



Renewable energy deployment in Europe: Do politics matter?

Nuno Silva¹ · José Alberto Fuinhas¹ · Matheus Koengkan² ·
Emad Kazemzadeh³ · Volkan Kaymaz⁴

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Abstract

This study analyzes non-hydroelectric renewable capacity across 27 European countries from 2000 to 2020, using advanced econometric techniques like the Dumitrescu and Hurlin panel Granger non-causality method, Panel Autoregressive Distributed Lag and Panel Quantile Autoregressive Distributed Lag estimations. This investigation reveals complex relationships extending beyond immediate variables. These relationships, rooted in pairwise causalities and broader interactions, underpin observed phenomena. Causality tests show that achieving non-hydroelectric renewable capacity is a long-term endeavor, emphasizing persistent policy approaches for effective energy transition. Three key variables emerge as potent policy drivers: maintaining an environment conducive to economic freedom, fostering financial development, and driving non-hydroelectric renewable patents' research and development. These variables play a pivotal role in capacity expansion. Additionally, the findings of this empirical investigation spotlight the role of political orientations. Leftist governments have lagged in prioritizing energy transition, prompting questions about neglecting environmental concerns and necessitating comprehensive policy reform. In essence, this study offers novel insights into non-hydroelectric renewable energy deployment. By unraveling complex relationships, emphasizing persistent policies, and identifying key variables, this investigation provides a nuanced perspective in line with sustainable energy transition urgency. As global ecological imperatives heighten, our work guides informed policy decisions for a greener future.

Keywords Non-hydroelectric renewable installed capacity · Political positions of democratic countries · European countries · Economic freedom · Financial development

1 Introduction

Fossil fuels are still the biggest source of energy today. While the share of fossil fuels in total energy consumption was 83% in 1990, this share decreased by only 13 points in 2021 (Eurostat, 2023a, 2023b). The idea that renewable energy investments will increase energy prices, lobbying activities, the perception that incentives and subsidies will create a burden on the central budget, the fact that governments think that they will not be able to see the

Extended author information available on the last page of the article

results of long-term investments before the election period is an artificial obstacle to green investments. However, with the understanding of climate change, it turns out that renewable energy investments are a necessity in order to reduce carbon emissions and the negative effects of climate change.

Sachs (2015) claims that many countries are able to grow economically, but they cannot overcome environmental problems and create a welfare economy. Renewable energy consumption and investments vary from country to country and even within the country. For instance, the share of renewable energy in total energy consumption stands at 85% in Iceland, yet this proportion drops significantly to 13% in Belgium (Eurostat, 2021). Variances in renewable energy consumption and investment within a country can be attributed to local initiatives, state laws, geographic factors, and resource availability. This divergence becomes evident in Germany, where Saxony-Anhalt prioritizes wind energy investments owing to favorable geographical conditions, while solar energy investments are concentrated in the southern region. Furthermore, countries with expansive geography, like China, India, and Australia, witness the non-uniform distribution of renewable energy investments across their territories. Many political and economic factors, such as the perception of climate change, fossil resources owned by countries, institutional factors, bureaucracy, variable energy prices, research and development activities, and economic integration, play a role in the basis of the differences in investments. The fact that the negative effects generated by climate change are being understood by society and the formation of public opinion on this issue causes politicians to enter a competition on renewable energy. However, there is no clear consensus on the impact of governments' political views and political stability on renewable energy investments.

According to the International Renewable Energy Institute (2023), 75% of renewable energy investments were made by the private sector in the period between 2013 and 2020; however, private sector investments are not independent of the policies followed by governments, political risks, freedom of enterprise, investment costs and financial development. This situation shows that there are economic and political aspects of renewable energy investments and reveals the need to encourage the private sector.

The approach to the regulations for the energy market, the unclear impact of green investments on the workforce, and the uncertainties of the structural transformation cause governments to be cautious about renewable energy investments. However, in countries where governments do not provide investment support and where political risk is high, the costs of renewable energy investments are unpredictable, and the insurance costs of investments increase (Zhang et al., 2022), so the private sector can shift investments to other countries or sectors.

This study delves into the intricate relationship between renewable energy investments, a multifaceted subject, and economic as well as political factors. This research scrutinizes the data spanning 2000–2020 from 27 European countries employing econometric analysis. Its objective is to derive policy recommendations that can effectively amplify private sector investments. As a result, this study serves to advance the realization of a sustainable green economy. What sets this study apart is its incorporation of political and economic variables, distinguishing it from other research efforts.

In Fig. 1 below, the evolution of non-hydroelectric installed capacity is depicted across countries and over time. Notably, the total capacity experienced a remarkable growth of over ten-fold from 2000 to 2020. By 2020, Germany led the pack with the largest non-hydroelectric installed capacity, exceeding an impressive 133 GW. The UK followed with 45 GW, trailed closely by Spain (41 GW), Italy (37 GW), France (31 GW), and the Netherlands (18 GW).

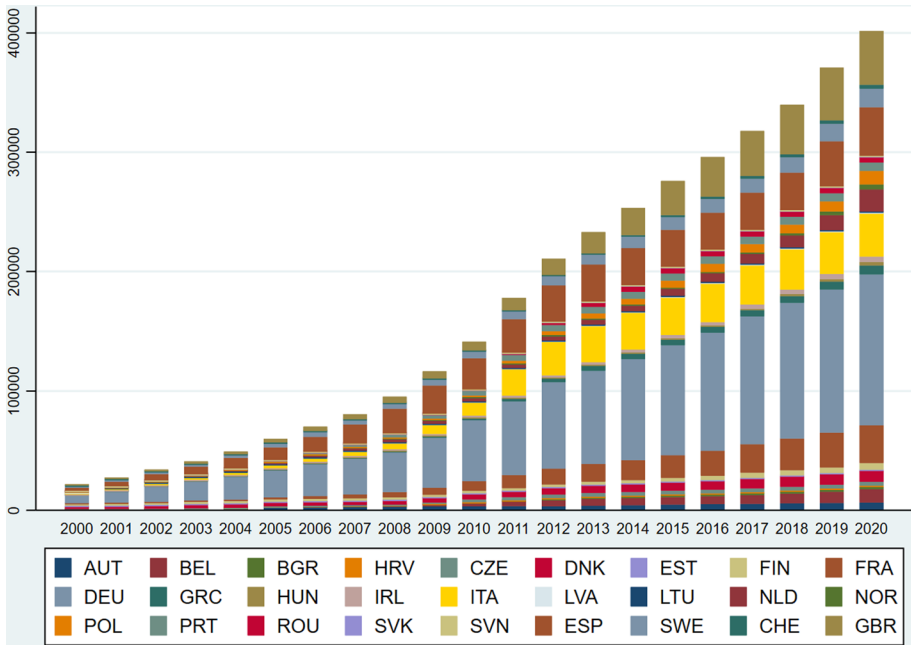


Fig. 1 Non-hydroelectric installed capacity in MW. AUT—Austria; BEL—Belgium; BGR—Bulgaria; HRV—Croatia; CZE—Czech Republic; DNK—Denmark; EST—Estonia; FIN—Finland; FRA—France; DEU—Germany; GRC—Greece; HUN—Hungary; IRL—Ireland; ITA—Italy; LVA—Latvia; LTU—Lithuania; NLD—Netherlands; NOR—Norway; POL—Poland; PRT—Portugal; ROU—Romania; SVK—Slovakia; SVN—Slovenia; ESP—Spain; SWE—Sweden; CHE—Switzerland; GBR—United Kingdom

Figures 2 and 3 below showcase distinctive attributes of the governments within the scope of European countries. On average, Denmark, Estonia, and Bulgaria emerged as having the most substantial proportion of government members affiliated with right-wing parties. Conversely, Sweden and Lithuania exhibited a scenario where over half of the cabinet members hailed from left-wing parties (see Fig. 2 below). Turning to Fig. 3, it becomes evident that the average portion of majority governments, along with their year-to-year transitions, was below the 20% mark in 2000 and 2001. Subsequently, this metric surpassed the 20% threshold and sustained this elevation. Additionally, a subtle trend is discernible, indicating a marginal decline in the prevalence of majority governments in recent years.

This study concentrates on understanding the factors influencing the changes in non-hydroelectric installed capacity across 27 European countries. The analysis incorporates explanatory variables encompassing various facets of the political landscape, including government ideology, parliamentary support, and shifts in governance. Additionally, other pertinent covariates are incorporated to account for relevant factors in explaining the adoption of renewable energy: (i) Non-hydroelectric technology patents, (ii) Gross domestic product; (iii) Financial Development Index, and (iv) Economic Freedom Index. The hypotheses of this research are as follows.

H.1 deploying non-hydroelectric renewable installed capacity involves politics, economics, finance, and technology. If so, this mix of determinants reveals that renewable energy sources deployment is multidimensional and involves complex solutions.

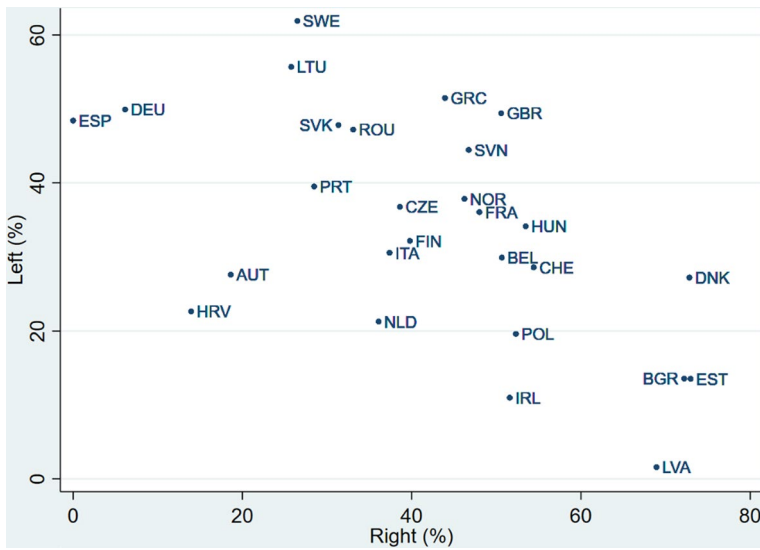


Fig. 2 Average government political leaning by country. AUT—Austria; BEL—Belgium; BGR—Bulgaria; HRV—Croatia; CZE—Czech Republic; DNK—Denmark; EST—Estonia; FIN—Finland; FRA—France; DEU—Germany; GRC—Greece; HUN—Hungary; IRL—Ireland; ITA—Italy; LVA—Latvia; LTU—Lithuania; NLD—Netherlands; NOR—Norway; POL—Poland; PRT—Portugal; ROU—Romania; SVK—Slovakia; SVN—Slovenia; ESP—Spain; SWE—Sweden; CHE—Switzerland; GBR—United Kingdom

