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European Roadmaps to Achieving 2030 Renewable Energy Targets

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Abstract

Increasing the renewable energy share of electricity generation is central to decarbonization policies, and the European Union has set up binding 2030 targets. This study evaluates the potential enhancement of these countries' paths toward these targets and provides insights into their performance in meeting their National Energy and Climate Plan targets. It predicts the distance to these targets through a three-step approach and estimates potential improvements. European performance could improve by 1.65% by 2030 if it emulates top-performing countries, independent of further policy interventions. These insights can aid policymakers in designing effective policies and utilities in developing industrial strategies.

1. Introduction

The current global context is forcing a paradigm shift in the energy sector, where the transition toward a more sustainable energy generation mix has become imperative (Gao and Chen, 2023) for both environmental and economic reasons. In the face of necessary climate change mitigation policies, sound strategies to decarbonize the energy sector (Hassan et al., 2022) are needed. However, severe concerns persist (Hassan et al., 2022) due to potential costs. Although the overall investment needs in the energy sector are remarkable, the additional investment required to make the transition is deemed sustainable (Gielen et al., 2019). Sustainable development goals for renewable energy (RE) are strongly felt globally (B. Li et al., 2023), as evidenced by the United Nations' commitment under Agenda 2030 (Colocci et al., 2023).

Emission reduction targets are challenging; for example, the European Commission established legally binding targets to reach a 55% reduction in greenhouse gas emissions by 2030 (Pastore et al., 2022) to achieve climate neutrality by 2050. The European Commission has set ambitious RE targets published in the so-called National Energy and Climate Plans (NECPs) for 2030. However, there is considerable endogenous variation in countries' strategies for meeting their decarbonization targets (Maris and Flouros, 2021). Previous literature has focused on how to assess the impact of policies on national energy and climate plans, and the impact has been described through measures of effectiveness and stages of development to assess the impact of energy policies (Balode et al., 2021). Similarly, another study aimed to analyze the extent to which the NECP works in synergy with climate policies formulated in other documents to assess potential overlaps (Aboltins and Jaunzems, 2021). Other studies have delved into the technological advances that push nations closer to their goals. In addition, socioeconomic factors and their interaction with national energy policies have been critical in shaping the transition (De Paoli and Geoffron, 2019). The path toward these targets is not uniform among the European countries (Veum and Bauknecht, 2019), as several underlying geographic, infrastructural, economic, and social factors dictate the pace and direction of their commitment.

This study explores the drivers and challenges influencing the progress of European countries toward the 2030 targets set out in their NECPs. Through specific research questions (RQs), the aim is to explore the dynamics that contribute to existing performance gaps, the efficiency of the growth trajectory, and potential outcomes by 2030.

The first RQ explores the impact of various identified factors on a country's ability to meet the 2030 targets outlined in the NECP. The second RQ assesses the performance of countries in achieving these targets under a business-as-usual (BaU) scenario projected for 2030. Finally, the third RQ aims to forecast the potential collective gains if all countries adopt the best-performing strategies to pursue the targets.

By answering such RQs, the main objectives are as follows: to understand the role of the identified factors in the gap in achieving the 2030 targets set by the NECP, to assess country performance, and to identify countries that may need additional policies to support RE development, and to estimate the positive outcomes achievable by emulating the best-performing countries. A mixed methods research approach explicitly aims to offer a framework for combining methods (Timans et al., 2019) is applied, as we combine empirical analysis with simulation and forecasting techniques. The findings indicate that, although certain countries are on course and surpassing targets, others are hindered by infrastructural, economic, or political obstacles. Notably, aspects like the density of the electricity grid and the historical share of renewable energy (RE) in electricity generation stand out as significant drivers of the transition. The findings indicate that by implementing the right policies and strategies, it is possible to decrease the distance to the target by 1.65%. Through this study, we shed light on the multiple determinants of RE to inform policies, investments, and strategies to accelerate the transition toward a cleaner energy system. By understanding the nuances of the differences between countries, we highlight the importance of tailor-made support schemes.

The policy implications are straightforward, as highlighting the drivers and challenges of multiple countries can be a valuable aid in creating roadmaps to refine public policies. Such insights can improve the effectiveness of initiatives and facilitate a coherent and synergistic approach to achieving the 2030 targets. The remainder of this article is organized as follows: After the introduction, we present a detailed background that captures the essence of previous studies related to NECP assessments. The next section explains the research methodology, followed by the results, discussion, and concluding remarks.

2. Background

The European Union (EU) has established challenging objectives to expand the role of RE sources in its energy portfolio, as delineated by György et al. (2020). In pursuit of sustainable energy development, the EU has committed to enhancing the proportion of electricity generated from RE to a minimum of 27% by the year 2030 (Almutairi et al., 2018). These targets are part of the EU's broader efforts to achieve climate neutrality by 2050, as outlined in the European Green Deal and the 2030 Framework Agreement on Climate and Energy (Włodarczyk et al., 2021). The upward trend in the RE share of electricity generation in all EU member states analyzed is also clear, driven by the need to meet national targets (Musiał et al., 2021) and the 2050 decarbonization target (O'Connell and Keane, 2021). Due to recent geopolitical tensions, EU energy transition targets are vital for reducing dependence on foreign energy imports

(Cucchiella et al., 2018). The above studies emphasize that the commitment to increase the RE share of electricity generation in the energy mix by 2030 is a pillar of energy and climate policies.

