the argument that Romania looks stronger on outcome status but weaker on progress dynamics, compared to the 'EU27'. At the same time,

relative to its neighbours Bulgaria and Hungary, Romania's outcome status is higher, yet the three countries show broadly constrained progress profiles compared with the EU benchmark.

Conclusion

This paper introduces an efficient and replicable measurement framework of the energy transition in the EU, built exclusively from simple economic data. The main contribution is the definition of two complementary indices, namely ET-Simple which captures the annual level of transition, and the ET-Progress Index which captures the dynamics of improvement since the base year 2010. The results can be customised to include only outcomes or outcomes with a minimum capacity component, and the framework improves cross-country comparability and reduces sensitivity to extreme values. The transparency of the components is also maintained by normalizing annually by percentiles and explicitly treating the electricity mix.

The results show that, at the aggregate level, the EU27 remains in a moderate performance zone in both status and relative progress, while at the national level the overlap between top performers and top movers is limited, confirming that 'being well positioned' and 'moving fast' are distinct and differently relevant dimensions for policy assessment. The case study on Romania illustrates the interpretative value of separating status-progress and comparing energy-and-climate outcomes versus outcomes with GDP per capita included, because a country may have a relatively good status in outcomes but relatively modest dynamics, and the inclusion of the capacity component may change the comparative reading without replacing energy-and-climate outcomes. The practical importance of these findings is that the proposed indicators can be used as a periodic screening and monitoring tool to identify patterns of convergence and maturity in the energy transition, supporting impact analysis and prioritization assessment (not normative recommendations) in EU and national policy. Moreover, the same indicators can also be used on a large scale, comparing other countries outside the EU, or even regions across the globe - given that the needed classical outcomes are accessible.

At the same time, the study has methodological limitations that must be considered. First, the scores are influenced by fixed weights and the compensability of linear aggregation, so different weighting systems may produce different results. Second, including nuclear as clean energy affects how countries with significant nuclear shares in the electricity mix are analysed. Third, the framework is intentionally outcome-focused and does not explicitly include dimensions such as energy security, price or affordability, social acceptability or institutional quality, thus it should not be interpreted as a complete welfare or readiness indicator.

For future work, researchers could test different weighting schemes, add additional dimensions like security or price indicators, and apply the method to later periods and non-EU samples while keeping the analysis transparent and replicable.

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