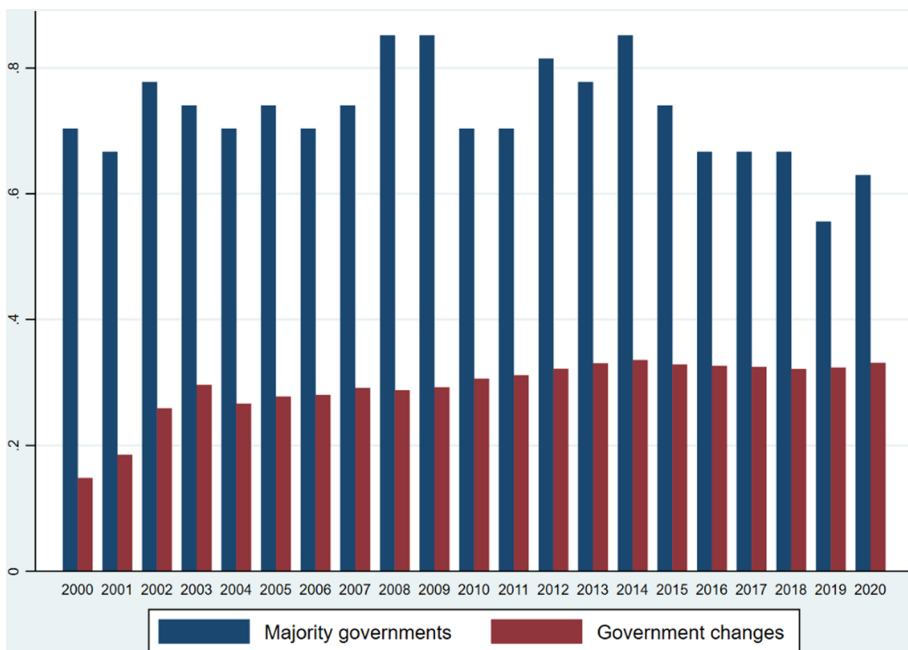


Fig. 3 The average fraction of majority governments (cabinet posts held by majority parties as a percentage of total cabinet posts weighted by the number of days in office in a given year) and the average number of changes in government per year

H.2 based on political discourse, different political spectrums are expected to have different aptitudes in implementing renewable energy. In this case, leftist parties were expected to be more likely to deploy renewable energy. Nevertheless, the energy transition also implies vast investment opportunities, and it can be expected that right-wing parties were favorable to increasing renewable deployment.

H.3 the government's parliamentary support hampers the development of non-hydroelectric renewable installed capacity. If so, environmental concerns are a primary apprehension of society but not one of the political communities.

This study aims to bridge a gap in current research by scrutinizing the interplay between renewable energy investments and the economic and political aspects within European nations. While prior studies have investigated factors impacting the adoption of renewable energy, this research takes a distinctive route by intricately weaving together dimensions like politics, economics, finance, and technology. This fusion yields a more holistic comprehension of the intricate dynamics characterizing the implementation of renewable energy solutions.

The impetus behind this study emanates from the growing consciousness of climate change and the pressing need for a shift toward sustainable energy alternatives. Despite the urgency surrounding the transition from fossil fuels to renewables, there exist challenges and uncertainties that both governmental bodies and private sectors grapple with. This research endeavors to delve into the driving forces, barriers, and repercussions surrounding renewable energy investments, delving into the interwoven nature of economic and political influences.

In the contemporary world, where the repercussions of climate change are increasingly tangible, the topic of renewable energy investments holds great significance. With fossil fuels still dominantly shaping the energy landscape, comprehending the ways in which economic and political factors mold the adoption of renewable energy sources becomes pivotal for policymakers, governments, businesses, and researchers. The findings of this study could furnish insights guiding policy recommendations that effectively foster private sector investments, thereby contributing substantively to the realization of a sustainable green economy.

The study's innovation lies in its holistic methodology, amalgamating political, economic, and technological facets to decipher the dynamics underpinning renewable energy investments. Through the inclusion of a diverse array of variables, the research aspires to unearth intricate correlations and offer guidance for impactful policy measures. This holistic approach ensures a more comprehensive grasp of the challenges and possibilities entailed in the transition toward renewable energy sources across European nations.

In pursuit of a comprehensive investigation, this study will meticulously adhere to a structured sequence of theoretical research steps. These meticulously chosen steps, as visually depicted in Fig. 4 below, have been thoughtfully designed to ensure a consistent and rigorous exploration of the subject matter.

The remainder of this study is structured as follows. Section 2 contains a literature review on renewable energy investments. Section 3 describes the estimation methods and presents the data used in the study. Sections 4 and 5 present and discuss the results obtained. Section 6 concludes.

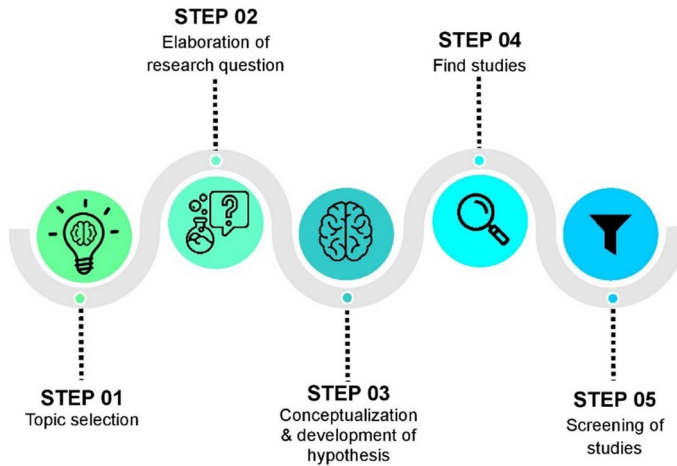


Fig. 4 Theoretical investigation steps. This figure was developed by the authors

2 Literature review

The development of renewable energy is influenced by a complex interaction of various factors. In this research, some of the most important ones, such as politics and policy frameworks (Barnea et al., 2022; Hille & Oelker, 2023; Su et al., 2021), economic growth (Awijen et al., 2022; Khan et al., 2021; Tiwari et al., 2022), green innovations (Hille & Oelker, 2023; Khan et al., 2021; Solarin et al., 2022), financial development (Eren et al., 2019; Ji & Zhang, 2019; Kim & Park, 2016; Samour et al., 2022), and economic freedom (Amoah et al., 2020), are discussed. In the upcoming section, the theoretical channels through which independent variables influence the development of renewable energy will be presented. Additionally, the review will encompass previous studies that have examined the effects of politics on renewable energy development.

The relationship between GDP and renewable energy development is influenced by various factors. According to research, as GDP increases, investment in research and development increases, leading to technological advances in renewable energy (Khan et al., 2021). Furthermore, growth in GDP provides a conducive environment for the development of new renewable energy technologies driven by efficiency improvements and cost reductions, making renewable energy more competitive (Awijen et al., 2022). The combination of these factors has contributed to the growth and adoption of renewable energy as a viable alternative to conventional energy sources (Tiwari et al., 2022).

Through various channels, financial development plays an important role in promoting the development of renewable energy. Firstly, robust financial markets, banking systems, and venture capital enhance access to capital for renewable energy projects, enabling developers to secure financing at competitive rates and attract investment (Eren et al., 2019; Kim & Park, 2016). Secondly, well-developed financial systems facilitate mechanisms for managing risks and ensuring renewable energy projects, such as weather derivatives (allow businesses and individuals to manage the risk associated with fluctuations in weather conditions) and catastrophe bonds (used to transfer the risk of natural disasters or catastrophes from the issuer of the bond to investors) (Eren et al., 2019; Samour et al., 2022). As well, financial development contributes to the advancement of technological innovation and

research in renewable energy through the provision of funding and financial incentives (Ji & Zhang, 2019). Moreover, developed financial systems provide opportunities for investment in renewable energy projects, such as green bonds, venture capital, and crowdfunding platforms (He et al., 2019). Lastly, improvements to financial development promote financial inclusion, enabling individuals and communities in rural areas to gain access to financial services and, as a result, facilitate the development and usage of affordable and clean energy sources (Anton & Nucu, 2020). Empirical research provides a divergent perspective on the impact of financial development on renewable energy consumption and production. While Raza et al. (2020), Sheraz et al. (2022), and Isiksal (2021) highlight a positive correlation, Saadaoui (2022) and Saygin and Iskenderoglu (2022) yield findings indicating no significant influence of financial development on renewable energy.

Technological innovation plays a critical role in advancing and deploying renewable energy technologies. Khan et al. (2021) emphasize that technological innovation leads to more efficient and cost-effective renewable energy solutions. Additional studies further underscore the affirmative effects of technological progress on renewable energy consumption. These effects have been observed in various contexts, such as Bangladesh (Murshed & Alam, 2021), the BRICS nations (Solarin et al., 2022), OECD countries (Su et al., 2021), as well as the G7 countries (Borozan, 2022). Moreover, policy instruments such as grant programs or tax incentives can exert a significant influence on international renewable energy capacity expansion (Hille & Oelker, 2023). Economic and environmental factors also come into play, with economic growth and energy demand driving the adoption of innovative renewable energy technologies (Solarin et al., 2022).

There are several theoretical directions in which economic freedom impacts the development of renewable energy. Firstly, economic freedom enhances market efficiency and resource allocation, allowing for better allocation of resources toward renewable energy projects. Secondly, it promotes entrepreneurship and investment in renewable energy infrastructure, resulting in a higher level of investment in these areas. Thirdly, economic freedom is associated with policies and regulations that encourage the use of renewable energy. Finally, it facilitates the liberalization of the energy market, making it possible to integrate renewable energy sources into the energy mix. Generally, economic freedom contributes positively to the development of renewable energy by promoting market efficiency, attracting investment, supporting innovation, and creating favorable policy environments (Amoah et al., 2020; Betila, 2023; Tu et al., 2022). However, the empirical assessment of the effect of economic freedom on renewable energy remains an unsettled topic, as other research (i.e., Borozan, 2022) reports that economic freedom reduces renewable energy consumption.