Scholars have focused on how countries have applied support policies and policy instruments, such as feed-in tariffs, premiums, tradable certificates, incentives, grants, financial support, and energy efficiency policies (Gkonis et al., 2020). They have also reported trends toward convergence in the design of policies (Kitzing et al., 2012), confirming the importance of policy adaptation and suggesting that single tools, such as incentives, are insufficient (Bersalli et al., 2020). In contrast, when a plethora of instruments with the same purpose coexist, there may be circumstances in which their interaction can lead to undesirable and costly outcomes (Flues et al., 2014).

The policy framework provided by NECPs serves as a guiding mechanism to harmonize and rationalize these different instruments, reducing potential policy conflicts and inefficiencies and guiding future objectives (Beccarello and Di Foggia, 2023). Consequently, a new research interest has emerged in assessing the evaluation methods, approaches, and perspectives surrounding NECPs. The legal framework underlying the NECPs is Regulation 2018/1999, which entered into effect in 2018 (Rosenow et al., 2017). The regulation determines how countries should work together to achieve their goals (Ringel and Knodt, 2018). A key feature is that it recognizes that countries can contribute to meeting European energy targets differently by setting targets based on their specific situation and needs (Geissler et al., 2022).

No wonder the corpus of literature evaluating NECPs is still limited. In this regard, De Paoli and Geoffron (2019) reviewed the EU's energy-climate objectives and Europe's long-term climate-neutral vision for 2050 and critically assessed the planning process. Considering country-specific analyses, the following few papers provide specific insights. Laes and Verbruggen (2019) analyzed the Belgian case, raising doubts about Belgium's ability to meet its commitments in a complex context. Cruciani and Geoffron (2019) analyzed the French case and reported that significant uncertainties remain while the targets are ambitious. Linares (2019) analyzed the Spanish case and suggested that the goals set in the plan are achievable, but serious efforts need to be made on the means to achieve those goals. Buchmann et al. (2019) analyzed the German case and concluded that Germany could come close to meeting its targets, even if there is a significant gap between the measures and the 2030 climate goals. De Paoli (2019) analyzed the Italian case. They reported that while the targets are ambitious, the measures span all sectors, and their implementation requires administrative capacity, which is sometimes lacking due to the complex institutional framework. Williges et al. (2022) analyzed the Austrian, Greek, and Dutch cases, showing that success is not guaranteed and that overlooking crucial factors can lead to modest results. Streimikiene et al. (2022) analyzed three Baltic states, Estonia, Latvia, and Lithuania, providing ad hoc insights for each.

A combined analysis of the above works showed that studies assessing NECPs are still limited. However, the existing analyses provide an overview of each country's challenges and potential under the EU's energy-climate goals. From the cases of Belgium, France, Spain, Germany, Italy, Austria, Greece, the Netherlands, Estonia, Latvia, and Lithuania, doubts emerge about the effectiveness of the measures taken and the ability of the various countries to achieve their targets, underscoring the importance of an integrated strategy that considers the specificities of each nation.

While the above studies provide a wealth of information and capture different views and perspectives on NECPs in different countries, a gap remains without a unified, comparable approach. This paper fills this gap by proposing a standardized method for assessing countries' compliance in meeting the goals set in their NECPs. However, unlike the common circular economy targets across Europe (Di Foggia and Beccarello, 2022), the targets are set according to country characteristics.

Considering the technological and socioeconomic aspects that drive the development of RE, Marques and Fuinhas (2011) suggest that the level of RE used is more influential than social awareness of sustainability, climate change mitigation, or emission reduction targets, which, according to the author, are not enough to motivate the switch. However, the influence of drivers varies across countries, as what may be a critical barrier or driver in one state may have minimal impact on another; interestingly, policy stability is a critical driver of the successful deployment of renewable technologies (Shivakumar et al., 2019). Indeed, previous literature highlights public policy as a primary catalyst for RE development; in this regard, Marques and Fuinhas (2012) investigate this claim and suggest that public policy initiatives significantly promote RE deployment. Similarly, Cadoret and Padovano (2016) emphasize that industry lobbying hinders

RE deployment, while conventional indicators of government quality positively influence this process. Moreover, from a political perspective, they suggest that left-wing parties are more supportive than their right-wing counterparts. Fossil fuel prices are also important, as underlined by del Río (2011), according to which the main drivers include public policies and increases in fossil fuel prices. In this respect, prices also affect investment in RE, which, despite its many benefits, still accounts for only a small share of the primary energy supply. One possible reason could be that private investment, while potentially lucrative, is still insufficient (Masini and Menichetti, 2013). The development of RE has also been examined in the context of energy security, given Europe's vulnerability due to its significant dependency on energy imports and limited energy reserves. Gökgöz and Güvercin (2018) empirically confirm that RE can effectively reduce the need for energy imports. Moreover, countries with scarce fossil fuel reserves tend to accelerate the development of RE (Papież et al., 2018). The above studies suggest that various technological and socioeconomic factors influence the adoption and development of RE.

Simionescu et al. (2020) provide evidence of the relationships between GDP and RE, suggesting that RE implementation positively affects GDP, economic growth, and competitiveness. Saint Akadiri et al. (2019) also confirm a positive relationship between environmental sustainability, renewable energy (RE) development, and economic growth. This relationship is sustainable over the long term, as Knopf et al. (2015) estimate that the marginal costs of achieving higher RE shares in the energy mix amount to approximately 1% of total system costs. However, when considering the distribution of efforts across countries, the authors highlighted that achieving significant RE shares cost-effectively requires diverse contributions from EU-27 countries.

