Renewable energy production capacity and consumption in Europe

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Abstract

Faced with the prospect of achieving 32% renewable energy (RE) consumption by 2030 and climate neutrality by 2050, Europe has embarked on a path of promoting the use of clean energy through policies and investments essential to its development. Against this backdrop, the aim of the present article is to analyse both RE production capacity and the determinants of RE consumption in a sample of 30 European countries for the period 2010-2019. Through the construction of a synthetic measure by the zero unitarization method, the four types of RE (hydro, wind, solar and biofuels) are jointly assessed, yielding a ranking of countries categorized as being in a favourable, fairly favourable, rather unfavourable, or unfavourable situation. Furthermore, the possible relationship between RE production capacity and consumption is estimated with a sample of panel data (fixed effects and random effects). The results show that Sweden (SM: 0.419), Austria (SM: 0.384) and the Netherlands (SM: 0.381) are at the top of the ranking, demonstrating their leadership in RE generation and providing a model to follow for Eastern European countries whose production levels are still well below average. Moreover, the study provides evidence that the RE production capacity (Coeficient: 0.253***), low gas emissions (Coeficient: -0.479***), energy productivity (Coeficient: 0.333***), and the size of the country (Coeficient: 0.016***) foster the use of RE.

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Overall, European countries are on the right track to achieve the goals set, although they may be progressing at different speeds.

1. Introduction

One of the challenges the European Union (EU) faces is cutting carbon dioxide (CO_2) emissions by reducing the consumption of fossil fuels, to which end it is essential to find new replacements for traditional sources of energy (Meyer et al., 2021). Thus, renewable energy (RE) is the cornerstone of European energy systems and climate change mitigation. RE enables the transition to greener, more resource-efficient, competitive and low-carbon economies (Angheluta et al., 2019; Čeryová et al., 2020). Its promotion is related to the main positive aspects of green energy: the impact on the environmental impact, the impact on a country's level of development, and social pressure (Liobikienė and Dagiliūtė, 2021). Nevertheless, the different socioeconomic structures of each European state and their varying degrees of commitment to achieving the energy transition give rise to marked heterogeneity among countries, leading to very different outcomes (Hafner and Raimondi, 2021).

The EU has been a pioneer in the field of RE generation. Directive 2009/28/EC (European Parliament, 2009) on the promotion of the use of energy from renewable sources has been a central element in its energy policy, setting an overall target of a 20% share of gross final consumption of energy coming from RE by 2020. The recent revised version of the directive (Directive 2018/2001, European Parliament 2018) forms part of a package of measures "Clean energy for all Europeans" aimed at maintaining a global leadership position and helping to meet its emission reduction commitments under the Paris Agreement. The directive calls for RE consumption to increase to a 32% share by 2030.

Over the longer term, the ambitious goal of reaching climate neutrality by 2050 raises the possibility of using RE exclusively in all sectors (Maruf, 2021). At present, the European Green Deal reaffirms European commitments to achieving the energy and climate transition. Some consider economic growth crucial in order to finance this transition and claim the new plan will further stimulate growth (Mastini et al., 2021). Others, such as Martí and Puertas (2022), state that the economic and political context shapes sustainable energy development.

In this context, where RE plays a fundamental role in economic and social development, the aim of the paper is analyse the changes that occurred in the production capacity and the determinants of RE consumption in European countries during the period 2010–2019. Using a sample of 30 nations, two research questions will be answered:

Q1. Has there been a positive evolution in RE production capacity in Europe?

A synthetic measure (SM) is constructed by the zero unitarization method to assess the infrastructure for RE generation; specifically hydro, wind, solar and biofuels (solid biofuels, biogasoline, and biodiesel) over a 10-year period (2010-2019). The advantage of the method is its simplicity and the lack of methodological controversies for its application (Zadrag and Kniaziewicz, 2017). Analysing the potential production of sources of RE can help to guide decision-makers in their efforts to generate clean energy.

Q2. Do factors that mitigate climate change drive RE consumption?

A sample of panel data is used to shed light on the possible relationship between RE consumption and the proposed SM. The results allow a more accurate characterization of the profile of European countries, with three different models used depending on the ultimate purpose of the renewables consumed: electricity; heating and cooling; and overall consumption.

The findings of this paper will reveal whether the countries at the top of the ranking belong to an area of Europe, demonstrating their leadership in RE generation and providing a model to follow for other countries whose production levels are still well below average. Moreover, the study will provide evidence that the RE production capacity, low gas emissions, energy productivity, and the size of the country foster the use of RE.