Political decisions and policy frameworks play an important role in the development and deployment of renewable energy. There are a number of studies that have examined the impact of politics on the transition to renewable energy sources. According to Christiansen (2002) and Jacobsson and Lauber (2006), case studies of Norwegian and German politics highlight the role of policy in promoting renewable energy development and transforming energy systems. Laird and Stefes (2009) conducted comparative studies to examine the divergent paths taken by German and United States policies for renewable energy, shedding light on the sources of differences and their implications for renewable energy deployment. Chowdhury et al. (2014) emphasize the importance of policy in driving energy system transformation, focusing specifically on the diffusion of photovoltaic technology in Japan and Germany. Kuzemko et al. (2016) and Cruz (2018) explore the governance aspects of sustainable energy system change, focusing on the role of politics, contextual factors, and conflict in the siting of renewable energy projects. Sequeira and Santos (2018) have

conducted systematic reviews to consolidate knowledge about the relationship between renewable energy and politics. Country-specific studies have examined wind energy development in China (Sahu, 2018) and renewable energy policies in Southeast Asia (Mamat et al., 2019). Other studies examine renewable energy politics in India (Behuria, 2020), the USA (Hazboun et al., 2020), and South Africa (Fraser, 2021). Su et al. (2021) and Shahzad et al. (2021) evaluate how fiscal decentralization, political risk, and policy instruments influence renewable energy consumption. Comparative studies by Barnea et al. (2022) highlight the importance of policy instruments in supporting renewable energy development across different countries, while Wang et al. (2009) examine the impacts of institutional quality and political risk on renewable energy consumption in OECD countries, emphasizing the importance of political factors in driving renewable energy adoption. Lastly, Werner and Lazaro (2023) analyze the policy dimension of energy transition in Brazil, focusing on the efforts and outcomes of promoting renewable energy from 2000 to 2022, while Hille and Oelker (2023) highlight the importance of innovation and the choice of policy instruments in driving the expansion of renewable energy capacities internationally.

Another facet of the literature directly addresses the impact of government ideology on renewable energy development. Numerous studies reveal a favorable effect of left-wing governments on renewable energy development (Abban & Hasan, 2021; Arslan & Yildiz, 2022; Bireselioğlu & Karabrahimoglu, 2012; Cadoret & Padovano, 2016). In the case of right-leaning governments, Arslan and Yildiz (2022) conclude that they have no discernible influence on renewable energy, while parties following populist radical right-wing tendencies impede renewable energy deployment (Cetkovic & Hagemann, 2020; Hess & Renner, 2019). Beyond the political leaning of governments, political stability emerges as a pivotal factor in fostering investor confidence and promoting renewable energy. Given that many renewable energy forms necessitate significant initial investments, these investments materialize if investors only have faith in the stability of the regulatory landscape. Grounded in this concept, several researchers have explored the repercussions of political uncertainty on renewable energy deployment, consistently revealing its detrimental impact (Awijen et al., 2022; Awosusi et al., 2023; Wang et al., 2022).

Wang and Chang (2014) conducted an assessment of the support for low-carbon governance in China. Their findings indicated that the existing legislation and industrial standards in China need regular updates to effectively bolster the low-carbon development strategy.

In a separate study, Chang (2015) examined marine renewable energy in the USA, the United Kingdom, and Canada. The results highlighted the essential requirement of establishing a relevant legal governance framework as a foundational prerequisite for creating a viable marine renewable energy program.

A subsequent study conducted by Chang and Wang (2017), focusing on China, emphasized several key recommendations. They proposed that the Chinese government should optimize its administrative management system, reinforce financial regulations, including taxation, and place a strong emphasis on sustainable development. These steps are essential to foster the growth of marine renewable energy.

Wang et al. (2018) investigated the efficiency of carbon reduction technologies using a cross-border DEA approach. Their research indicated that biomass, nuclear, and conventional power plants equipped with CCS (Carbon Capture and Storage) demonstrate the highest efficiency in reducing carbon emissions within the power plant sector. Conversely, wind power, hydropower, and solar power exhibit lower efficiency in this regard.

Chang et al. (2020) delved into the China-Japan-Korea Free Trade Agreement and the legal complexities surrounding the construction of the Northeast Asia Energy Network. Their analysis suggested that while the China-Japan-Korea Free Trade Area and the

Northeast Asian Energy Interconnection hold significant potential for further development, they also face common obstacles that need addressing.

Khan et al. (2020) pointed out that Pakistan is grappling with an energy crisis attributable to its reliance on costly fossil fuels and insufficient electricity infrastructure. They asserted that to ensure both security and sustainable economic growth, Pakistan must transition from fossil fuels to extensive renewable energy sources.

Lastly, a study conducted by Chang et al. (2021) examined the development of marine renewable energy in the USA. Their findings underscored the comprehensive legal system in place for marine renewable energy development. However, they also stressed the importance of reinforcing the organizational structure to enhance competitiveness and achieve the desired objectives.

The existing literature provides valuable insights into the influences of various factors on renewable energy development, including policy, economic growth, green innovations, financial development, and economic freedom. However, certain research gaps remain to be explored. Firstly, despite the importance of technological innovation in driving renewable energy development, further research is required to examine the specific mechanisms that influence renewable energy growth. Secondly, there are very few studies that have examined the role economic freedom plays in the development of renewable energy. Therefore, more research in this field is necessary to contribute to the existing literature and provide a deeper understanding of the relationship between economic freedom and the development of renewable energy resources. Thirdly, while previous studies have utilized various econometric models, the use of the Quantile Autoregressive Distributed Lag (QARDL) method has been largely overlooked. By utilizing this method, it becomes possible to analyze both short-term and long-term effects of variables on renewable energy development on a decile-by-decile basis.

2.1 State of the art

The exponential expansion of new renewable energy sources, notably wind and solar technologies, has garnered global research interest. This surge is propelled by the consistent cost reductions of these technologies and the imperative to facilitate the transition toward sustainable energy systems. Researchers worldwide have delved into a myriad of factors influencing the growth of renewable energy, encompassing economic, institutional, political, technological, and sociological dimensions. Within the realm of political dynamics, previous studies have concentrated on governmental ideology, stability, and form. However, to the best of our knowledge, no study has undertaken a comprehensive analysis that concurrently examines the impacts of government orientation, support mechanisms, and tenure on renewable energy development. This study makes contributions to the literature on multiple levels. First, the effects of governments' political orientations on renewable energy deployment are assessed while simultaneously controlling for government support and stability. Second, a measure of renewable energy deployment is adopted, specifically the per capita installed capacity of non-hydro renewable energy sources. This selection eliminates the introduction of estimation noise resulting from climate conditions, as often observed when using renewable energy production or consumption as metrics. Moreover, the exclusion of hydroelectric energy, primarily installed prior to our sample period, provides a more accurate representation of the explanatory variables' impact on renewable energy development.

Third, the focus on European countries is justified by their prominence in the energy transition movement. Fourth, the panel quantile autoregressive distributed lag model is employed to distinguish between two critical aspects: (i) the short and long-term effects of

the covariates on renewable energy capacity and (ii) the varying impacts of the explanatory variables on the conditional distribution of renewable energy capacity.

Finally, a comprehensive array of control variables is incorporated into the analysis, including those for which the effects on renewable energy development remain subjects of debate. Thus, this study contributes to shedding light on the influence of variables such as financial development and economic freedom on the progress of renewable energy development.

3 Data and methods

In the initial segment of this section, the data employed in this research are introduced, along with their respective sources and accompanying descriptive statistics. In the subsequent segment, the estimation methods and preliminary tests are delineated. These preliminary tests serve the purpose of evaluating the suitability and appropriateness of the chosen estimation methods. After introducing the theoretical investigative procedures, the next phase involves presenting the empirical investigation steps that will be meticulously followed. The sequential progression of empirical research, as delineated in Fig. 5 below, is poised to demonstrate the practical implementation of the study's theoretical underpinnings. These steps have been carefully structured to translate theoretical concepts into tangible actions, enabling the study to gather real-world data and observations.

Figure 5 graphically outlines these empirical investigation stages, providing a visual representation of the systematic approach the study will undertake. By following this methodical framework, the study aims to bridge the gap between theory and real-world application, fostering a holistic comprehension of the subject matter. Each empirical step will be executed with precision, anchoring itself in the prior stage to foster a coherent and progressive flow of investigation.

Through this meticulous approach, the study seeks to derive actionable insights and substantive conclusions that contribute to both academic scholarship and practical understanding. By meticulously adhering to the presented empirical investigation steps, the study endeavors to validate its theoretical assumptions and shed light on intricate nuances that might emerge in the real-world context. This methodological transparency not only bolsters the study's credibility but also equips other researchers with a clear roadmap to replicate and extend this empirical investigation in the future.

3.1 Data

The primary objective of this study is to evaluate the political factors influencing the deployment of new renewable energy sources in Europe. This objective was achieved using annual data on non-hydroelectric installed capacity per million inhabitants (Non_Hydro) collected for 27¹ European countries, including Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom (as depicted in Fig. 6 below). The data span from the year 2000 to 2020.

There are multiple reasons for the choice: (i) excluding hydroelectric capacity because most of it was installed long before the start of the dataset, (ii) focusing on renewable

¹ The selection of countries and the time period was based on data availability.