Many previous studies on scenarios up to 2030 exist. Bigerna et al. (2016) simulate a coordinated approach among member countries grounded in two main components: national binding targets for RES and a cost minimization methodology rooted in a general translog function. Scenario studies are timely in this writing, given that they help discuss how the European Green Deal can transition the EU economy to a sustainable trajectory (Wolf et al., 2021). Another study examines European laws promoting RE alongside the literature that applies portfolio theory to energy policy to question whether RE technology shares in the European power mix are efficient (deLlano-Paz et al., 2015). Various initiatives are underway, focusing on installing intelligent systems and introducing carbon capture and sequestration in existing power plants; according to Magnolia et al. (2023), optimally integrating these technologies emerges as one of the most needed strategies to meet these targets.

The introduced body of literature highlights the complexity of RE adoption in Europe as multiple factors, from policies and economic conditions to technological advancements and country-specific challenges, shape the trajectory to 2030. This paper adds to earlier literature addressing the identified gaps. First, it assesses the drivers of a country's success in achieving the 2030 renewable targets in the NECP. Second, it evaluates the performance of all EU-27 countries in meeting these targets. Third, a scenario where countries mirror the strategies of the top-performing countries to estimate potential gains is proposed.

3. Methods and research design

The analysis was conducted in three stages to ascertain the research questions (RQs): first, we examined the drivers influencing countries' performance in achieving the targets set in the NECPs; this step consisted of an econometric analysis of panel data. This approach is appropriate because it allows us to analyze long-term variations and trends, control for unobserved heterogeneity by holding constant variables specific to individuals, and study differences in behavior between subjects, helping to improve the robustness of the results (Croissant and Millo, 2008). Second, the distance to the target can be predicted via autoregressive integrated moving average modeling. This approach, which uses time series data to predict future patterns (Hyndman and Khandakar, 2008) for forecasting purposes, is consistent with this analysis because of the need to predict data through 2030. Scenario analysis is used to estimate potential improvements based on defined assumptions, in this case, mirroring top-performing countries. Figure 1 shows the abovementioned steps.

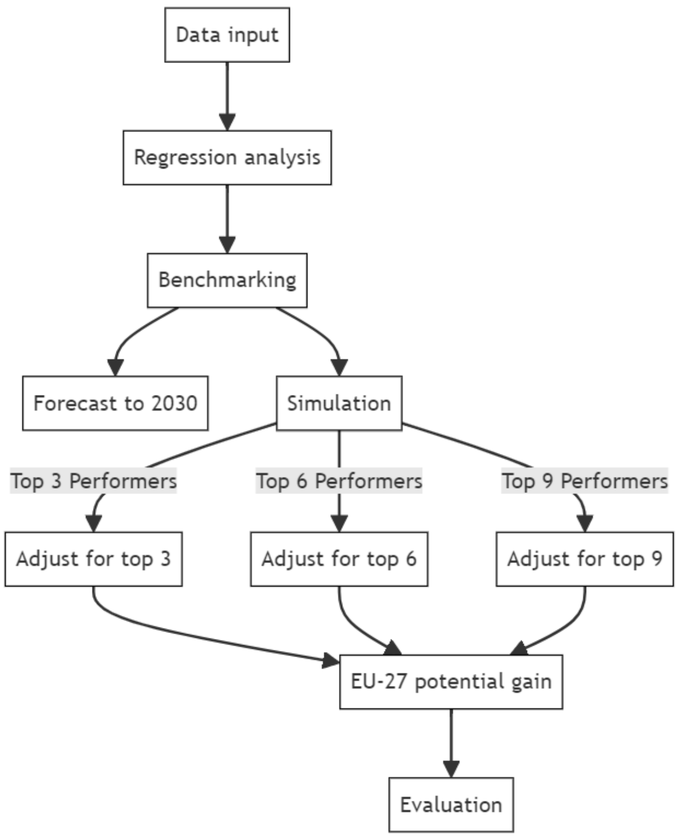

Figure 1: Research flowchart

Thus, these three stages of analysis combine to provide an in-depth understanding of countries' performance in meeting the NECP targets, predict the gap to meeting the targets, and estimate potential improvements, thus offering a forward-looking vision.

3.1. Data

Several variables were identified to run the analyses, each offering distinct insights and spanning from 2012 to 2022. The distance to the target (y) represents a country's gap in reaching the 2030 RE share of electricity generation in its electricity generation. Km of the power distribution network per km2 (x1) is the density of the distribution network that can be a determining factor for integrating and distributing RE effectively. The RE share of electricity generation in 2012 (x2) offers insights into the marginal cost of its future trajectory. Fossil share of electricity generation (x3): A high dependence on fossil fuels has the potential to slow the transition to RE due to existing investment and infrastructure. Hydropower share of electricity generation (x4): The contribution of hydropower offers insights into a country's natural resources and technological capacity. Heat pumps capturing ambient heat (x5) can show a country's commitment to end-use electrification. The prevalence of electric vehicles per km of electric grid (x6) can highlight a push toward sustainable transportation and its implications for the electric grid. The population (x7) influences the energy demand, making considering this influence in energy forecasting essential. Share of companies with at least 5 percent electricity generation (x8) given that a diversified energy sector can indicate a competitive landscape, potentially fostering innovation and efficiency in achieving the goals. The wholesale electricity price (x9) refers to the wholesale price of electricity times the share of RE, as it can influence consumer behavior, investment in renewable technologies, and policy direction. While the average wholesale electricity price until 2020 was 40 Euro/MWh, this scenario changed dramatically in 2021 and 2022 due to the combined impacts of the pandemic and geopolitical crises, leading to a significant increase in wholesale electricity prices—up to 166 Euro/MWh. Because this variable represents the product of the wholesale electricity price and the RE share of electricity generation, it is not a direct representation of actual prices but rather a value designed to capture the interaction between renewable energy penetration and electricity prices. In this regard, Table 1 summarizes the key descriptive statistics of the variables.