There has been an abundance of recent literature underlining the importance of RE as a key instrument of climate policy. For example, Akadiri et al (2019) infer that the exploitation of renewable energy sources in the EU-28 countries is a reliable pathway toward environmental pollution mitigation. Čeryová et al. (2020) monitor a number of indicators to identify the situation in EU countries, confirming a lack of homogeneity in the implementation of European energy policies. Other authors such as Bórawski et al. (2019) analyse the evolution of the RE market, paying particular attention to biofuels in the EU. Also, in the literature there are papers focusing only on renewable energy generation in Europe (Matuszewska-Janica et al. 2021; Li and Lee, 2022; Naqvi et al., 2022), while others focus on the use of renewable energies (Akadiri et al, 2019; Asiedu et al, 2021; Tutak and Brodny, 2022). However, the novelty of this paper is that it unifies both RE generation and use over the same sample of countries and time period. So this research constructs a representative SM of ER production capacity, before going on to analyse its connection with consumption. The results will add to the knowledge base about the energy transition in Europe and can help guide leaders in aiming their policies at achieving the environmental goals set in different international agreements.

The rest of the article is structured as follows. Section 2 reviews the literature on RE and specifically the main lines of research in the area of synthetic indicators and the determinants of consumption. Section 3 explains the methodology and sample used in the empirical analysis. Section 4 presents the results that provide an answer to the research questions raised. Lastly, the main conclusions and future lines of work are summarized in section 5.

2. Literature review

2.1 Synthetic indicators aimed at assessing the energy situation

A comprehensive analysis is needed of the energy transition and countries' degree of preparedness; such an analysis should account for the multiple dimensions that characterize all the aspects influencing this new approach. Synthetic indexes have become established as useful tools for monitoring progress towards sustainability. In the last decade, the scientific community has designed several indexes aimed at analysing the situation in each country, facilitating the design of appropriate strategies that identify existing needs and the advances made in the field of renewables (Table 1). La Rovere et al. (2010) highlight the ability of composite indicators to capture multidimensional concepts and provide solutions for decision-making, in their evaluation of sustainability in the electricity sector.

Table 1. Synthetic indicators on RE

Authors	Synthetic indicator
World Energy Council (2010)	Energy Trilemma Index (ETI)
Schlör et al. (2013)	Standardized sustainability energy index (SSEI)
Liu (2014)	General Sustainability Indicator for renewable energy systems (GSI)
Lee and Zhong (2015)	Renewable Energy Responsible Investment Index (RERII)
Warren (2015)	Renewable Energy Country Attractiveness Index (RECAI)
Cîrstea et al. (2018)	Renewable Energy Sustainability Index (RESI)
Global Energy Institute (2018)	International Index of Energy Security Risk
Gatto and Drago (2021)	Renewable Energy Index (REI)

All the proposed indexes present certain specific features that enable the analysis of the situation from different perspectives. ETI is used internationally as a tool to support decision-making in energy policy and governance. Due to the broad spectrum covered by this index, it has given rise to an extensive literature, seeking to highlight the lack of political and ecological aspects, and linking energy security—understood as security of supply—to the other two dimensions of energy equity and environmental sustainability (WEC, 2020). The GSI and the RERII consider different environmental elements (social, ecological, governmental, economic) to quantify the degree of sustainability of a set of countries. Warren (2015) developed the RECAI to rank the top 40 markets based on investment opportunities and the level of development of their RE. Focusing on Europe, Cirstea et al. (2018) proposed the RESI to assess the weaknesses and strengths of 15 countries in terms of the production of RE, enabling those responsible to design strategic solutions to move forward in the implementation of environmentally-friendly energies. Also, The International Index of Energy Security Risk (2018) estimates global energy security risks using a qualitative and quantitative reference model in order to better understand their importance (Global Energy Institute, 2018). More recently, Gatto and Drago (2021) developed the REI composite indicator for 230 nations, concluding that oil producers are less inclined to use renewables, while territories endowed with natural resources, such as Brazil, achieve better results in this regard.

The construction of these indexes primarily relies on two methods: namely, multicriteria analysis and data envelopment analysis (DEA). The literature contains studies that have applied multicriteria analysis based on the level of development of RE sources and aspects related to countries' social, political, economic and technological characteristics (Kaya and Kahraman, 2011; Cucchiella et al., 2017; Neofytou et al., 2020; Piwowarski et al., 2021). The application of this method reveals areas for improvement and supports policy-makers in designing appropriate pathways towards a more sustainable economy.

Another stream of the research has centred on the use of DEA to construct synthetic indexes enabling the measurement of RE development at both country and company level. Combining the DEA technique with TOPSIS, Wang et al. (2021) provide a method to determine the potential RE production of different regions, facilitating the design of stimulus packages for a clean energy future and thus accelerating sustainable development. Along the same lines, Rodríguez-Lozano and Cifuentes-Yate (2021) study the efficiency of electricity generation from renewable and non-renewable sources, evaluating 126 countries; notably, Oceanian countries are found have the highest average efficiency. For their part, Chachuli et al. (2020) conduct a literature review to provide a systematic analysis of RE performance, offering an understanding of the divergent paths in clean energy development in different places.

2.2 Analysis of the determinants of RE consumption

Mitigating climate change requires the implementation of new forms of production, as well as a shift in consumers' habits. Signatory countries to international environmental agreements have begun the transition towards the introduction of RE at all levels of the economy; however, the process is slow and often inadequate (Hrnčić et al., 2021; Bhattarai et al., 2022). There are a number of studies in the literature that analyse the consumption and/or production of RE using a panel data sample including both developed and developing countries (Table 2).

