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The contributory capacity of natural capital to energy transition in the European Union

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ABSTRACT

In spite the growing attention on the role of carbon capturing and sequestration schemes in mitigating emissions, its contribution to the deployment of renewable energy remains uncomfortably low, especially in Europe. Thus, the current study contributes to the literature by investigating how natural capital captured by biocapacity amidst carbon emission influences renewable energy deployment by controlling for the role of openness to trade and oil utilization among the European countries. Based on a panel data analysis of over the period 1990–2016, we follow rigorous econometric approaches that accommodates country-specific factors such as the cross-sectional dependence, country-specific heterogeneity, and the non-stationarity dimension of the variables. Fundamentally, the results confirm the presence of significant long-term association among variables. The empirical results also authenticate that oil utilization and carbon emissions discourage renewable energy deployment by inelastic proportions. In essence, the result suggests that energy transition advancement is propelled by the deployment of carbon sequestration techniques through the expansion of natural capital. Moreover, evidence illustrates that the productive capacity of the Europe's ecosystem and openness to trade are critical to the region's energy transition policy, thus an influential factor of renewable energy supply. Furthermore, the causality analysis reveals a feedback effect between biocapacity and renewable energy, and between trade and renewable energy. The findings offer a platform for re-invent policy implications for the region.

1. Introduction

Since the ratification of the Kyoto Protocol in 1997, most European countries took leadership in international climate policy by adopting internal initiatives to fulfill the Kyoto protocol targets under the European Commission's guidance. To achieve their commitments, most EU State members are kin on the implementation of the continent energy and climate guidelines such as the energy efficiency Directive (EU) 2018/2002, Energy Performance of Buildings Directive (EU 2018/844), and the emission trading scheme (ETS) that aims to elaborate the clean development mechanisms, thus strengthening the pace of the green economy. In parallel to the increasing use/production of renewable sources, many EU countries are still dependent on imported fossil fuels, of which oil accounts for 87%, and natural gas, 62.7% [1]. This dependence on fossil fuels contributes to several prominent issues. Thus, there is a pressing need to develop a new energy paradigm capable of solving these significant global problems such as energy security and global warming in such a context. Renewable energy generation constitutes an essential pillar of the new energy paradigm, and it has become a high priority among energy policy strategies on a global scale. Following these influences, the knowledge of renewable energy determinants is central to designing a successful energy transition framework.[1]

In this respect, drivers of renewable energy have been examined from various perspectives. These perspectives mainly consider (i) the economic, market, and technological barriers to the

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[1] Against this background, an investigation of the determinants of European countries' renewable energy supply is much needed.

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Nomenclature

ADF	Augmented Dickey Fuller
ARDL	Autoregressive Distributed Lag
AMG	Augmented Mean Group
BEKK	Baba, Engle, Kraft and Kroner (1990)
BIO	Biocapacity
BRICS	Brazil, Russia, India, China, and South Africa
CE	Carbon dioxide emissions
CIPS	Cross-sectionally Augmented IPS
CSD	Cross-sectional Dependence
CADF	Cross-sectionally Augmented Dickey Fuller
DOLS	Dynamic Ordinary Least Square
DH	Dumitrescu and Hurlin
EC	Error Correction-based
ETS	Emission Trading Scheme
EU	European Union
FMOLS	Fully Modified Ordinary Least Square
GARCH	Generalized Autoregressive Conditional Heteroskedasticity
GDP	Gross Domestic Product
GHA	Global Hectares
IPS	Im, Pesaran and Shin (2003)
LM	Lagrange multiplier
Ln	logarithmic value
OECD	Organization for Economic Co-operation and Development
Oil	Oil consumption
OPEN	Openness to Trade
OLS	Ordinary Least Squares
PV	Photovoltaics
RE	Renewable Energy
RPS	Renewable Portfolio Standards
SSA	Sub-Saharan Africa
TOE	Tonnes of Oil Equivalent

deployment of renewable energy [2–5] (ii) social and institutional barriers [6,7] (iii) the role of solar, hydro, and wind energy [8–10] (iv) macroeconomic combined with environmental factors [11–14] (v) the contribution of traditional energy sources including coal, oil, natural gas and nuclear [13,15–17]. None of these studies has considered the role of biocapacity in affecting and explaining the deployment of renewable energy. In recent times, the burden of human activities on the biosphere's renewable natural capital has raised concerns about the sustainability of biodiversity [18,19]. The depletion of the natural ecosystem is likely to pose critical threats to renewable energy (RE) development since biodiversity offers striking inputs (water, land, forest, natural resources) for the deployment of renewable sources. The relatively lower biocapacity of developed countries Coscieme et al. [20] coupled with the increasing human burden on the existing renewable natural capital poses new challenges to the sustainability of renewable sources.