Table 1: Descriptive statistics

variables	Source	Formula	Min	Mean	Sd	Max
y	NECPs	$RE_{2030} - RE_t$	-5.820	20.719	15.642	87.800
x1	EDSO	Network length/Km_2	0.369	3.143	3.022	16.738
x2	Eurostat	RE %	1.300	26.317	19.167	74.71
x3	Eurostat	Fossil %	1.490	47.468	25.044	99.50
x4	Eurostat	Hydro %	0.000	14.606	17.164	67.04
x5	Eurostat	Ambient heat cap GW_h	4.101	4811.04	8134.63	42282.02
x6	Various	EVs/Network km	0.000	0.074	0.241	3.488
x7	Eurostat	Population m	0.418	16.474	21.743	83.23
x8	Eurostat	% utilities > 5% of generation	25.480	68.184	17.442	100.00
x9	Ember	Price * % of RE	0.000	1031.57	1707.44	13062.1

Source: The authors, EUROSTAT, Ember.

3.2. Model setting

This analysis aimed to delineate the relationship between the dependent variable y, which represents the gap in achieving the 2030 renewable targets, and the leading independent variables to answer RQ1. Central to this modeling effort was the understanding that various factors influence each country's path to the 2030 goal. This approach is a prominent contribution of this study, as it complements previous literature that has comprehensively analyzed determinants of renewable development (Bourcet, 2020; Papież et al., 2018; Tu et al., 2022).

By incorporating these variables into the model, we aim to account for and control for the specific effects they might exert on the gap. This approach is essential for improving forecast accuracy and understanding which variables, among those considered, play a role in influencing a country's performance toward the 2030 target. Such an approach provides insight into the challenges and opportunities faced by each country and a better understanding of each country's context, thus laying the foundation for the following stages of analysis, i.e., forecasting.

We developed a linear panel model using the random estimation method for development. The formula used for the regression is represented as Equation 1, where y_{it} is the gap for country i at time t and u_{it} is the error term. After fitting the model, the residuals representing the difference between the observed and predicted values were calculated and added to the dataset for each country.

$$y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \ldots + \beta_n x_{nit} + u_{it} \qquad (1)$$

The model is based on the framework of determinants of renewable energy development identified in the literature. It is further enriched with variables less investigated as determinants, ensuring their relevance in the context of NECP commitments to 2030. Each variable is selected based on its practical significance in NECPs. By integrating established and new determinants, our idea aligns with theoretical frameworks in the renewable energy literature but also introduces new perspectives considering the latest policy and market developments.

Switching to the positioning of countries, we aim to obtain the average efficiency of countries concerning their growth trajectories, aiming to answer RQ2. By leveraging the residuals obtained from the regression analysis, we intend to measure the deviation of each country's actual performance from what the model predicts. This approach enables us to identify which countries outperform or underperform relative to the model's expectations. This assessment offers insights into the effectiveness of each country's strategies (or proposals outlined in the NECPs) and their efforts toward achieving the 2030 goal.

First, we aggregated the residuals by country to calculate their average values, offering a comprehensive view of each country's performance trend over period T. Second, we ranked countries according to their average residuals, with particular attention to negative residuals, which are indicative of outperformance relative to the forecast. Since y in Equation 1 represents a gap, and the objective is to reduce this gap, a negative residual indicates that the actual gap was smaller than predicted. Hence, countries with negative residuals outperformed the model's expectations in this efficiency context. The results of the regression analysis are presented in Table 2.

By applying Equation 2, we calculated the average residual for each country and then ranked it by $\overleftarrow{\overline{u_i}}$ in descending order for consistency with the simulation approach.

$$\overleftarrow{\overline{u_i}} = \frac{1}{T}\sum_{t=1}^{T} u_{it} \qquad (2)$$

Third, we derived the average residuals for the top-performing countries in narrowing the gap. For this specific analysis, the average residual, as outlined in Equation 3, was computed for groups of top-performing countries. Here, 'n' represents the number of top-performing countries, and we set 'j' indices to 3, 6, and 9 to conduct a sensitivity analysis:

$$\overleftarrow{u}_{top_n} = \frac{1}{n}\sum_{j=1}^{n} \overleftarrow{\overline{u_j}} \qquad (3)$$

The economic literature has presented analyses grounded in theory and modeling to understand the future impacts of climate policies (Goulder et al., 2016; Rezai et al., 2013). Since these kinds of studies incorporate a range of variables and assumptions that might yield diverse outcomes, they are instrumental in exploring alternative scenarios, especially various decarbonization trajectories (Nasirov et al., 2020). Nevertheless, there is a pressing need to complement these economic models with additional models to fully encapsulate the intricacies and challenges of the transition period (Fragkos and Fragkiadakis, 2022). To our understanding, there is a noticeable need for new literature regarding insights into the likelihood of achieving binding targets and governments’ commitment.

To address RQ3, the primary goal is to forecast each country's progression toward its 2030 targets, as detailed in their respective NECPs. This forecast is refined by applying the efficiency parameters identified in the previous analysis phase, enabling an assessment of the collective advancement as countries intensify their renewable energy efforts, emulating the most advanced countries in this domain. Unlike circular economy targets, which are uniformly set at the EU level, the benchmarks in this sector are tailored to each European country, reflecting their unique circumstances and goals.