Table 2. Studies focused on the determinants of the use and production of RE

Authors	Objective	Sample	Methodology	Period
Marques et al. (2010)	To analyze the motivations behind RE use in European Countries	24 European countries	Fixed effects vector decomposition	1990-2006
Aguirre and Ibikunle (2014)	To investigate factors influencing country level RE growth	EU countries, the remaining OECD countries and the BRICS	Fixed effects vector decomposition and panel corrected standard errors	1990–2010
Omri and Nguyen (2014)	To investigate the impact of CO2 emissions, crude oil price, economic growth, and trade openness on RE consumption.	64 countries around the world	System generalized method of moments	1990-2011
Akadiri et al (2019)	To investigate environmental sustainability between renewable energy consumption and economic growth	EU-28 countries	Dynamic panel growth model using an autoregressive distributed lag model framework.	1995-2015
Alola et al (2019a)	To built on the specifics of renewable energy consumption in relation to the region's carbon emissions and the housing construction policy vis-àvis allocation for dwellings and built housing structures amidst uncertainty	CoastlineMediterranean Countries	ARDL models	1999–2014
Alola et al (2019b)	To investigate the impact of renewable energy consumption and migration on the carbon dioxide emissions of the panel of European Union's largest economies	Germany, UK and France	Fully-modified ordinary least square and dynamic ordinary least square estimators	1990-2016
Domhnaill and Ryan (2020)	To examine the factors contributing to the deployment of non-hydropower renewable sources of electricity	EU countries	Hybrid mixed effect model	2000-2015
Przychodzen and Przychodzen, (2020)	To fill the gap in existing empirical knowledge by examining the effects of several different macroeconomic and institutional characteristics on RE production	27 post-socialist countries	Panel data analysis.	1990-2014
Wang and Wang (2020)	To establish a nonlinear panel threshold model to explore the relationship between RE consumption and economic growth	34 OECD members	Panel Threshold Regression model	2005-2016
Alola et al (2021)	To examine the role of domestic material consumption, income and renewable energy utilisation	EU-28 countries	PMG-ARDL approach	2000-2017
Asiedu et al (2021)	To examine the nexus among renewable, non-renewable energy consumption, CO_2 emissions, and economic growth	26 European countries	Unit root and panel cointegration	1990 - 2018

Azam et al. (2021)	To determine the effect of natural gas, RE and nuclear energy consumption on economic growth and carbon dioxide emissions in the ten highest CO2 emitting countries	China, USA, Canada, Germany, India, Korea Rep, Iran, Russia, Japan and UK	Panel cointegration test	1990-2014
Azretbergenova et al. (2021)	To investigate whether RE consumption creates employment for EU countries, representing developed countries.	27 EU	Panel ARDL test	2006-2019
Usman et al. (2022)	To assess the effects of domestic material consumption, renewable energy, financial development, and greenhouse gas emissions on environmental quality	EU-28 countries	Generalized Method of Moments	2000-2017

Studies published in the last decade have shown that the drivers of the use of RE include the need to reduce CO_2 emissions and the benefits of reducing non-renewable energy dependence (Marques et al., 2010; Domhnaill and Ryan 2020). In turn, there is an extensive literature related to the dilemma between economic growth and pollution (Xie et al, 2019; Qiao et al., 2019; Yang et al., 2021; Sivarethinamohan et al., 2021), where RE use is gaining ground in replacing traditional supplies (Ashraf et al., 2020; Šikić, 2020; Adedoyin et al., 2021; Bigerna et al., 2021). In this vein, Akadiri et al. (2019), Wang and Wang (2020) and Azam et al. (2021) find a significant and positive link over the long term between RE consumption and economic growth, while Azretbergenova et al. (2021) demonstrate the positive effect of RE on employment. Focusing on the post-socialist economies of Eastern Europe, Przychodzen and Przychodzen (2020) conclude that greater economic growth along with rising unemployment and public debt stimulate the generation of RE. For their part, Bersalli et al. (2020) argue that policies promoting RE have a positive and significant effect on investment in both developing and developed countries, whereas the same cannot be said of tax incentives.

Multidimensional Comparative Analysis (MCA) methods take into account the complexity, multidimensionality and long-term nature of RE development, thus aiding decision-making processes (Piwowarski et al., 2021). The literature supports the suitability of this technique; for example, Kryk and Guzowska (2021) use it to evaluate the EU's implementation of the climate/energy goals set out in the Europe 2020 Strategy. Similarly, Ossowska and Janiszewska (2020) use MCA to construct a synthetic indicator for the EU relating to sustainable energy consumption. More recently, Bąk et al. (2021) calculate an SM for variables that reflect the use of RE in the EU.