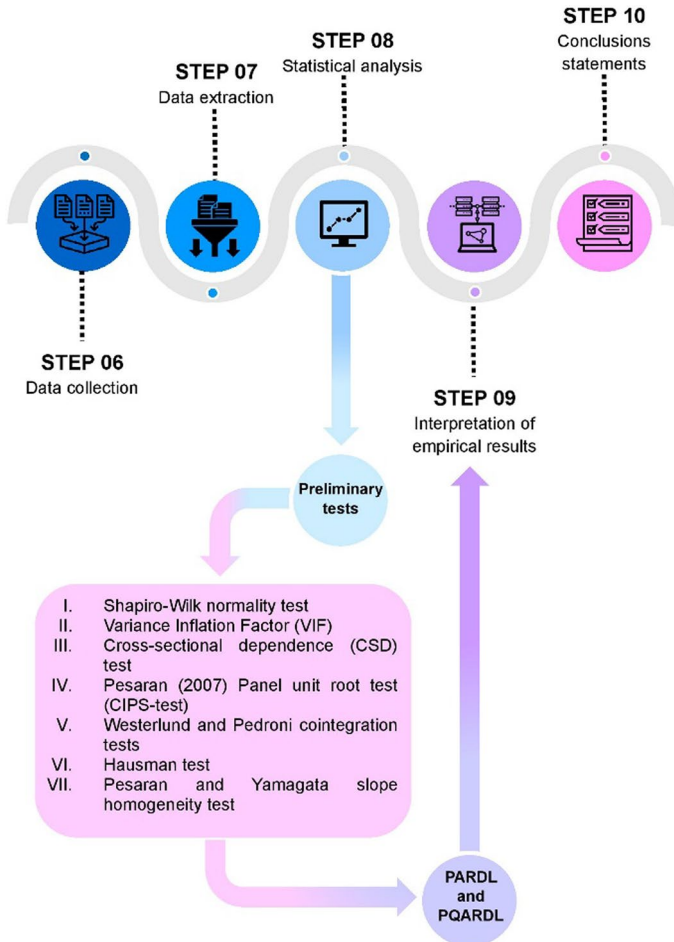


Fig. 5 Empirical investigation steps. This figure was developed by the authors

energy capacity rather than production because the latter is sensitive to idiosyncratic weather conditions, and (iii) normalizing the capacity by dividing it by population to avoid bias due to the different sizes of countries.

This investigation considers several types of determinants of renewable energy development, covering politics, economics, finance, and technology. The political variables were retrieved from the Comparative Political Data Set (Armingeon et al., 2023a, 2023b). This comprehensive database includes information on the political leanings of governments, government parliamentary support, and government instability. The authors measure governments’ political tendencies through the fraction of cabinet seats held by right-wing (GovR) and left-wing (GovL) parties.² Parties underwent classification into three categories:

² In the Comparative Political Data Set, the sum of the fraction of seats held by right-wing, left-wing, and center parties adds to 100%. The latter variable is, therefore, redundant.



Fig. 6 European Union countries were selected for this empirical investigation. This figure was created by the authors using MapChart (2023)

right-wing, left-wing, and center, following Schmidt's criteria (1996). For parties not categorized within this framework, Armigeon et al. (2023) employed the subsequent criteria: (i) left-wing encompassed social democrats and parties positioned to the left of social democrats; (ii) right-wing encapsulated liberal and conservative parties; (iii) the center category encompassed parties advocating for "moderate social amelioration in a location to the left of conservative or conservative-neoliberal parties," including entities such as Christian Democratic or Catholic parties. Regarding government parliamentary support, a dummy variable is created that assumes the value of one when government parties hold more than half of the seats in the parliament (GovSup). Finally, government instability is measured by the average number of government changes per year (GovCh).

In addition to policy variables, other control variables are also used that may affect renewable energy deployment. First, Gross Domestic Product (GDP) per capita represents the economic development of countries, which is an essential determinant of their ability to invest in new renewable energy installations. Second, economic freedom (Freedom) may foster entrepreneurship and renewable energy. Third, a sound financial system is essential for promoting projects in this sector, as they require large upfront investments (Silva et al., 2021). Therefore, among the determinants, the Financial Development Index (FDI) is included, which is a comprehensive indicator of financial

Table 1 Data description

Variables	Description
NonHydro	Non-hydroelectric renewable installed capacity (IRENA, 2023) per million inhabitants (WBD, 2023) in megawatts. Non-hydroelectric renewable installed capacity is the sum of marine, wind, solar, geothermal and bioenergy installed capacity
GovR	Cabinet posts held by right-wing parties as a percentage of total cabinet posts weighted by the number of days in office in a given year (Armingeon et al., 2022a; Armingeon et al., 2022b)
GovL	Cabinet posts held by left-wing parties as a percentage of total cabinet posts weighted by the number of days in office in a given year (Armingeon et al., 2022a; Armingeon et al., 2022b)
GovCh	Average number of changes in government per year (Armingeon et al., 2022a; Armingeon et al., 2022b)
Patents	Non-hydroelectric renewable patents (OWD, 2023) per million inhabitants (WBD, 2023). Non-hydroelectric renewable patents are the sum of marine, wind, solar, geothermal, and bioenergy patents. We express this variable in cumulative form
GDP	Gross domestic product per capita in 2015 constant USD (WBD, 2023)
FDI	Financial Development Index (IMF, 2023). This index is a relative ranking on the access, efficiency, and depth of their financial markets and institutions
Freedom	Index of Economic Freedom (Heritage Foundation, 2023). This index is based on twelve qualitative and quantitative factors grouped into four categories: the size of government, open markets, regulatory efficiency, and rule of law
GovSup	Dummy variable that equals one when the government has majority support in the parliament (Armingeon et al., 2022a; Armingeon et al., 2022b)

Table 2 Descriptive statistics

Variables	Obs	Mean	Std.-Dev	Min	Max
lNonHydro	567	4.7221	1.6919	0	7.3804
lGovR	567	2.8912	1.7660	0	4.6151
lGovL	567	2.4756	1.8709	0	4.6151
lGovCh	567	0.2445	0.1574	0	0.6931
lPatents	567	4.1195	1.7757	0.0931	8.6078
lGDP	567	10.1036	0.7165	8.2209	11.3751
lFDI	567	3.9561	0.4640	2.3382	4.6052
lFreedom	567	4.2224	0.1034	3.8565	4.4140
GovSup	567	0.7266	0.4461	0	1

“l” preceding the name of the variable indicates that it is logarithmized. Obs. denotes the number of observations; Std.-Dev. denotes the Standard Deviation; Min. and Max. denote Minimum and Maximum, respectively

access, depth, and efficiency. Finally, the technological development of countries is evaluated through the cumulative per capita patents on non-hydro renewable energy (Patents). Table 1 below presents a brief description of all variables and their sources.

Table 2 below shows the descriptive statistics. The natural logarithm was applied to all variables except for the GovSup dummy variable. However, prior to executing this transformation, a constant value of one was added to the variables NonHydro, GovR, GovL,

GovCh, and Patents. This adjustment was necessary due to the presence of zero values in these variables, which would otherwise result in divergent negative infinity logarithmic values. This transformation has several advantages as it reduces the number of outliers, and the estimated coefficients can be interpreted as elasticities. The average for the log of non-hydroelectric installed capacity amounts to 4.7221, and its standard deviation is approximately one-third of the mean value. Regarding government tendencies, there is a slight dominance of right-wing parties. The average of the $\log(\text{GovCh})$ implies an average government duration of over three years. Patents, with a mean log of 4.1195, show a wide range across countries. On the contrary, there is a small dispersion for gross domestic product, reflecting the homogeneity of countries. The Financial Development Index and the Economic Freedom Index have similar averages, but the former is more volatile than the latter. Finally, the average of GovSup indicates that almost three-quarters of governments benefited from a parliamentary majority.

3.2 Methods

The section begins with the presentation of a battery of preliminary tests designed to assess the properties of the data and choose the appropriate estimation method. Then, the Dumitrescu and Hurlin (2012) panel Granger non-causality methods are described. Finally, the model and main estimation methods are presented: Panel Autoregressive Distributed Lag (PARDL) and Panel Quantile Autoregressive Distributed Lag (PQARDL).

3.2.1 Preliminary tests

Before estimating the models, several tests need to be conducted to evaluate the data's properties and determine the most appropriate estimator:

- (i) Shapiro–Wilk normality test (Royston, 1983). The null hypothesis is that the data distribution is normal. Non-normal data support our decision to use quantile regression.
- (ii) The Variance Inflation Factor (VIF) checks whether the regressors are multicollinear. This can lead to unreliable estimates.
- (iii) Cross-sectional dependence (CSD) test (Pesaran, 2021). This test examines the cross-sectional dependence between the variables in the panel of countries. Its null hypothesis is cross-sectional independence.
- (iv) Pesaran (2007) Panel unit root test. The null hypothesis of this test is that the variables are non-stationary, while the alternative is that they are stationary.
- (v) Westerlund (2005) and Pedroni (1999) cointegration tests. When dealing with non-stationary variables, it is crucial to check for cointegration to avoid the well-known spurious regression problem. The null hypothesis of both tests states there is no cointegration, while the alternative assumes cointegration in some (Westerlund) or all panels (Pedroni).
- (vi) Hausman test (Hausman, 1978). This test relies on comparing the fixed and random effects estimates. Both estimators are consistent under the null hypothesis, and the random effects estimator is preferable because it is efficient.
- (vii) Pesaran and Yamagata (2008) slope homogeneity test. This test checks whether slopes in a panel regression are homogeneous. The null hypothesis assumes they

are. A violation of this hypothesis leads to biased estimates when using traditional fixed or random effects estimators.

3.2.2 Dumitrescu and Hurlin panel Granger non-causality test

The classic version of the Granger causality test aims to find linear dependencies between variables in a time series framework. Its direct application to panel data may lead to erroneous conclusions, as it implicitly assumes parameter homogeneity throughout the panel. Whenever parameters are non-homogeneous, the estimated coefficients are biased, which may lead to a misleading acceptance of the null hypothesis of Granger non-causality. To overcome this problem, Dumitrescu and Hurlin (2012) developed an alternative testing procedure, which is robust to heterogeneity and assesses whether a variable Granger causes another anywhere in the panel. This test rests on the cross section average of the Wald statistics for standard Granger causality tests.

It is necessary to estimate the following equation for each country to conduct this test:

$$y_{i,t} = \alpha_i(\tau) + \sum_{p=1}^P \gamma_i^p y_{i,t-p} + \sum_{p=1}^P \beta_i^p x_{i,t-p} + v_{i,t}, \quad (1)$$

P is the number of lags, and $v_{i,t}$ is the error term for year t and country y . Subsequently, the individual Wald statistics are computed to test the null hypothesis that the variable y_i is not Granger caused by x_i , $\beta_i^{(p)} = 0$, for $p = 1, \dots, P$. Dumitrescu and Hurlin (2012) propose various test versions for the null hypotheses that Granger causality is absent against the alternative that it exists for at least one country. Among those, this investigation selects \tilde{Z}_N^{Hnc} because it shows the lowest size distortion in small samples. The value of this statistic is:

$$\tilde{Z}_N^{\text{Hnc}} = \sqrt{\frac{N}{2 \times P} \times \frac{(T - 2P - 5)}{(T - P - 2)}} \times \left[\frac{(T - 2P - 3)}{(T - 2P - 1)} W_{N,T}^{\text{Hnc}} - P \right], \quad (2)$$

where T is the number of years, N represents the number of countries, and $W_{N,T}^{\text{Hnc}}$ is the mean of the individual Wald tests across countries. Dumitrescu and Hurlin (2012) prove that $\tilde{Z}_N^{\text{Hnc}} \xrightarrow{d} N(0, 1)$ as the number of countries goes to infinity.