Initially, we calculated each country's distance from its 2030 target. These forecasts were then adjusted to incorporate efficiency considerations, creating a scenario analysis that considers three different performance levels based on the number of countries included. Consequently, this scenario predicts a future where all European countries adopt the most efficient practices and strategies, narrowing the gap. This approach highlights the potential benefits of joint efforts in renewable energy adoption. This study emphasizes the importance of following the policies and strategies of countries to meet renewable energy targets. A clearer view of the potential gains that depend on a country's commitment to improving its RE is provided by comparing initial predictions with efficiency-adjusted forecasts. First, a country-specific forecast using an autoregressive integrated moving average model was used to predict each country's distance to the target in 2030. This model captures patterns and trends in historical data and uses them to predict future values (Barbosa et al., 2018). Second, forecast adjustments were made based on the efficiency analysis. The process involved running an autoregressive integrated moving average model for each country, as outlined in Equation 4, to forecast the renewable energy gap by 2030. The model was calibrated to each country's data, providing a tailored forecast that represents the expected gap for each country as they approach the 2030 targets:

$$\hat{y}_{i,2030} = Forecast(y_{it}) \qquad (4)$$

For countries classified as performing, the predicted distances to their 2030 targets remain unchanged in the scenario. This approach assumes that leading countries are already on the optimal path to meet their 2030 targets, and their current trajectory accurately represents their expected performance by the end of the forecast period. In contrast, for countries not among the top performers, their 2030 forecasts are adjusted. This adjustment involves subtracting the average residual of the best-performing countries from their projected 2030 renewable energy figures. This method aims to evaluate potential improvements under the assumption that these improvements can reach the same efficiency levels as those of the best performers. The rationale for this approach is to estimate the progress possible if these countries were to emulate the strategies of the leading countries. Adjustments are made following the method outlined in Equation 5.

$$\hat{y}_{i,2030}^{adj} = \begin{cases} \hat{y}_{i,2030} & \text{if country } i \text{ is in top group} \\ \hat{y}_{i,2030} - \bar{u}_{group} & \text{otherwise} \end{cases} \qquad (5)$$

This methodology provides insights into the relationship between the predictors and the dependent variable and a nuanced understanding of country-specific efficiencies and their potential trajectory through 2030. The gains δ based on the adjusted forecasts are computed as follows:

$$\delta_{i,group} = \hat{y}_{i,2030} - \hat{y}_{i,2030}^{adj} \qquad (6)$$

where $\delta_{i,group}$ is the gain for country i in the given group (top 3, 6, or 9), $\hat{y}_{i,2030}$ is the original forecast for 2030, and $\hat{y}_{i,2030}^{adj}$ is the adjusted forecast for 2030.

4. Results

This section presents the data and analysis of the renewable energy targets set in European countries' NECPs. Initially, the output of the estimated regression model is examined. Next, the efficiency analysis and country ranking based on the regression results are highlighted. The section concludes with a simulation that explores the potential collective benefits to the EU of adopting the strategies of the best-performing countries in terms of renewable energy. This part of the article thus provides an in-depth and structured view of the performance of European countries in achieving renewable energy targets. Regarding RQ1, after introducing the variables, Equation 1 can be formalized as Equation 7.

$$y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \beta_3 x_{3it} + \beta_4 x_{4it} + \beta_5 x_{5it} + \beta_6 x_{6it} + \beta_7 x_{7it} + \beta_8 x_{8it} + \beta_9 x_{9it} + u_{it} \quad (7)$$

The model is a good fit for the data, as it explains 94.97% of the variation in the dependent variable. Since the model employs contemporaneous variables without any lagged dependent variables, concern about Nickell bias, typically associated with including lagged dependent variables, was avoided. The coefficients of the predictors were all statistically significant. The individual effects were approximately 94% of the total variance, whereas the idiosyncratic effects were relatively small. The median residual was -0.14. The chi-square statistic was 5421.83, with 9 degrees of freedom, which was considered to indicate statistical significance.

Table 2: Regression output

Variable	Label	Beta	SE	VIF
Intercept		-39***	4.62	
x1	Density of the distribution network	-1.687***	0.496	1.9
x2	Initial RE share of electricity generation	0.663***	0.103	1.2
x3	Fossil share of electricity generation	0.842***	0.021	2.5
x4	Hydropower share of electricity generation	-0.23***	0.042	1.5
x5	Heat pump ambient heat	-0.002***	0.000	1.3
x6	EVs per km of network	-3.213***	0.806	2.4
x7	Population	0.206*	0.088	1.1
x8	Share utilities > 5% of energy generation	0.135***	0.027	1.8
x9	Wholesale price x hare of RE	0.002	0.000	1.8

Source: Own elaboration. *** p < 0.01, ** p < 0.05, and * p< 0.1.

Table 2 presents the unit effects of standardized variables, enabling a comparison of the coefficients' magnitudes to ascertain which predictors exert the most significant impact on bridging the target gap. The dependence on fossil-based resources for generating electricity is confirmed to significantly influence the slowing of a country's path to its energy goals, with a pronounced effect of 0.842***. Besides, x2, with an effect of 0.663***, indicates how increasing the percentage of RE increases the marginal cost of further development. Indeed, countries with earlier integration of RE may face higher marginal costs, given that development paths also depend on past and current status (L. Li et al., 2022). These observations refer specifically to the development of renewable energy (RE) relative to the targets set in the NECPs of European countries, not to the general development of RE. The variable x7, with an effect of 0.206*, reflects the influence of country size. Larger countries such as Germany, Italy, Spain, and France, which have set ambitious targets in their NECPs, tend to have more complex socioeconomic and industrial environments, thus influencing progress. Additionally, x8, which measures market concentration with an effect of 0.135***, suggests that increased competition in the electricity sector may slow decarbonization efforts. For the variables that help close the gap, x6 has a significant effect of -3.214**, indicating the importance of formulating industrial policies to decarbonize the transportation sector and achieve the goals of the NECPs. Provided that a well-developed distribution network helps close the gap, RE can be used more efficiently by implementing smart grid technologies (Hossain et al., 2016). Consistently, x1, which relates to the density of the distribution network, shows a significant influence of -1.687***, confirming the hypothesis. The variable x5, indicative of heat pump technology penetration, with an effect of -0.00264***, further supports these conclusions.