3. Methodology and sample

3.1 Methodology: Zero Unitarization Method and Panel Estimation

The SM provides an assessment of RE production capacity. It has been calculated using the zero unitarization method, which is part of the group of Multidimensional Comparative Analysis (MCA) techniques. In order to construct the SM, the positive/negative impact (stimulants and destimulants) of each variable on the phenomenon under study must be identified, and then transformed to ensure the comparability of all variables (Kukula and Bogocz, 2014).

$$\text{Stimulants variables } Z_{i,j} = \frac{x_{i,j} - \min x_{i,j}}{\max x_{i,j} - \min x_{i,j}} \tag{1}$$

$$\text{Destimulants variables } Z_{i,j} = \frac{\max\, x_{i,j} - x_{i,j}}{\max x_{i,j} - \min x_{i,j}} \tag{2}$$

where $Z_{i,\,i}$ represents the transformed value of variable *i* for country *j* and X_{ij} the original value of variable *i* for country *j*. $Z_{i,\,j}$ provides results ranging between 0 and 1, with 0 being the least positive state and 1 the opposite end of the scale. According to the assumption of the zero unitarization method , SM_i is an arithmetic mean of the $Z_{i,j}$ of the *n* variables for each of the *r* elements of the sample. Ordering the SM_i provides a ranking of all the observations of the analysed sample. Subsequently, the mean and standard deviation of SM_i can be used to divide the sample into four groups according to the following criteria:

Favourable situation	*(Group I):*	*$SM_i \geq$ Mean SM + Standard Deviation SM*
Fairly favourable situation	*(Group II):*	*Mean SM + Standard Deviation SM > SM_i> Mean SM*
Rather unfavourable situation	*(Group III):*	*Mean SM >SM_i>Mean SM - Standard Deviation SM*
Unfavourable situation	*(Group IV):*	*Mean SM - Standard Deviation SM > SM_i*

The second stage of the research involves analysing the determinants of RE consumption; that is, the drivers of climate change mitigation. To do so, we estimate a fixed and/or random effects model with panel data. The fixed effects specification assumes that the characteristics of the individuals (countries) can have an impact on or bias the explanatory variables of the model, which we should try to control for. Conversely, the random effects specification assumes there is no correlation between the specific characteristics of the individual and the independent variables. The Hausman test is used to determine which model is suitable. The null hypothesis is that random effects is the appropriate model, which is accepted when the p-value > 0.05.

3.2 Sample

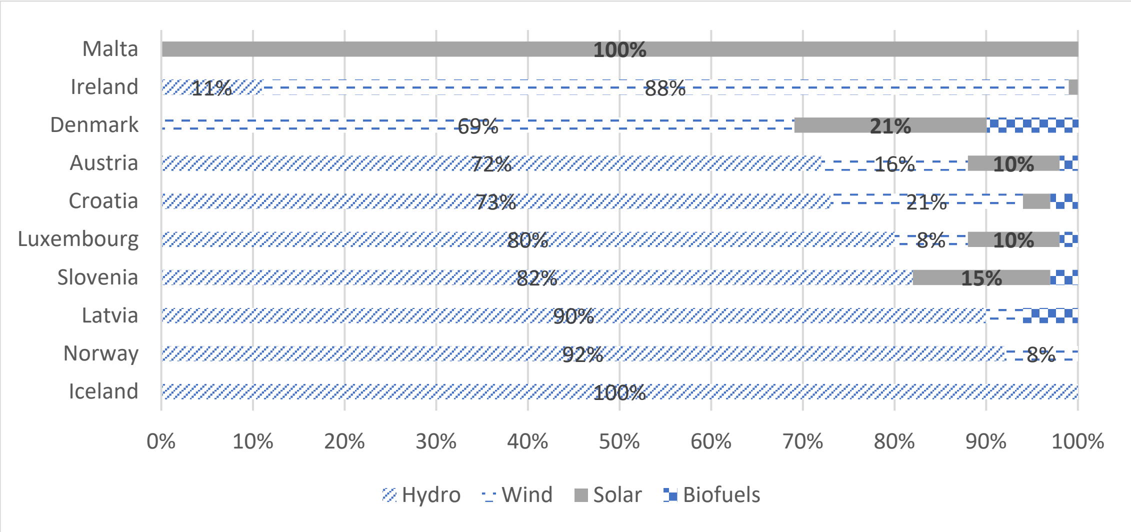
The SM_i has been produced for 30 European countries[2] using variables representative of renewable electricity production capacity by source:

- Electricity production capacities for renewables and waste: Hydro (megawatt)
- Electricity production capacities for renewables and waste: Wind (megawatt)
- Electricity production capacities for renewables and waste: Solar (megawatt)
- Electricity production capacities for renewables and waste: Solid biofuels (megawatt)
- Liquid biofuels production capacities: pure biogasoline (thousand tonnes)
- Liquid biofuels production capacities: pure biodiesel (thousand tonnes)
- Solar thermal collectors (thousand square metres)

All of them have been calculated using annual data provided by Eurostat. In addition, in order to take into account the size of each country and ensure comparability, the variables have been transformed into per capita units. RE production largely depends on the biophysical conditions of a country. As such, European nations' electricity production capacity differs widely according to the types of RE listed above (Figure 1). The statistical information confirms that in 2019 hydro accounted for more than 70% of the renewables used by seven European countries, where the mountainous terrain favours the development of this source (Iceland, Norway, Latvia, Luxembourg, Croatia and Austria).