3.2.3 PARDL and PQARDL

Panel Autoregressive Distributed Lag (PARDL) models are dynamic model specifications that can assess lags in the response of the dependent variable to changes in the covariates by including their lagged values. It also allows the researcher to disentangle the short-run response to a change in an independent variable from the long-run response. Furthermore, it is compatible with the simultaneous use of integrated order one and stationary variables and is immune to endogeneity.

In this research, a modified PARDL(1,1) model is considered, incorporating a dummy variable that signifies whether the government enjoys parliamentary majority support. The model can be expressed as follows:

$$D\text{INonHydro}_{i,t} = \alpha_i + \gamma \text{INonHydro}_{i,t-1} + \sum_{j=1}^7 \beta_j DIX_{i,t-1}^j + \sum_{j=1}^7 \theta_j IX_{i,t-1}^j + \delta \text{GovSup}_{i,t} + \varepsilon_{i,t}, \quad (3)$$

where $X_{i,t}^j$ represents the value of the covariate j for year t and country i , $X = \{\text{GovR}, \text{GovL}, \text{GovCh}, \text{Patents}, \text{GDP}, \text{FDI}, \text{Freedom}\}$, GovSup is a dummy variable that assumes the value one when the government benefits from a parliamentary majority, “ I ”, and D are the logarithm and first difference operators, respectively, and $\varepsilon_{i,t}$ is the error term for year t and country j . In this model, β_j is the short-run effect of the explanatory variable j on non-hydroelectric installed capacity, while the long-run elasticity for this variable can be calculated as $-\theta_j/\gamma$.

As stressed before, the PARDL model offers many advantages for the researcher. However, it also has some flaws, as it implicitly assumes the data distribution is normal and focuses only on the effects of the covariates on the conditional mean of the dependent variable. The Quantile Autoregressive Distributed Lag (Cho et al., 2015) model surmounts these limitations, as it allows the researcher to focus on other regions of the dependent variable conditional distribution besides the mean and is largely insensitive to the distribution of the data and outliers. The PQARDL(1,1) model for non-hydroelectric installed capacity can be represented as follows:

$$\begin{aligned} D\text{INonHydro}_{i,t} = & \alpha_i(\tau) + \gamma(\tau) \text{INonHydro}_{i,t-1} + \sum_{j=1}^7 \beta_j(\tau) DIX_{i,t}^j + \sum_{j=1}^7 \theta_j(\tau) IX_{i,t-1}^j \\ & + \delta(\tau) \text{GovSup}_{i,t} + U_{i,t}, \end{aligned} \quad (4)$$

where $U_{i,t} = \text{INonHydro}_{i,t} - Q_{\text{NonHydro}}(\tau \vee I_{t-1})$, and $Q_{\text{NonHydro}}(\tau \vee I_{t-1})$ represents the τ -quantile of the conditional distribution of INonHydro given the information available at year $t-1$ (I_{t-1}). Note that this model permits different effects of the explanatory variables on NonHydro for different quantiles of its conditional distribution. Equation 4 is estimated using quantile regression following the removal of country-fixed effects, using the procedure introduced by Canay (2011).

Additionally, the robustness of both PARDL and PQARDL estimations to outliers is assessed through the incorporation of dummy variables.

4 Results

The section begins by presenting the outcomes of the preliminary tests. Subsequently, the causality among the variables is examined through the Dumitrescu and Hurlin (2012) Granger non-causality test. Finally, the PARDL and PQARDL estimates are showcased.

In Table 3, it can be observed that the null hypothesis, indicating the normality of data distribution, is strongly rejected for all variables, with the exception of the dummy variable GovSup , denoting the parliamentary majority. This finding justifies the utilization of quantile methods, which remain relatively unaffected by data distribution.

Table 4 demonstrates that all variance inflation factors (VIF) comfortably remain below the commonly accepted threshold of ten, and the mean VIF stands significantly below six. Consequently, concerns regarding multicollinearity are unwarranted.

Table 3 Shapiro–Wilk test for normality

Variables	Obs	W	V	Z	Prob > z
INonHydro	567	0.936	24.030	7.686	0.0000
IGovR	567	0.812	70.899	10.301	0.0000
IGovL	567	0.877	46.26	9.269	0.0000
IGovCh	567	0.981	7.321	4.812	0.0000
IPatents	567	0.984	5.942	4.308	0.0000
IGDP	567	0.961	14.596	6.480	0.0000
IFDI	567	0.908	34.570	8.565	0.0000
IFreedom	567	0.978	8.348	5.130	0.0000
GovSup	567	0.996	1.465	0.923	0.1779

According to the Shapiro–Wilk test null hypothesis, the data is normally distributed. All variables are logarithmized except for GovSup. Obs. denotes the number of observations. W, V, and Z represent the test values for the Shapiro–Wilk W, V, and Z test versions, respectively. The last column presents the p value corresponding to the null hypothesis of normally distributed data for the Z version of the Shapiro–Wilk test

Table 4 Variance inflation factor (VIF)

Variables	VIF	Mean VIF
IGovR	1.49	2.00
IGovL	1.41	
IGovCh	1.18	
IPatents	1.53	
IGDP	4.21	
IFDI	3.21	
IFreedom	1.88	
GovSup	1.10	

All variables are logarithmized except for GovSup. The second column presents the variance inflation factors for all variables. The last column displays the mean variance inflation factor

The results of the Pesaran CD test, as presented in Table 5, indicate the presence of cross-sectional dependence in all variables except for IGovR. Given this scenario, the standard errors of fixed effects estimators are subject to bias. To counteract this issue, Driscoll and Kraay's (1998) standard errors are employed.

Table 6 below displays the panel unit test results for the variables in logarithms and their first differences. All variables are stationary in logarithms except for IGovR, IGovL, and IGDP. Considering the specification with a trend, the dependent variable is non-stationary, while the stationarity assessment for the remaining variables remains unchanged. The right part of the table below reveals that all the variables are stationary in the first differences.

The presence of non-stationary variables in a regression framework requires testing for cointegration to avoid the spurious regression problem. Table 7 below demonstrates that the null hypothesis of no cointegration is rejected at the 1% level for both the West-erlund and Pedroni tests, suggesting a long-term relationship between the variables under consideration.

Table 5 Pesaran CD test

Variables	CD test	<i>p</i> value	Corr	Abs (corr)
INonHydro	81.047	0.000	0.92	0.92
IGovR	-1.356	0.175	-0.02	0.26
IGovL	1.847	0.065	0.02	0.29
IGovCh	14.143	0.000	0.16	0.47
IPatents	85.917	0.000	0.98	0.98
IGDP	61.882	0.000	0.70	0.80
IFDI	31.460	0.000	0.37	0.45
IFreedom	29.714	0.000	0.34	0.45
GovSup	2.378	0.017	0.03	0.13

According to the null hypothesis of the Pesaran CD test, the variables cross-sectionally independent. All variables are logarithmized except for GovSup. The second column shows the values of the Pesaran cross section dependence test. The third column presents the *p* values for the null hypothesis of this test. Columns 4 and 5 show the correlation coefficients and their absolute values, respectively

Table 6 Panel unit root test (CIPS)

CIPS			CIPS		
Variables	(Zt-bar)		Variables	(Zt-bar)	
	No trend	Trend		No trend	Trend
INonHydro	-2.385***	-0.363	D_INonHydro	-8.699***	-7.503***
IGovR	-0.387	1.875	D_IGovR	-8.416***	-6.135***
IGovL	0.308	1.134	D_IGovL	-9.976***	-6.945***
IGovCh	-5.051***	-3.379***	D_IGovCh	-12.224***	-10.145***
IPatents	-11.759***	-9.993***	D_IPatents	-14.182***	-12.010***
IGDP	-0.339	2.226	D_IGDP	-5.144***	-2.528***
IFDI	-3.819***	-5.167***	D_IFDI	-15.746***	-13.600***
IFreedom	-3.538***	-1.785**	D_IFreedom	-12.998***	-10.592***

“I” denotes variables in the natural logarithms, and “D” indicates the first difference. Columns 2 and 3 show the values of the Pesaran (2007) panel unit root tests without and with a time trend, respectively. Columns 4 and 5 show the values of the Pesaran (2007) panel unit root tests, for the variables in first differences, without and with a time trend, respectively. *** and ** denote statistical significance at 1% and 5% levels, respectively. H_0 : series is I(1)

Table 7 Westerlund and Pedroni cointegration tests

Test	Statistic	<i>p</i> value
Westerlund variance ratio	2.4659	0.0068
Pedroni modified Philips-Perron <i>t</i>	7.1090	0.0000

The null hypothesis for both the Westerlund and Pedroni cointegration test is no cointegration. The alternative hypotheses state there is cointegration in some or all the panels for the Westerlund and Pedroni tests, respectively. The second column presents the test values, while the last column shows the corresponding *p* values

Table 8 Hausman test

Test	Statistic	<i>p</i> value
Chi-squared(16)	76.82	0.0000

The null hypothesis of the Hausman test is that the random effects estimator is consistent. The second column shows the test value and the last one the associated *p* value

Table 9 Pesaran and Yamagata slope homogeneity test

Test version	Statistic	<i>p</i> value
Pesaran and Yamagata (2008)	-0.595	0.552
Blomquist and Westerlund (2013)	1.697	0.090

According to the null hypothesis, the slopes are homogeneous. The second column presents the tests values, and the last one shows the associated *p* values

Table 10 Dumitrescu and Hurlin panel Granger non-causality test

Variables	INonHydro	
	Is caused by	Causes
IGovR	2.255**	-0.094
IGovL	2.725***	3.249***
IGovCh	4.984***	17.799***
IPatents	11.250***	23.592***
IGDP	2.995***	6.8263***
IFDI	6.567***	3.948***
IFreedom	8.761***	5.894***

The null hypothesis for the Dumitrescu and Hurlin test is the absence of a causal relationship in any panel. ‘I’ denotes variables in the natural logarithms. The second column presents the test values for the null hypothesis that the explanatory variables do not Granger-cause INonHydro. The third column shows the test values for the null hypothesis of no Granger causality in the opposite direction. *** and ** denote statistical significance at 1%, and 5% levels, respectively

The Hausman test result (see Table 8 below) strongly rejects the null hypothesis that the random effect estimator is consistent. Therefore, the fixed effects estimator is utilized.