Apart from the issue of biocapacity, the implications of trade openness, oil consumption, and carbon emissions are of profound interest for practitioners and scholars. However, the existing energy literature is still far from conclusive. For instance, some authors claim that RE might not fully replace non-renewable sources (coal and natural gas), and recent studies have shown the existence of unidirectional causality running from renewable energy to non-renewable energy consumption [21]. Marques et al. [22] applied the ARDL approach Granger causality to explore the relationship between fossil fuels and RE across ten European countries from 1990 until 2014. Their investigation concludes that the substitution effect has been practical in solar PV, contrary to wind power. Furthermore, scholars have no agreement on the substitution effect between renewable and non-renewable energy sources [21,22] and the effects of carbon emissions and trade openness on renewable energy [12–20].

The main goal of your study is to investigate the impact of biocapacity on renewable energy by controlling for potential triggers discussed in the literature including, carbon emission, trade openness, and oil energy utilization. The case of European countries is studied thoroughly because (i) the member countries are subject to joint EU environmental policies and the majority of European countries also have national carbon emissions reductions and renewable energy targets alongside the regional goals; (ii) the EU region plays a significant role in environmental politics and policy-making across the world as its environmental and energy policies are expected to influence other regions in the world [26]; (iii) the region has increased their research and programs for energy and have deployed their renewable energy sources and technology over recent decades [27]. Regrettably, existing literature has relatively missed out of the inter-relationships among renewable energy supply, biocapacity, and carbon mitigation drive.

The contribution of the study is threefold. Firstly, we empirically explore the link between natural capital and renewable energy supply by accounting for the role of carbon emissions, oil consumption, and trade openness from 1990 to 2016. Secondly, we provide a better perspective on the consideration of natural capital in the energy transition debates in Europe. To the best of our knowledge, this is the first study looking at the potential of biocapacity in shaping the supply of renewable energy. Thirdly, we increase the policy relevance of our study by using panel data model to control for cross-sectional dependence and unobserved heterogeneity among panel members.

The remaining of the study is structured as follows: section 2 surveys past studies, section 3 introduces the data used and specifies the model, section 4 underlines the estimation strategy, section 5 presents and comments the empirical outcomes, section 6 discusses the outcomes in detail and provides relevant policy implications, section 7 concludes our study.

2. Review of existing studies

According to Table A, institutional factors play a considerable role in deploying renewable energy [16,28]. Carley [28] has studied the effectiveness of state energy programs through the linkage between renewable portfolio standards and renewable energy electricity generation accross states with state-level data from 1998 to 2006. He showed that states with RPS policies have significantly higher total RE deployment rates than states without RPS policies. In research done on BRICS from 1990 to 2010, Aguirre and Ibikunle [24] indicate that renewable technologies cannot be competitive as traditional energy technology without supporting policies. Likewise, several scholars discuss how government-backed energy policies play a major role in deploying RE [16,29,30]. As reported in Table A, Renewable portfolio standards, democracy, EU membership, subsidies, direct investment, research and development, feed-in tariffs and green certificate are among the political and institutional factors affecting significantly renewable energy.

The second group includes socio-economic factors, such as energy prices, GDP, income, oil, coal, and natural gas consumption, and carbon dioxide emissions. The fossil energy prices play an important role in determining the use of RE [31]. Bird et al. [32] investigated the policies and market factors driving wind power development in the United States and showed that higher natural gas prices positively impact RE sources. Their results suggested that the increasing cost-competitiveness of wind was attributable to higher hydrocarbon (natural gas) prices. Their findings have been contradicted by Ref. [33]. Indeed, Sadorsky [33] applied the panel cointegration technique to estimate the major drivers behind RE consumption. He found that oil price increases have a smaller although the negative impact on RE consumption. Sadorsky [34] employed a multivariate GARCH model to explore the volatility spillovers between oil prices and the stock prices of clean energy. He found that oil prices have volatility spillover effects on clean energy companies, and oil futures can be used to hedge an investment in clean energy stock prices. Wen et al. [35] also documented the return and volatility spillover effect between stock prices of Chinese new energy and fossil fuel companies using the asymmetric BEKK model. They found that positive news about new energy stock returns causes a subsequent fall in fossil fuel returns, which leads to a rise in new energy returns. Reboredo [36] established that oil price and RE displayed time-varying average and symmetric tail dependence. He showed that oil price dynamics contribute around 30% to the downside and upside risk for RE companies. Recently, Reboredo et al. [37] studied co-movement and causality between oil and RE stock prices. They provide evidence that there exists nonlinear causality ranging from RE to oil prices. The Sadorsky [33] results were further corroborated by Silva et al. [31], who concluded that the price of fossil fuels negatively affects renewable sources. The impact of oil prices on RE remains inconclusive. Da Silva et al. [31] studied the determinants of RE growth in SSA. They found that an increase in GDP per capita positively influences the adoption of renewable sources while population growth and carbon emission negatively impact renewable sources.