These data underscore the importance of investing in the upgrade and expansion of electrical distribution networks. Unlike the variables for photovoltaic and wind energy, x4, which represents hydropower, has a moderate effect of -0.227***, aligning with expectations. The hydropower potential is more closely related to the specific morphological characteristics of certain countries. Furthermore, x9, which refers to the price signal variable, supports the assumption that wholesale prices incentivize renewable energy producers, although this effect is not statistically significant.

Moving on to RQ2, Figure 2 ranks countries according to the residuals of Equation 7 to understand the relative performance of EU countries in meeting the goals set in the NECPs.

Countries above the reference line, set at 0, are those that, according to the model, outperform. In contrast, countries below the reference line may require additional policies to meet the 2030 target.

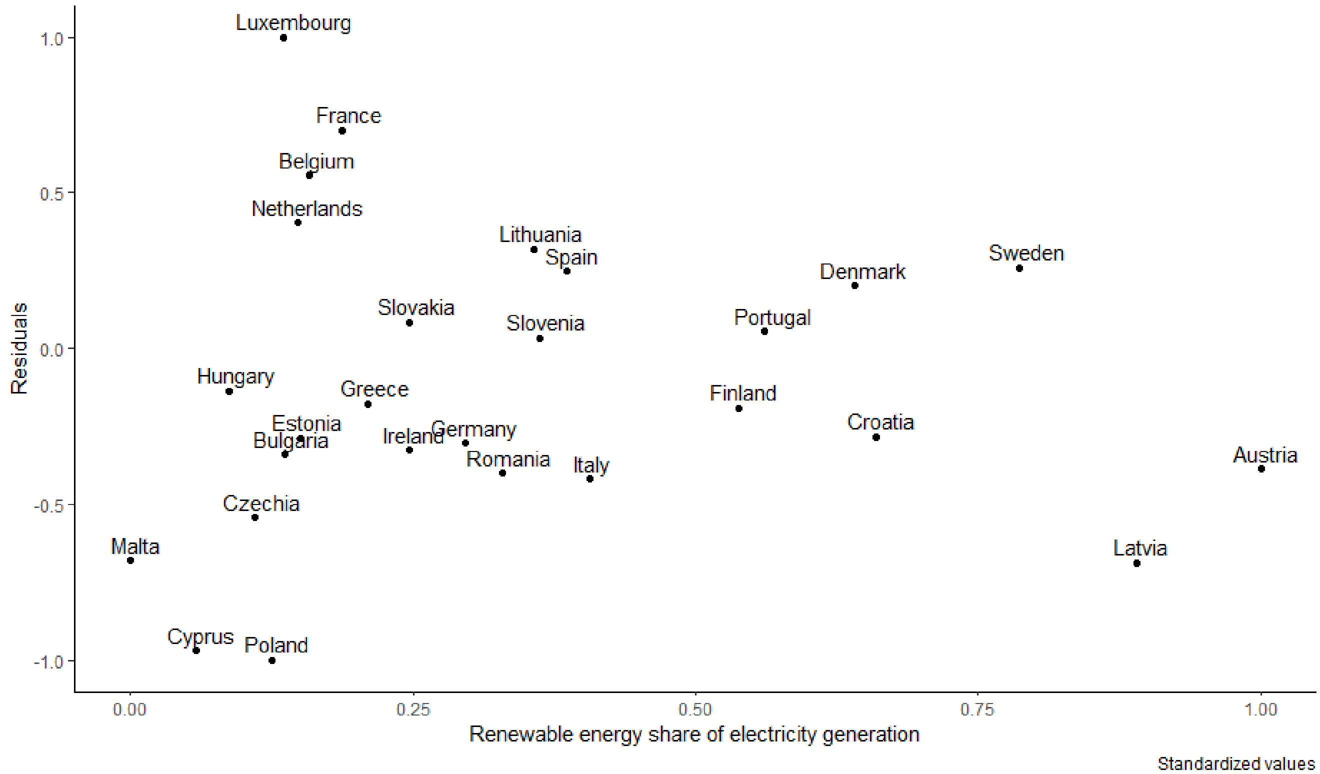

Figure 2: Benchmarking analysis. *The x-axis is normalized to the 0-1 scale, whereas the y-axis is normalized to the -1 to 1 scale. See Annex 1 for additional details*. Share of RE refer to 2012, i.e. the first year of the panel data

The x-axis represents the RE share of electricity generation, while the y-axis illustrates the residuals from the previous regression. These residuals were used to define the positioning of European EU-27 countries where a positive value indicates good performance.

Additionally, by analyzing Figure 2, several observations can be made. For example, smaller countries, such as Cyprus, Malta, Luxembourg, and Latvia, are at the upper and lower edges of the figure. Various intrinsic factors could influence this phenomenon. Additionally, although some of these countries are islands and not interconnected, the methodology of this study was to maintain a holistic view, including all EU-27 countries. Geographical clusters may influence countries' renewable paths. Western countries such as France, Belgium, the Netherlands, and

Luxembourg typically exhibit positive residuals. The analysis period spans from 2012 to 2022, starting when the proportion of renewable energy in electricity generation was initially low. This indicates that despite a slow initial uptake of renewable energy in 2012, the subsequent acceleration in RE adoption across these countries is significant. Some Eastern countries, such as Poland, the Czech Republic, Bulgaria, and Romania, show predominantly negative residuals. Like their Western counterparts, the RE share of electricity generation in 2012 suggests systemic challenges or policy differences that these nations face, hindering their growth in RE adoption. Eventually, the northern bloc of Sweden, Finland, and Denmark presents a different situation. These countries sit in the middle of the graph with residuals close to zero. Notably, their higher initial RE share of electricity generation underscores a legacy of green energy adoption.