[2] Austria, Germany, Spain, Belgium, Sweden, Finland, Czechia, Denmark, Latvia, Portugal, Greece, Cyprus, France, Norway, Lithuania, Italy, the Netherlands Slovakia, Iceland, Luxembourg, Hungary, Poland, Ireland, Bulgaria, the United Kingdom, Estonia, Slovenia, Croatia, Malta and Romania.

Figure 1. Countries with marked concentration in one type of RE in 2019



Note: Biofuels includes solid and liquid biofuels

The conditions in the coastal regions of Northern Europe are suitable for the development of wind energy: in Ireland and Denmark this type accounts for 88% and 69% of the total, respectively. Some of these countries are opting to construct large offshore wind farms to continue generating more environmentally-friendly energy (Pinson et al, 2017). On the other hand, areas with high levels of solar radiation are well-suited to the production of solar energy, with Malta and Hungary being where this type of RE predominates (100% and 65%, respectively).

The empirical analysis in the second stage of the research reveals the determinants of RE consumption broken down by different end uses: electricity; cooling and heating; and total uses. The explanatory variables of the model represent issues related to climate change (SM, GHG and EP), country size (POP), and the evolution of RE consumption over the analysed period (as indicated by the dummies included). The model is specified as follows:

$$\mathrm{Ln}(RES_{i,t}) = \beta_1 + \beta_2\,\mathrm{Ln}(SM_{i,t}) + \beta_3\,\mathrm{Ln}(GHG_{i,t}) + \beta_4\,\mathrm{Ln}(EP_{i,t}) + \beta_5\,\mathrm{Ln}(POP_{i,t}) + \beta_6\,D_{2010} + \beta_7\,D_{2011} + \beta_8\,D_{2018} + \beta_9\,D_{2019} + u_{i,j,t} \quad (4)$$

$\beta_2, \beta_4, \beta_5, \beta_8, \beta_9 > 0$ and $\beta_3, \beta_6, \beta_7 < 0$

The dependent variable $RES_{i,t}$ measures the share of country *i* 's total energy consumption that comes from renewable sources in year *t*. Two other models are similarly estimated, where RES represents the different end uses of energy: electricity, and heating and cooling.[3] The independent variables are:

$SM_{i,t}$: synthetic measure previously constructed to assess renewable electricity production facilities that country *i* has in year *t*.

$GHG_{i,t}$: greenhouse gas emissions measured in tonnes per capita. This variable includes carbon dioxide, nitrous oxide, methane and fluorinated gases.

$EP_{i,t}$: energy productivity calculated as gross domestic product (GDP) divided by the gross available energy, with the unit of measurement being euro/kw.

$POP_{i,t}$: population of country *i* in year *t*, in millions of people.

D_{2010}: dummy variable that takes the value 1 if the observation is from the year 2010 and 0 otherwise. The dummy variables D_{2011}, D_{2018} and D_{2019} are constructed in the same way. They represent the evolution of RE consumption.

Mean RE consumption in Europe displays a rising trend over the last decade, primarily driven by EU energy policies (Worsdorfer, 2021). Specifically, electricity has gone from a share of 25.5% in 2010 to 37.4% in 2019, followed by heating and cooling with shares of 23.4% and 31% in 2010 and 2019, respectively (Figure 2).

Figure 2. Evolution of mean RE use in the EU

[3] The consumption of RE in transport has not been taken into account due to its low levels of use (EU average under 10%).