Panel heterogeneity is a common concern among researchers, as it can lead to inconsistent fixed effects estimates. Table 9 below reveals that slope homogeneity is not rejected at the 5% level for either the standard version of the Pesaran and Yamagata (2008) delta test or the Blomquist and Westerlund (2008) heteroskedasticity and autocorrelation-consistent version.

The results of the Granger non-causality test of Dumitrescu and Hurlin (2012) (see Table 10 below) show bidirectional causality between the dependent variable and almost all the covariates. The only exception is IGovR, which causes INonHydro but is not caused by it.

Table 11 below presents the estimation results for the non-hydroelectric renewable installed capacity regression without dummies to control for outliers.

Table 11 Estimation results without dummies

Dependent variable (D_INonHydro)						
Independent variables	Mean	Quantiles				
		10th	25th	50th	75th	90th
Constant	-5.5300***	-5.2403***	-5.2117***	-4.3434***	-4.3530***	-3.1333***
D_IGovR	0.0107	-0.0018	0.0071	0.0083*	0.0106	0.0019
D_IGovL	-0.0152	-0.0090**	-0.0079*	-0.0065	-0.0132*	-0.0166
D_IGovCh	0.2968***	0.2595*	0.2823**	0.0589	0.0498	-0.1327
D_IPatents	0.1058	0.1736***	0.1513**	0.1218**	0.1598	0.1205
D_IGDP	-0.3194*	0.2839*	0.1472	-0.1212	-0.2583	-0.1210
D_IFDI	0.1617	0.1560	0.1196	0.2388*	-0.0628	-0.0682
D_IFreedom	0.7836	0.8296***	0.7086**	0.7708**	0.2193	0.2085
L_INonHydro	-0.1661***	-0.0982***	-0.1217***	-0.1473***	-0.1756***	-0.2333***
L_IGovR	0.0233**	0.0061**	0.0088***	0.0228***	0.0296***	0.0331***
L_IGovL	0.0010	0.0040	-0.0060	0.0024	0.0007	0.0028
L_IGovCh	-0.0629	-0.1117	-0.1025**	-0.1528***	-0.2533***	0.1725
L_IPatents	0.1259***	0.1103***	0.1106***	0.1233***	0.1231***	0.1191***
L_IGDP	-0.0078	0.0025	0.0272	0.0129	0.0140	0.0735
L_IFDI	0.5863***	0.5773***	0.5489***	0.5439***	0.5392***	0.4272***
L_IFreedom	0.8883**	0.6868***	0.6969***	0.5555***	0.6263***	0.4081*
GovSup	-0.0461	-0.0271**	-0.0340***	-0.0219*	-0.0450**	-0.1079***

This table presents the estimated coefficients and significance levels for the PARDL and PQARDL models without dummies. “Mean” corresponds to the mean estimates (PARDL), and “10th”, “25th”, “50th”, “75th”, and “90th” are the PQARDL estimates for the 10%, 25%, 50%, 75%, and 90% quantiles of the non-hydroelectric installed capacity conditional distribution. “l” denotes variables in the natural logarithms, and “D” indicates the first difference. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively

The mean regression (PARDL) demonstrates that the first difference of IGDP hinders the growth of INonHydro, while government changes foster it. Regarding the lagged variables, right-wing government members of the executive, patents, financial development, and economic freedom enhance non-hydroelectric renewable installed capacity.

The signs of the PQARDL estimates for the variables in the first differences are broadly coherent with those of the PARDL. An exception is D_IGDP, which significantly impacts D_INonHydro in the lowest quantile. The political tendency reveals a positive influence of right-wing parties in the middle quantile and a negative one on left-wing parties in the 10%, 25%, and 75% quantiles. Furthermore, changes in patents and economic freedom exert a positive influence on the lowest quantile, while the effect of changes in financial development is only sensible in the middle quantile. Regarding lagged variables, the positive influence of right-wing parties strengthens as one moves to higher quantiles. The opposite pattern is observable for economic freedom, while the positive effects of patents and financial development are largely insensitive to the quantile. Finally, for the PQARDL estimates, the government’s parliamentary support negatively impacts the development of non-hydroelectric renewable installed capacity.

The description of the short-run impacts and long-run elasticities (Table 12) was based on the PARDL estimates indicate that the short-run effects of government changes

Table 12 Short-run impacts and long-run elasticities without dummies

Dependent variable (D_INonHydro)						
Independent variables	Quantiles					
	Mean	10th	25th	50 th	75th	90th
<i>Short-run impacts</i>						
D_IGovR	0.0107	-0.0018	0.0071	0.0083*	0.0106	0.0019
D_IGovL	-0.0152	-0.0090**	-0.0079*	-0.0065	-0.0132*	-0.0166
D_IGovCh	0.2968***	0.2595*	0.2823**	0.0589	0.0498	-0.1327
D_IPatents	0.1058	0.1736***	0.1513**	0.1218**	0.1598	0.1205
D_IGDP	-0.3194*	0.2839*	0.1472	-0.1212	-0.2583	-0.1210
D_IFDI	0.1617	0.1560	0.1196	0.2388*	-0.0628	-0.0682
D_IFreedom	0.7836	0.8296***	0.7086**	0.7708**	0.2193	0.2085
<i>Long-run elasticities</i>						
L_IGovR	0.1406***	0.0625**	0.0722**	0.1548***	0.1688***	0.1418***
L_IGovL	0.0058	0.0414	-0.0492	0.0163	0.0042	0.0120
L_IGovCh	-0.3789	-1.1371*	-0.8417**	-1.0378***	-1.4430***	-0.7393
L_IPatents	0.7582***	1.1236***	0.9086***	0.8373***	0.7013***	0.5105***
L_IGDP	-0.0467	0.0253	0.2230	0.0879	0.0798	0.3150
L_IFDI	3.4232***	5.8788***	4.5093***	3.6938***	3.0713***	1.8309***
L_IFreedom	5.3475***	6.9940***	5.7245***	3.7723***	3.5676***	1.7489*
<i>Speed of adjustment</i>						
ECM	-0.1661***	-0.0982***	-0.1217***	-0.1473***	-0.1756***	-0.2333***

This table presents the short-run impacts, long-run elasticities, and the speed of adjustment for the PARDL and PQARDL models without dummies. ECM denotes error correction model. “Mean” corresponds to the mean estimates (PARDL), and “10th”, “25th”, “50th”, “75th”, and “90th” are the PQARDL estimates for the 10%, 25%, 50%, 75%, and 90% quantiles of the non-hydroelectric installed capacity conditional distribution. “I” denotes variables in the natural logarithms, and “D” indicates the first difference. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively

and GDP have opposite signs but similar magnitudes. The long-run elasticities reveal a strong positive response to changes in economic freedom and financial development: a 1% increase in IFreedom and IFDI generates a 5.35% and 3.42% increase in INon-Hydro over the long run, respectively. Patents and right-wing government membership exhibit positive but lower elasticities (0.76 and 0.14, respectively). The speed of adjustment implies a rapid return (within six years) of the dependent variable to its long-run equilibrium.

For the PQARDL model, the elasticities of patents, financial development, and economic freedom decrease as one moves up the quantiles, while the reverse happens for GovR. The estimates also show negative elasticities for government changes in all the quantiles except for the highest one (see Table 12 below).

Tables 13 and 14 below present the estimation results and the short-run impacts and long-run elasticities, respectively, with the inclusion of dummies to control for outliers. Any observation more than three standard deviations away from the mean is considered an outlier.

The overall pattern remains very similar with the inclusion of dummies; however, there are a few exceptions in the short and long run. D_IGovR is no longer statistically

Table 13 Estimation results with dummies

Dependent variable (D_INonHydro)						
Independent variables	Quantiles					
	Mean	10th	25th	50th	75th	90th
Constant	-5.9806***	-5.7100***	-5.8246***	-4.7476***	-4.9171***	-3.4886***
D_IGovR	0.0104	0.0005	0.0060	0.0070	0.0031	0.0099
D_IGovL	-0.0095	-0.0034	-0.0071	-0.0065	-0.0179**	-0.0163
D_IGovCh	0.0990**	0.3334*	0.3096**	0.01647	0.2349	-0.1632
D_IPatents	0.0555	0.1584***	0.1210*	0.1068**	0.0692	0.1346
D_IGDP	-0.1653	0.3881***	0.2316	-0.0869	-0.1374	-0.0816
D_IFDI	0.1549	0.1729	0.1506	0.2719**	-0.0463	-0.0079
D_IFreedom	0.8264	0.7630***	0.8020***	0.4940**	0.2640	0.1888
L_INonHydro	-0.1583***	-0.0887***	-0.1168***	-0.1387***	-0.1682***	-0.2284***
L_IGovR	0.0243***	0.0079***	0.0068*	0.0205***	0.0243***	0.0387***
L_IGovL	0.0041	0.0081***	-0.0039	0.0016	-0.0027	0.0051
L_IGovCh	0.0522	-0.0117	-0.0031	-0.0732	-0.1541*	-0.2209
L_IPatents	0.0857***	0.0911***	0.0946***	0.1031***	0.1037***	0.1218***
L_IGDP	-0.0111	0.0367*	0.0517***	0.0628***	0.0484*	0.0416
L_IFDI	0.5848***	0.5796***	0.5557***	0.5593***	0.5799***	0.4829***
L_IFreedom	0.9966**	0.7134***	0.7828***	0.5272***	0.6509***	0.5038**
GovSup	-0.0488	-0.0341***	-0.0399***	-0.0294***	-0.0410*	-0.1071***

This table presents the estimated coefficients and significance levels for the PARDL and PQARDL models with dummies. “Mean” corresponds to the mean estimates (PARDL), and “10th”, “25th”, “50th”, “75th”, and “90th” are the PQARDL estimates for the 10%, 25%, 50%, 75%, and 90% quantiles of the non-hydroelectric installed capacity conditional distribution. “I” denotes variables in the natural logarithms, and “D” indicates the first difference. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively

significant at the 75% quantile, while D_IGovL becomes significant only at the 75% quantile. The same applies to D_IGDP in the PARDL model. In the long run, there is a loss of statistical significance for GovL and GovCh in the 10% and 25% quantiles, respectively. On the other hand, GDP now has a positive and statistically significant effect on the dependent variable in the 10% through 75% quantiles.