The benchmarking analysis is a starting point for the simulation approach presented in the methodological section. The projections are based on Equation 4, and subsequent adjustments assume that all countries adopt the efficiency of the best-performing nations, as in Equation 5. In addition, the average distance to the target for the entire EU-27 and the potential gains in each scenario are estimated. Column 1 of Annex 2 represents the distance to the target in the BaU scenario. Column 2 refines this forecast by assuming that each country emulates the trajectory of the top nine best-performing countries pursuing RE integration. Similarly, according to the assumption that all European countries match the development path of the top six countries, column 3 modifies the original forecast. Column 4 aligns the forecast with the three best-performing countries, which represents the best-case scenario.

Focusing on RQ3, the potential benefit for the EU in terms of distance to the target gains and convergence emerges. Indeed, although marginal, a steady reduction in the standard deviation is observed across the three scenarios. It stands at 16.45 in the Top 9, 16.33 in the Top 6, and 16.37 in the Top 3 scenarios, compared to 16.55 in the BaU hypothesis. Figure 3 shows the average distance to the target projected for 2030 in the scenarios under analysis and offers valuable insights into the NECPs. Indeed, the European commitment appears challenging, given that a 6.456% average increase in the RE share of electricity generation is required over a decade to meet the targets indicated in the NECPs. This necessitates clear strategies and sound policy support. The Top 3 scenario predicts the distance to the target to reduce to 4.801% at the European scale. The Top 6 scenario culminates with a European distance targeting a forecast value of 5.3601%. Finally, the Top 9 scenario leads to an adjusted forecast reaching a 5.688% distance from the target.

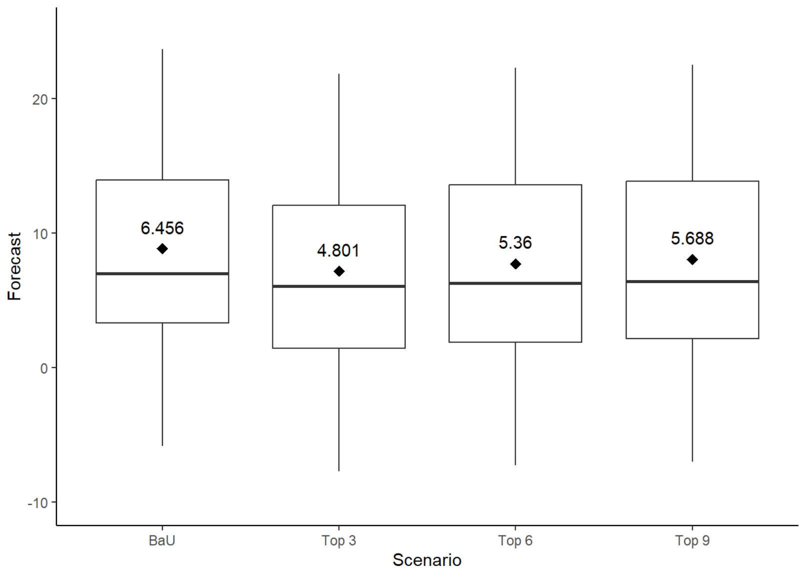

Figure 3: Scenario outcomes

As Figure 3 shows, by adopting the practices of best-performing countries, the EU-27 has the potential to narrow its target gap by 1.65% by 2030, irrespective of additional policy measures.

5. Discussion

Numerous papers have addressed various aspects of RE strategies through 2030, and we contribute novel insights to this topic. This paper shares some similarities with other works focusing on RE pathways to 2030, such as del Río et al. (2017), which assess pathways within a harmonized European policy framework according to different criteria. Another study, focusing on future conditions such as energy market design and integration, assesses the relevance of electricity balancing markets (Ortner and Totschnig, 2019). Additionally, Duscha et al. (2016) evaluate whether and how RE can contribute to addressing climate change, improving the security of supply, and providing socioeconomic benefits. A common feature across these studies is the uncertainty regarding the diversification of power generation technologies (deLlano-Paz et al., 2016). This paper contributes to shedding light on these power generation paths. Specifically, the results contribute to a better understanding of the potential development of the sector, providing evidence of European convergence in environmental targets in combination with the findings of previous works (Di Foggia and Beccarello, 2023). Results reveal several drivers that have not been widely investigated, notably heat pumps, electric vehicles, and prevailing market conditions. The positioning of countries provides valuable information about their commitment to meeting targets.

This research uniquely offers two main features: first, it underscores drivers for meeting the 2030 targets; second, its scenario-building approach centers on country performance, presenting a clearer indication of each nation's commitment level. Therefore, at least three points constitute the added value of this paper. It adopts a mixed-methods research approach, allowing an in-depth examination of the dynamics influencing EU countries' progress toward the 2030 renewable energy targets. This approach does so through a novel approach, as the study uniquely addresses the variation in renewable energy targets set by different EU countries in their NECPs. This focus on different national targets, as opposed to a common EU-wide target, contributes significantly to policymaking for renewable energy development.