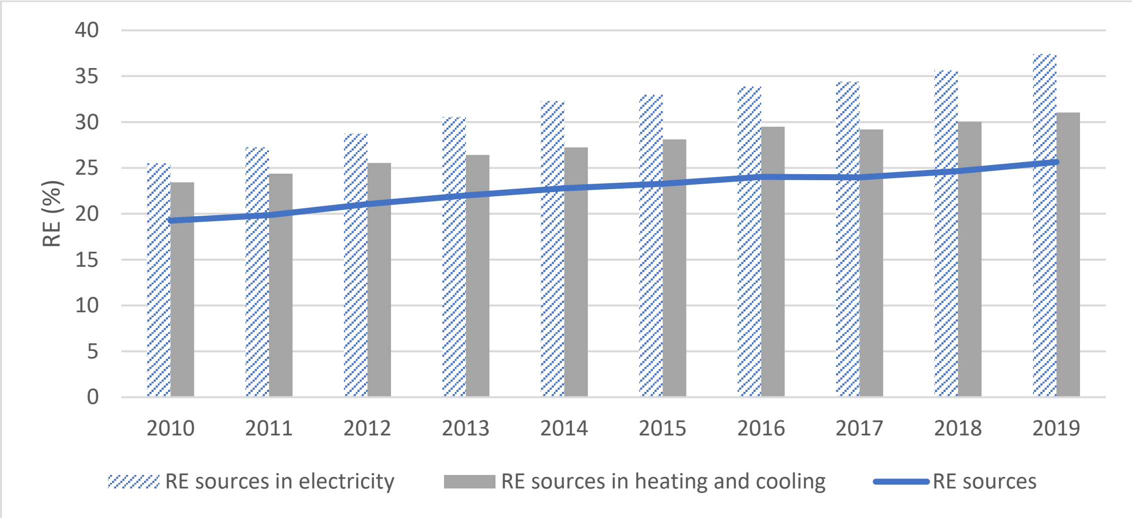


Table 3 presents the main statistics and the correlation matrix for the independent variables. According to the results, there is not a high level of variability: the standard deviations are lower than the means. In addition, the correlation matrix confirms the independence of the variables analysed: in no case is the coefficient close to one (except for the correlation between the different uses of RE, which does not represent a problem as they are not in the same model).

Table 3. Main statistics and correlation matrix

	Mean	SD	Max	Min	SM	GHG	EP	POP	RES(T)	RES(E)	RES(H)
SM	0.19	0.10	0.43	0.01	1						
GHG	9.78	7.44	45.70	1.70	-0.087	1					
EP	6.82	3.27	19.64	1.76	0.347	-0.085	1				
POP	16.94	22.46	83.02	0.32	0.220	-0.143	0.253	1			
RES (T)	22.60	17.12	78.2	0.98	0.148	0.285	-0.053	-0.283	1		
RES (E)	31.84	25.41	110.8	0.03	0.244	0.227	0.207	-0.139	0.905	1	
RES (H)	27.41	17.55	79.45	3.10	0.078	0.179	-0.284	-0.405	0.838	0.620	1

Note: RES (T): RE source in total; RES (E): RE source in electricity; RES (H): RE sources in heating and cooling

Iceland registers the maximum values in GHG emissions, mainly due to the use of polluting fuels in the fishing sector; at the same time, it leads the way in RE consumption for heating and cooling and in total (79.45% and 78.2%, respectively). According to the International Energy Agency, this country has been able to cover almost all its energy needs with renewable sources. For its part, Ireland registers the maximum in EP, and

Austria in electricity production capacity, with its production primarily concentrated in hydro (SM).

The island of Malta records the minimum values in the use of RE (0.98%), with electricity accounting for just 0.03%. Romania is in the worst position in terms of production capacity and Iceland in terms of energy productivity. Switzerland, considered one of the most sustainable and environmentally-friendly countries, records the minimum value in GHG emissions, underpinning the reputation it has gained thus far.

4. Results and discussion

Europe is on a trajectory characterized by effective energy policies and major investments (Hoerber and Weber, 2021). Having access to information on the progress made will help guide forthcoming governmental action. Below, the production and consumption of RE is analysed, providing an answer to the research questions raised.

Q1. Has there been a positive evolution in RE production capacity in Europe?

The proposed SM_i represents the renewable electricity production capacity (hydro, wind, solar and biofuels) of all the countries analysed, allowing the construction of a ranking to identify the leading nations in these types of facilities. Countries are then classified into four groups according to their situation: *favourable* (Group I), *fairly favourable* (Group II), *rather unfavourable* (Group III) and *unfavourable* (Group IV). Furthermore, in order to shed light on the evolution of RE in Europe, Table 4 shows the ranking at three different times—2010, 2015 and 2019—allowing an assessment of European countries' performance over time.

Table 4. Ranking of countries according to the SM

	SM 2010	Group		SM 2015	Group		SM 2019	Group
Austria	0.426	I	Austria	0.384	I	Sweden	0.419	I
Germany	0.368	I	Sweden	0.380	I	Austria	0.384	I
Spain	0.353	I	Germany	0.353	I	Netherlands	0.381	I
Belgium	0.341	I	Belgium	0.291	I	Germany	0.361	I
Sweden	0.328	I	Finland	0.284	I	Greece	0.353	I
Finland	0.259	II	Spain	0.278	I	Finland	0.346	I