5 Discussion

The present study aimed to investigate the political determinants of new renewable energy deployment in Europe, providing valuable insights into the factors influencing renewable energy development and the dynamics between them.

Initially, preliminary tests conducted in this study revealed that the data distribution was non-normal for most variables, except for the dummy variable “GovSup,” representing whether the government has a parliamentary majority. This finding justified the use of quantile methods, which are less sensitive to deviations from normality. By employing quantile regression, the study obtained robust estimates and reliable inferences regarding the relationships under investigation.

Table 14 Short-run impacts and long-run elasticities with dummies

Dependent variable (D_INonHydro)						
Independent variables	Quantiles					
	Mean	10th	25th	50 th	75th	90th
Short-run impacts						
D_IGovR	0.0104	0.0005	0.0060	0.0070	0.0031	0.0099
D_IGovL	-0.0095	-0.0034	-0.0071	-0.0065	-0.0179**	-0.0163
Dlugosch	0.0990**	0.3334*	0.3096**	0.01647	0.2349	-0.1632
D_IPatents	0.0555	0.1584***	0.1210*	0.1068**	0.0692	0.1346
D_IGDP	-0.1653	0.3881***	0.2316	-0.0869	-0.1374	-0.0816
D_IFDI	0.1549	0.1729	0.1506	0.2719**	-0.0463	-0.0079
D_IFreedom	0.8264	0.7630***	0.8020***	0.4940**	0.2640	0.1888
Long-run impacts						
L_IGovR	0.1536***	0.0888***	0.0579*	0.1476***	0.1445***	0.1696**
L_IGovL	0.0260	0.0915***	-0.0331	0.0113	-0.1606	0.0225
L_IGovCh	0.3294	-0.1320	-0.0266	-0.5279	-0.9166*	-0.9673
L_IPatents	0.5410***	1.0270***	0.8102***	0.7436***	0.6168***	0.5331***
L_IGDP	-0.0704	0.4142**	0.4422***	0.4532***	0.2880*	0.1821
L_IFDI	3.6934***	6.5326***	4.7576***	4.0336***	3.4486***	2.1140***
L_IFreedom	6.2946***	8.0406***	6.7016***	3.8023***	3.8707***	2.2058**
Speed of adjustment						
ECM	-0.1583***	-0.0887***	-0.1168***	-0.1387***	-0.1682***	-0.2284***

This table presents the short-run impacts, long-run elasticities, and the speed of adjustment for the PARDL and PQARDL models with dummies. ECM denotes error correction model. "Mean" corresponds to the mean estimates (PARDL), and "10th", "25th", "50th", "75th", and "90th" are the PQARDL estimates for the 10%, 25%, 50%, 75%, and 90% quantiles of the non-hydroelectric installed capacity conditional distribution. "I" denotes variables in the natural logarithms, and "D" indicates the first difference. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels, respectively

Furthermore, the analysis addressed the issue of multicollinearity by examining the variance inflation factors (VIFs), which indicated no significant multicollinearity concerns as all VIF values were well below the threshold of six. This ensured that the estimated coefficients were reliable and not affected by high intercorrelations between the independent variables. Additionally, the Pesaran CD test revealed cross-sectional dependence among the variables, except for "IGovR." To address this, the study employed Driscoll and Kraay's (1998) standard errors, which provided more accurate estimates in the presence of cross-sectional dependence.

Panel unit root tests were conducted to assess the stationarity of the variables in logarithms and their first differences. The results indicated that all variables were stationary in the first differences, while some variables, such as "IGovR," "IGovL," and "IGDP," were non-stationary in logarithms. This finding highlighted the importance of considering the first differences of these variables in the regression analysis to avoid spurious regression problems.

Cointegration analysis was performed to examine the existence of a long-term relationship among the variables. Both the Westerlund and Pedroni cointegration tests rejected the

null hypothesis of no cointegration, indicating a long-term relationship among the variables under consideration. This suggested that changes in these factors had a lasting impact on non-hydroelectric renewable installed capacity.

The Hausman test was employed to choose between fixed effects and random effects estimators. The test results strongly rejected the null hypothesis of consistency for the random effects estimator, providing evidence in favor of using the fixed effects estimator. This implied that panel heterogeneity played a significant role in explaining the variation in non-hydroelectric renewable installed capacity.

In terms of causality analysis, the Granger non-causality test of Dumitrescu and Hurlin (2012) revealed bidirectional causality between the dependent variable (“INonHydro”) and most of the covariates. However, “IGovR” was found to cause “INonHydro” without being influenced by it. These findings suggested a complex interplay between political and economic factors in the development of non-hydroelectric renewable energy sources.

Finally, the estimation results for the non-hydroelectric renewable installed capacity regression without dummies were discussed. The PARDL (mean regression) and PQARDL (quantile regression) estimates provided valuable insights into the short-run and long-run impacts of the independent variables.

In the PARDL model, it was observed that changes in government increased the deployment of renewable energy in the short run. This relationship has been identified in several studies, such as Behuria (2020), Hazboun et al. (2020), Mamat et al. (2019), and Sahu (2018). According to Behuria (2020), who studied the case of India, it was identified that following a change in government, the installed solar energy capacity increased significantly while also managing to attract tariffs of Rs. 2.44 per unit. Hazboun et al. (2020), in their study of the USA, identified a correlation between a change in political control and the advancement of renewable energy development. In the study conducted by Mamat et al. (2019) focusing on India and China, it was observed that political pressures could indeed influence the development of renewable energy.

Therefore, governments worldwide are recognizing the urgent need to address climate change and reduce greenhouse gas emissions, implementing policies and incentives to promote renewable energy sources, as highlighted by the Intergovernmental Panel on Climate Change (IPCC, 2018). Renewable energy offers a sustainable and domestic energy supply, enhancing energy security and reducing reliance on imported fossil fuels, as emphasized by the International Renewable Energy Agency (IRENA, 2020). Additionally, government support has driven technological advancements and cost reductions in renewable technologies, making them more competitive with traditional energy sources, as stated by the International Energy Agency (IEA, 2020). These combined efforts are facilitating a transition toward cleaner energy and fostering economic opportunities.

In the long run, right-wing government members of the executive, patents, financial development, and economic freedom were found to enhance non-hydroelectric renewable installed capacity. Right-wing governments, known for their market-oriented policies, create a favorable environment for renewable energy investments by reducing bureaucratic barriers and providing supportive regulatory frameworks (e.g., Amoah et al., 2020; Sequeira & Santos, 2018; Thoning et al., 2020). According to Amoah et al. (2020), the role of economic well-being and economic freedom as drivers of renewable energy consumption using the share of renewables in total energy consumption in 32 African countries over the period 1996–2017. The authors found that economic freedom contributes positively to the development of renewable energy by promoting market efficiency, attracting investment, supporting innovation, and creating favorable policy environments.

The positive influence of patents on non-hydroelectric renewable installed capacity enhancement is related to strong intellectual property protection, including patents, which incentivizes innovation and technological advancements in the renewable energy sector (Hille & Oelker, 2023). Moreover, right-wing governments, which prioritize free-market principles, are more likely to support robust intellectual property rights, spurring private sector investments in renewable technologies (Mansur et al., 2008).

Financial development's positive influence on non-hydroelectric renewable installed capacity enhancement is associated with increased access to capital and attracting private investments in renewable energy projects under right-wing governments (Cadoret & Padovano, 2016). This relationship has been found in several studies (Awijen et al., 2022; Khan et al., 2021). According to Khan et al. (2021), who explored the short-term and long-term impacts of technological innovation, finance, and foreign direct investment on renewable energy, non-renewable energy, and CO₂ emissions in 69 countries of the "Belt and Road Initiative (BRI)" from 2000 to 2014, the authors found that financial development is a positive determinant of renewable energy consumption in countries along the BRI. Awijen et al. (2022) also obtained similar results from the MENA countries. In their study, the authors indicated that governance quality, innovation, political stability, and financial development are the main drivers of renewable energy deployment.

Furthermore, economic freedom's positive influence on non-hydroelectric renewable installed capacity enhancement is related to stimulating the growth of the renewable energy sector through market forces, encouraging innovation, efficiency, and cost reduction (Amoah et al., 2020; Mansur et al., 2008; Solarin et al., 2022). As mentioned in the paragraph above, in the study conducted by Amoah et al. (2020), which examined the role of economic well-being and economic freedom as drivers of renewable energy consumption using the share of renewables in total energy consumption in 32 African countries from 1996 to 2017, the authors found that economic freedom has a positive impact on the development of renewable energy. This is achieved by promoting market efficiency, attracting investment, supporting innovation, and creating favorable policy environments.

On the other hand, the PQARDL model results confirmed that the signs of the parameters estimate of short-run variables (first differences) were generally consistent with those of the PARDL estimation, except for economic growth, which negatively impacted non-hydroelectric renewable installed capacity growth in the lowest quantile.

This result could be related to various factors. Firstly, the competition for resources between renewable and non-renewable energy sources may arise as a result of increased energy demands accompanying economic growth. This competition could lead to a prioritization of conventional energy sources over renewable alternatives (Bhuiyan et al., 2022). Secondly, during periods of economic expansion, investments in sectors like infrastructure and manufacturing may take precedence, potentially diverting resources away from the development of non-hydroelectric renewable energy (Pempetzoglou, 2014). Additionally, regulatory challenges and complexities associated with rapid economic growth could inadvertently create barriers and delays in the approval and implementation of renewable energy projects (Sovacool, 2012). Finally, cost considerations may play a role, as renewable energy technologies like solar and wind power can still be relatively more expensive or require higher initial investments compared to conventional energy sources (Hirth, 2014). While these factors suggest a potential negative relationship between economic growth and non-hydroelectric renewable installed capacity growth, it is important to note that the relationship is complex and can vary based on specific national contexts and policy frameworks (Sebri and Ben-Salha, 2020).

Regarding the political variables, right-wing parties in the middle quantile were found to stimulate non-hydroelectric renewable installed capacity deployment. These parties

often emphasize technological innovation, and research and development, recognizing the economic opportunities and job creation that can result from investments in renewable energy industries, as mentioned above.