By identifying factors and challenges in multiple countries, this study aids in the creation of more effective public policies and investment strategies tailored to individual country needs, facilitating a more coherent approach to achieving the 2030 goals. This approach, centered around simulating potential reductions in the distance to the target should all countries bolster their renewable capacity efforts, is especially relevant for policymakers. We considered official data from NECPs formally approved by the European Commission with a -40% emissions target by 2030 (Zell-Ziegler et al., 2021) as NECPs with a new -55% target entered into force by mid-2024. Results contribute to the development of new plans to achieve the -55% target. Although thorough, this study has several limitations. In this context, each country's targets are shaped by specific circumstances, unlike common targets, such as in the circular economy framework. Furthermore, the scenarios do not consider additional policies, which explains the persistence of the distance to the target even in 2030. In addition, the large sample of all EU-27 countries may dilute the specificity of the results; a smaller sample could provide results tailored to similar country profiles.

There is room for further research. Analyzing the public finance implications of further support for RE could provide essential insights. Studies focusing on the constraints and drivers of capacity development, especially in recent crises, could be informative. In addition, an analysis of the risks, including potential overlaps and the opportunities presented by support policies, would add supplementary insights to the understanding of the evolution of the energy sector.

6. Conclusion

Building on the influence of several factors on the gap between EU-27 countries in achieving the 2030 targets set in the NECPs, this study sought to assess each country's performance to identify those countries needing additional policy support to close this gap. This study demonstrates the potential benefit to the EU of the convergence of European countries toward decarbonization levels among the best-performing countries by developing a simulation to project the benefits at the European level, assuming that all European countries would perform as well as the best-performing countries.

Concerning drivers and barriers to meeting goals, dependence on fossil fuels is a significant obstacle to achieving energy goals. This dependence is directly related to the lower adoption of renewable energy and increasing difficulties in transitioning to cleaner energy sources. Moreover, we have observed that the increase in marginal costs associated with RE development appears to be an inevitable consequence of the need to invest in more advanced technologies and face more complex logistical and infrastructural challenges during the energy transition process. Another relevant aspect is the role of competition in the electricity sector. Among the crucial factors that favor progress toward energy goals, results suggest that increased competition could facilitate decarbonization efforts, the penetration of electric vehicles, the development of distribution networks, and the adoption of heat pump technology. These elements play a crucial role in reducing carbon emissions and promoting the use of renewable energy. However, despite the apparent correlation, the influence of wholesale price on renewable energy production was not found to be statistically significant.

Considering the unique characteristics of each country, the targets set for 2030 vary significantly. In this context, the simulation illustrated in this study provides relevant data and insights that account for these differences. If all the countries followed the path of the best performers, the EU-27 could achieve a 1.655% gap reduction by 2030, with clear societal benefits.

Potential extensions of this research include exploring the fiscal consequences of increased support for the industry, delving into the nuances of capacity building in the context of contemporary crises, and providing an in-depth assessment of the risks and benefits associated with incentive policies.

In bridging the gap between policy aspirations and tangible results, this study highlights the importance of informed policy and innovation. The likelihood of meeting binding targets depends on policy, technology, and commitment synergy. This paper provides valuable information for helping policymakers design policies and utilities when developing investment strategies.

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Annexes

Annex 1. Regression analysis data used in Figure 3

country	start	residuals
Austria	74.71	-0.5645231

country	start	residuals
Belgium	12.91	1.4421733
Bulgaria	11.29	-0.4662484
Croatia	49.67	-0.3440036
Cyprus	5.51	-1.8108766
Czechia	9.31	-0.9007928
Denmark	48.35	0.6868628
Estonia	12.29	-0.3548367
Finland	40.74	-0.1499518
France	15.03	1.7514669
Germany	23.05	-0.3874791
Greece	16.68	-0.1179917
Hungary	7.63	-0.0304232
Ireland	19.35	-0.4409765
Italy	31.10	-0.6350220
Latvia	66.61	-1.2055790
Lithuania	27.45	0.9383564
Luxembourg	11.23	2.3899012
Malta	1.30	-1.1932890
Netherlands	12.10	1.1181012
Poland	10.44	-1.8755613
Portugal	42.50	0.3771299
Romania	25.40	-0.5953833
Slovakia	19.38	0.4379954
Slovenia	27.85	0.3302026
Spain	29.61	0.7877227

country	start	residuals
Sweden	59.06	0.8130258

Annex 2: Simulation output

Country	BaU	Top 9	Top 6	Top 3
Austria	9.41	8.26	8	7.55
Belgium	15.55	15.55	15.55	15.55
Bulgaria	6.95	5.8	5.54	5.09
Croatia	13.93	12.78	12.52	12.07
Cyprus	3.78	2.63	2.37	1.92
Czechia	2.89	1.74	1.48	1.03
Denmark	13.59	13.59	12.18	11.73
Estonia	15.62	14.47	14.21	13.76
Finland	-5.82	-6.97	-7.23	-7.68
France	7	7	7	7
Germany	3.16	2.01	1.75	1.3
Greece	0.51	-0.64	-0.89	-1.35
Hungary	-17.27	-18.42	-18.68	-19.13
Ireland	23.67	22.52	22.26	21.81
Italy	21.56	20.41	20.15	19.7
Latvia	16.09	14.94	14.68	14.23
Lithuania	13.93	13.93	13.93	12.07
Luxembourg	-46.5	-46.5	-46.5	-46.5
Malta	5.99	4.84	4.58	4.13
Netherlands	-25.05	-25.05	-25.05	-26.91
Poland	2.21	1.06	0.8	0.35
Portugal	34.13	32.98	32.72	32.27
Romania	6.99	5.84	5.58	5.13
Slovakia	4.26	4.26	2.85	2.39
Slovenia	12.24	11.09	10.83	10.38
Spain	33.81	33.81	32.4	31.95
Sweden	1.67	1.67	1.67	-0.19