Czechia	0.253	II	Denmark	0.270	II	Denmark	0.337	I
Denmark	0.221	II	Greece	0.259	II	Belgium	0.310	II
Latvia	0.220	II	Cyprus	0.217	II	Spain	0.289	II
Portugal	0.208	II	Netherlands	0.211	II	Norway	0.245	II
Greece	0.207	II	Portugal	0.210	II	Portugal	0.225	II
Cyprus	0.194	II	Italy	0.192	II	Hungary	0.222	II
France	0.176	II	Hungary	0.190	II	Cyprus	0.216	II
Norway	0.168	III	Norway	0.175	III	France	0.195	III
Lithuania	0.166	III	Czechia	0.174	III	Italy	0.188	III
Italy	0.154	III	France	0.167	III	Luxembourg	0.178	III
Netherlands	0.154	III	Latvia	0.161	III	Latvia	0.176	III
Slovakia	0.144	III	Luxembourg	0.149	III	Czechia	0.168	III
Iceland	0.139	III	Slovakia	0.149	III	UK	0.167	III
Luxembourg	0.116	III	Iceland	0.143	III	Poland	0.156	III
Hungary	0.114	III	UK	0.135	III	Lithuania	0.150	III
Poland	0.104	III	Poland	0.128	III	Slovakia	0.141	III
Ireland	0.084	III	Lithuania	0.116	III	Iceland	0.138	III
Bulgaria	0.067	III	Bulgaria	0.111	III	Ireland	0.136	III
UK	0.064	III	Ireland	0.102	III	Bulgaria	0.109	III
Estonia	0.060	IV	Estonia	0.084	IV	Estonia	0.106	IV
Slovenia	0.054	IV	Romania	0.078	IV	Malta	0.092	IV
Croatia	0.040	IV	Malta	0.073	IV	Romania	0.073	IV
Malta	0.018	IV	Slovenia	0.068	IV	Croatia	0.066	IV
Romania	0.012	IV	Croatia	0.055	IV	Slovenia	0.065	IV

As can be seen in Table 4, Austria, Germany and Sweden maintain their position in Group I; they are characterized by having a *favourable situation* in terms of electricity production capacity. It is shown that the natural resource endowment and climatic conditions of the Nordic countries stimulate the development of RE. According to Wang and Zhan (2019) Germany government encouraging enterprises based on the generation of renewable energy to improve their technology level and reduce their production cost until the prices for renewable energy are competitive in the market. In 2019, the Netherlands, Greece, Finland and Denmark were also in Group I, all economies where a large share of production is concentrated in wind power (38%, 36%, 30% and 69%, respectively).

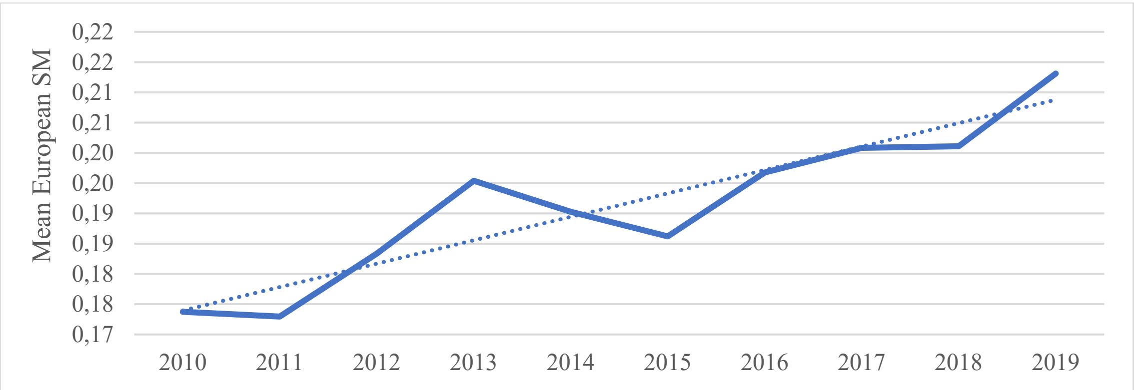
In Group II, Portugal and Cyprus are the only countries that remain stable in this category, displaying a *fairly favourable situation* in terms of the provision of infrastructure needed for RE. For Portugal, 52% of its capacity is concentrated in hydro energy production, while in Cyprus wind predominates (51%). It is of worthy note that Cyprus is the only EU member state whose electricity grid is not connected to the European power network, as it uses an independent network that relies on local production. Increasing the amount of renewable energy is one of the main options being looked at (Adun et al, 2022). In 2019, Belgium and Hungary (44% and 65% solar energy, respectively), Spain (44% wind) and Norway (92% hydro) were also classified in this group.

The path followed by the Netherlands merits special mention: in just 10 years the measures adopted in this country have enabled it to move from Group III in 2010 to Group I, eventually rising to third in the ranking. This is a nation that has managed to achieve the maximum electricity production capacity, with its resources oriented towards the generation of solar energy (60%) and wind energy (38%). According to Scheepers et al (2022) renewable energy – particularly from wind turbines and solar panels – is projected to account for the vast majority of electricity generation, around 99% in 2050.

Conversely, Estonia, Slovenia, Croatia, Romania and Malta have not been able to successfully direct their efforts towards the production of renewables, remaining in Group IV throughout the analysed period. The RE produced in Malta comes almost entirely from solar energy, since it is an island with numerous days of sunshine. Meanwhile, Slovenia, Croatia and Romania produce mainly hydro energy (82%,73% and 59%, respectively, in 2019) and Estonia mainly wind (51%).

In short, despite differences between territories, the EU is making a great effort to bring about a shift in energy generation, seeking out more production and use of renewable energies. Also, the EU pays particular attention to environmental protection and the development of the EU energy taxes (Wang and Zhan, 2019). All this is reflected in Figure 3, where it can be seen that the European SM follows a rising trend over the 10 years under analysis (Q1).