Conversely, left-wing parties in the 10%, 25%, and 75% quantiles were found to hinder the deployment of non-hydroelectric renewable installed capacity. This result contradicts the findings of previous studies such as Abban and Hasan (2021), Nicolini and Tavoni (2017), and Cadoret and Padovano (2016), which generally found that left-wing parties are more environmentally conscious than right-wing parties. In fact, Nicolini and Tavoni (2017) suggest that left-wing parties are more likely to support renewable energy (RE) investment compared to parties with different ideologies.

The possible explanation for this result is related to the potential conflict between environmental objectives and economic considerations in the countries under study. Left-wing parties often prioritize social welfare and equality, which may lead them to focus on immediate social and economic concerns rather than long-term environmental sustainability. As a result, their policies may prioritize sectors other than renewable energy, allocate limited resources differently, or introduce regulatory burdens that hinder the development of non-hydroelectric renewable energy sources. It is important to note that this explanation is highly dependent on the specific context and policies of left-wing parties in different countries. Further studies are needed to confirm and better understand this impact.

Additionally, changes in patents and economic freedom were found to increase non-hydroelectric renewable installed capacity in the lowest quantile, while the effect of changes in financial development was primarily observed in the middle quantile. Regarding the long-run variables, right-wing parties exhibited increasing influence on non-hydroelectric renewable installed capacity as quantiles increased.

In its entirety, this study offers a significant addition to our understanding of the intricate political dynamics underpinning renewable energy adoption across Europe. The findings underscore the pivotal role that governmental endorsement, patent activity, financial advancement, and economic autonomy play in amplifying the capacity for non-hydroelectric renewable installations. Moreover, the study illuminates the intricate nexus where political, economic, and environmental facets converge, jointly influencing the trajectory of renewable energy evolution.

While these revelations advance knowledge, it is imperative to emphasize the ongoing necessity for further research to corroborate and expand upon these insights. This requires delving into the nuances of individual national contexts and navigating the intricacies of varying policy frameworks. Undertaking such nuanced investigations can refine understanding, thereby fostering more informed decision-making in the pursuit of sustainable energy transitions.

6 Conclusion

The article endeavors to address a significant research inquiry: To what extent do the political orientations of democratic nations impact the adoption of renewable energy sources? The utilized database categorizes governments into the following groups: (i) the proportion of right-wing party cabinet posts within the total cabinet, (ii) the proportion of center party cabinet posts in relation to the overall cabinet posts, and (iii) the proportion of cabinet posts held by social democratic and other left-wing parties relative to the total cabinet posts. To mitigate issues of perfect multicollinearity and better understand the impact of political stance, the variable concerning center party cabinet posts as a percentage of total

cabinet posts have been excluded. As a result, the study's findings regarding political variables are grounded in the context of center parties serving as the baseline.

The investigation is centered on the European landscape. Why concentrate on European countries? European nations represent advanced economies with a robust commitment to transitioning toward sustainable energy. Their diverse political spectrum offers a unique opportunity to examine whether political ideologies play a role in shaping renewable energy adoption. Moreover, the study employs a comprehensive approach that encompasses a range of determinants influencing renewable energy deployment, including political, economic, financial, and technological factors. By adopting this approach, potential bias arising from omitted variables is minimized, thus enhancing the robustness of the empirical analysis.

Hence, the research primarily aims to evaluate the impact of political factors on renewable energy adoption in Europe. The empirical study delves into the non-hydroelectric renewable energy capacity of 27 European nations spanning the years 2000 to 2020, providing a comprehensive temporal scope. A set of independent variables with plausible explanatory power has been chosen to elucidate the dynamics of non-hydroelectric renewable energy capacity deployment. These independent variables encompass (i) the proportion of cabinet posts held by right-wing parties, weighted by days in office per year, (ii) the proportion of cabinet posts held by left-wing parties, weighted by days in office per year, (iii) the average annual government turnover, (iv) non-hydroelectric renewable energy patents per million inhabitants, (v) gross domestic product per capita in constant 2015 USD, (vi) the Financial Development Index, (vii) the Index of Economic Freedom, and (viii) a binary variable denoting parliamentary majority support for the government.

The intricate relationship between non-hydroelectric renewable energy capacity and political factors was uncovered by employing the Dumitrescu and Hurlin panel Granger non-causality method, as well as the Panel Autoregressive Distributed Lag (PARDL) and Panel Quantile Autoregressive Distributed Lag (PQARDL) estimation methods.

The Dumitrescu and Hurlin Granger causality tests unveil multifaceted interactions among variables, indicating nuanced causal relationships that extend beyond pairwise associations. The PARDL model outcomes suggest that, in the short term, changes in government positively influence renewable energy deployment. In the long term, right-wing government representation, patents, financial development, and economic freedom foster non-hydroelectric renewable energy capacity. The PQARDL model corroborates the trends observed in the PARDL estimation, with the exception of economic growth, which significantly impacts capacity growth at the lowest quantile. The analysis indicates that moderate right-wing parties stimulate renewable energy deployment in the middle quantile. Conversely, left-wing parties at the 10%, 25%, and 75% quantiles impede non-hydroelectric renewable energy adoption. Notably, patents and economic freedom drive capacity growth in the lowest quantile, while the effect of financial development is prominent in the middle quantile. In terms of long-term variables (lagged levels), the influence of right-wing parties on renewable energy capacity strengthens as quantiles increase. Economic freedom demonstrates an opposite trend compared to political variables. Patents and financial development consistently foster capacity deployment across quantiles. Finally, government parliamentary support inhibits non-hydroelectric renewable energy development across all quantiles.

6.1 Policy implications

The attainment of non-hydroelectric renewable installed capacity has been established as a predominantly long-term endeavor. To effectively steer the energy transition,

policymakers are advised to adopt strategies that prioritize sustained efforts. Within this context, three key variables emerge as promising policy avenues:

- I. **Fostering Economic Freedom** Creating an environment conducive to economic freedom proves to be an instrumental approach. This involves reducing regulatory barriers, encouraging entrepreneurship, and promoting competitive markets. Such measures can significantly enhance the prospects of successfully achieving non-hydroelectric renewable deployment.
- II. **Facilitating Financial Development** Nurturing financial growth is another pivotal strategy. By bolstering access to financing mechanisms tailored to renewable projects, policymakers can facilitate the flow of investments needed for the transition. This, in turn, accelerates the realization of non-hydroelectric renewable installed capacity targets.
- III. **Promoting Research and Development** Emphasizing research and development (R&D) in the realm of non-hydroelectric renewables emerges as a crucial driver. Encouraging innovation, particularly in patent creation, can yield groundbreaking advancements in renewable technologies. This not only augments capacity deployment but also establishes a foundation for sustainable growth.

Notably, the research findings also shed light on the role of political orientation. Leftist governments appear to have demonstrated less emphasis on energy transition priorities. This underscores the necessity to comprehensively address the implications of disregarding environmental concerns. Neglecting these concerns could potentially lead to substantial ecological and socio-economic repercussions, a fact that should be seriously considered by proponents of leftist ideologies.

7 Research limitations

The research findings reveal that the expansion of non-hydroelectric renewable installed capacity is intricately shaped by a multitude of influencing factors. The existence of numerous causal elements underscores the imperative for more in-depth investigation aimed at ascertaining whether distinct permutations of these determinants can yield analogous results. Furthermore, it is essential to acknowledge that the research is centered around a particular group of countries, potentially lacking representativeness across the global spectrum. This limitation underscores the urgency for more comprehensive studies encompassing a wider array of countries with greater diversity.

8 Research gaps deserving further analysis

The proposed avenues for further research can be refined and expanded to enhance the clarity and depth of the research gaps deserving further analysis:

- I. **Harnessing Advanced Methodologies** To address the intricate interplay between politics and renewable energy deployment, employing advanced statistical tech-

niques like fuzzy-set qualitative comparative analysis (fsQCA) emerge as a strategic approach. By applying fsQCA, researchers can systematically explore the intricate web of factors influencing the energy transition. This technique not only enables a more holistic comprehension of factor interactions but also offers policymakers an expanded array of viable pathways for achieving the transition while mitigating conflicting objectives.

- II. **Strategic Intermediate Analysis Integrating fsQCA as an intermediate analytical step** holds promise in refining the investigation into political factors' associations with renewable energy deployment. This intermediary phase allows researchers to discern and select the most pertinent relationships for in-depth scrutiny. By strategically focusing on the most influential factors, scholars can delve into comprehensive and targeted analysis, thereby uncovering nuanced insights that guide more effective policy decisions.
- III. **Globalizing the Analysis** The inherently global nature of the energy transition was recognized, and it is imperative to extend research beyond the current country's focus. Embracing a broader perspective involves cross-validating findings by incorporating developing nations and expanding the analysis to encompass a diverse range of countries worldwide. This panoramic view is essential for cultivating a more nuanced understanding of the intricate connections between political dynamics and renewable energy adoption on a global scale, ultimately yielding insights with greater cross-cultural applicability.

By adhering to these refined research steps, the exploration of the intricate interplay between politics and renewable energy deployment can be significantly enriched. This heightened understanding lays the foundation for robust policymaking, steering sustainable energy transitions, and addressing the complex challenges that lie ahead.

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Data availability Corresponding authors can provide the data used in the study on appropriate requests.

Declarations

Conflict of interest The authors declare no conflict of interest.

Consent to participate Not applicable.

Consent for publication Not applicable.

Ethical approval Authors are attested that this paper has not been published elsewhere, the work has not been submitted simultaneously for publication elsewhere, and the results presented in this work are true and not manipulated.

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Authors and Affiliations

Nuno Silva¹  · José Alberto Fuinhas¹  · Matheus Koengkan²  ·
Emad Kazemzadeh³  · Volkan Kaymaz⁴ 

✉ Nuno Silva
nunos@fe.uc.pt

José Alberto Fuinhas
fuinhas@uc.pt

Matheus Koengkan
matheus.koengkan@ij.uc.pt

Emad Kazemzadeh
Emad.kazemzadeh67@mail.um.ac.ir

Volkan Kaymaz
volkan.kaymaz@yeniyuzuil.edu.tr

¹ Faculty of Economics, and Centre for Business and Economics Research (CeBER), University of Coimbra, Coimbra, Portugal

² University of Coimbra Institute for Legal Research (UCILeR), Coimbra, Portugal

³ Department of Economics, Faculty of Economics and Administrative Sciences, Ferdowsi University of Mashhad, Mashhad, Iran

⁴ Faculty of Economics and Administrative Sciences, Istanbul Yeni Yuzyil University, Istanbul, Turkey