Figure 3. Evolution of mean SM values across Europe



Q2. Do factors that mitigate climate change drive RE consumption?

Climate change mitigation is one of the main concerns of developed countries, prompting a search for instruments to change the path they are on and ensure more sustainable development. Specifically, the reduction of GHG emissions, RE production capacity, and energy productivity facilitate this transition.[4] The panel data estimation yields evidence that confirms their influence on the consumption of renewables, differentiated by the end use of the RE (Table 5).

Table 5. Results of the estimation with panel data

	Total Random Eff.	Electricity Random Eff.	Heating and cooling Fixed Eff
	Model 1	Model 2	Model 3
SM	0.253***	0.682***	0.061*
GHG	-0.479***	-0.494***	-0.237***
EP	0.333**	0.299	0.461***
POP	0.016***	0.027**	0.012***
D_{2010}	-0.153***	-0.314***	-0.136***
D_{2011}	-0.117***	-0.133**	-0.093***
D_{2018}	0.113***	0.144**	0.083***
D_{2019}	0.083***	0.092	0.078***
R_{adj}	0.592	0.493	0.543
obs	300	300	300
Breusch and Pagan Lagrangian multiplier test			
Chibar2 (01)	1224.5	1059.7	1199.4
Prob>Chibar2	0.000	0.000	0.000
Hausman Test			
Chi(2)	12.84	4.17	20.32
p-value	0.117	0.841	0.009

Note: * p-value<0.1 ***p*-value<0.05, ****p*-value<0.01

Firstly, the Breusch–Pagan test indicate that the null hypothesis of homoskedasticity is rejected and heteroskedasticity assumed, then it is more appropriate to estimate with panel data. Secondly, the application of the Hausman test to each model confirms the suitability of random effects estimation in 1 and 2, with fixed effects being preferable in 3 (p-value

[4] Eurostat points to other factors besides these ones, but the available statistical information limits their analysis

<0.05). Thirdly, it has been tested with the Pesaran's test of cross sectional Independence that the residuals are independent of each other. The significance and the sign of the coefficients for the variables are homogeneous in all cases. The three factors that mitigate climate change behave in accordance with theoretical postulates: the coefficients of RE production infrastructure and energy productivity present a positive sign, while GHG emissions show a negative sign, in line with the literature (Marques et al., 2010; Marques and Fuinhas, 2012; Przychodzen and Przychodzen, 2020; Puertas and Martí, 2021a). According to Puertas and Martí (2021b), countries taking an active stance are managing to introduce RE into production systems, resulting in a reduction in GHG emissions. Given all of the above, Q2 can be answered in the affirmative.

The European population is displaying a keen awareness of environmental problems, hence the share of the population that supports the consumption of renewables. This coincides with the findings of Domhnaill and Ryan (2020), who concluded that the largest countries in Europe have done a better job of developing RE, by promoting its increased use. Furthermore, the positive evolution in the consumption of RE is reflected by the negative sign of the coefficients for the dummy variables D_{2010} and D_{2011} indicating that in the early years of the study, the consumption of renewables overall and for different end uses was lower than in the reference period (2012-2017). A reversal occurs at the end of the analysed period (2018-2019), where a positive sign appears. These results are in line with those reported by Kacperska et al. (2021), who also specify that the greatest changes in RE consumption occur in countries such as Malta, Estonia, Cyprus and Slovakia.

5. Conclusions

The need to invest in renewables to facilitate their use at all levels of society is an ever more crucial reality. RE is increasingly replacing fossil fuels for electricity generation, with steady growth established over the last decade; that said, the pace of the transition must increase if we are to achieve climate neutrality by 2050.

The results of the research provide an assessment of the achievements so far, allowing countries to determine their potential and facilitating the design of stimulus packages for a clean energy future. Sweden, Austria and the Netherlands head the ranking in RE production capacity in 2019, serving as a benchmark for Eastern European countries such as Romania, Croatia and Slovenia. However, moving up in the ranking would requires huge financial outlays, organizational and economic changes in most EU countries, including social acceptance of the introduced changes in individual countries.

Although different countries are progressing at different speeds, overall the European continent is displaying a positive evolution in its efforts to speed up the energy transition, demonstrating its strong commitment to mitigating climate change. In short, the conclusion to be drawn is that countries are increasing their use of cleaner, more environmentally-sustainable energy sources, although there is still a long way to go to achieve the established goals.

Other countries struggling to transit to renewable energy sources can learn from this study that the promotion of the use of energy from renewable sources should be a central element in its energy policy. Also, climate change mitigation factors allow for increased use of renewable energies, so countries should invest in promoting them. Ultimately, the improvement of the state of the environment, and hence the climate should become an absolute priority for the entire modern world.

The main limitation of this research is the lack of statistical information on both financial variables and the human capital needed for the implementation of RE. The results of this analysis can provide valuable information to leaders and companies dedicated to the supply of renewables. Future studies should seek to identify the impact of the indirect consequences of COVID on the path to clean energy use.

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