Some authors focused on the effect of economic growth on renewable development [13,15,27,38–41]. These studies provide mixed evidence regarding the impact of economic growth on renewable energy. For instance, Marques et al. [15], data supported the positive correlation between GDP and renewable energy. Papiez et al. [13], found that GDP per capita, the concentration of energy supply, and the cost of energy consumption obtained from fossil fuels positively influence the deployment of renewable energy. Unlike previous findings, Valdés Lucas et al. [42], analyzed the effect of different energy security concepts on the deployment of RE across 21 EU Member States. Their findings showed that per capita GDP negatively affect RE deployment. Cadoret and Padovano [38] and Eren et al. [40], have also reached a similar conclusion. In addition, Eren et al. [41], showed that oil consumption negatively influences RE deployment. This finding was corroborated by earlier scholars [44], who showed that a decrease in oil consumption positively influences RE consumption in China.

Another important socio-economic factor includes carbon dioxide emissions [13,16,23,25,45]. [16] evaluated the drivers of RE sources focusing in 24 European countries by using panel data analysis from 1990 to 2006. They proved that higher emissions of CO_2 tend to discourage the development of renewable energy. Most authors [13,23,25,45], confirm that environmental concerns are negatively correlated with RE development. Contrary to this argument [24], found that environmental concerns proxied by CO2 emissions levels positively influence renewables deployment.

The third group includes country-specific factors such as natural endowment, the structure of the energy market, and trade policies. Natural resource endowment has been an essential factor in investigating the preconditions and drivers of RE deployment [46]. Scholars have identified either positive, negative, or insignificant effects of natural resource endowment on RE development. For instance, some studies reported negative effects [15,24,28], while other authors found a positive correlation between natural resource endowment and RE deployment [46,47]. There is also literature describing RE structure in some countries, such as the wind energy sector Hitaj [48]. In the US, Lin and Zhu [49] in China, Matti et al. [50], in Spain, Bórawski et al. [51], in Europe. These authors highlighted the role of policy and markets for the development of RE sources. Another strand of publications focuses on the role of trade in the deployment of renewable sources. There is also a lack of consensus in the literature about the effect of trade on renewable energy. Although several studies have concluded to the positive effect of trade openness on RE [34,52], there is still ambiguity engulfing the direction of causation between trade openness and renewable energy. For instance, some authors found a bidirectional linkage between openness and RE [39], while some authors found unidirectional causality flowing from openness to RE [53,54]. In contrast, the existence of no causal relationship between trade openness and RE has been evidenced by Ref. [55].

3. Data collection and research model

In exploring the determinants of renewable energy, we collect data for the period 1990–2016 for 14 European countries that are driving the energy transition policy of the region: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, and Switzerland. These countries implemented national and international legislations to increase the share of RE in total energy, and most of the EU countries display huge differences in terms of investments in RE. Also, the level of development of renewable energy sectors in Europe plays a vital role in attaining regional and global renewable energy goals. For these reasons, our study focuses on the leading countries in the renewable sectors in Europe.

Data on renewable energy supply were gathered from the OECD database, trade openness is obtained from World Development Indicators, while the per capita biocapacity from the Global Footprint Network. Oil consumption and carbon dioxide emissions were extracted from the BP Statistical Review (2017). Stemming from 1990 to 2016, the study period covers the adoption of several international and national climate and RE policies such as the European-ETS initiative in 2005 and the Paris Agreement 2015. Table 1 presents information about the underlying variables. Moreover, a flow chat is presented as a guide to illustrate the respective procedures (from the preliminary test such as the correlation, cross-sectional dependence, stationarity, and cointegration) toward enabling the objective of the study (see Fig. 1).

The Table 2, 3-a, and 3-b respectively illustrates the summary statistics, countries' profile of the concerned indicators, and the correlations of the variables. The descriptive statistics of each series consist of their mean, standard deviation, maximum, minimum after taking the transformation into logarithms. On average, we record 8.520, 4.870, 4.347, as the highest mean of renewable energy, carbon dioxide emanations, and trade openness, respectively (Table 2). Our empirical statistics in Table 3—a reveal that France has the largest contribution of renewables to the total primary energy supply (9.785 thousand tonnes of oil equivalent (toe) % of primary energy supply) and Ireland has the smallest contribution of renewables to primary energy supply (5.841 thousand tonnes of oil equivalent (toe) % of primary energy supply). One may observe from Table 3—b that Finland, Sweden, and Norway have greater per capita BIO while other countries experience low BIO per capita. A higher proportion of oil consumption is observed in Europe, indicating that oil products are largely used in several sectors such as

Table 1
Description of variables.

Variables	Description
Renewable Energy (RE)	The share of renewable sources to total primary energy supply
Biocapacity (BIO)	The productivity of a nation's ecological assets (including cropland, grazing land, forest land, fishing grounds, and built-up land9
Trade (OPEN)	Ratio of exports and imports to GDP
Oil consumption (Oil)	Include crude oil, shale oil, biogasoline (such as ethanol), biodiesel, and derivatives of coal and natural gas
Carbon dioxide emissions (CE)	Carbon discharges stemming from oil, gas, and coal for combustion-related activities.

Note: All the variables are taken in natural logarithms in the empirical analysis.

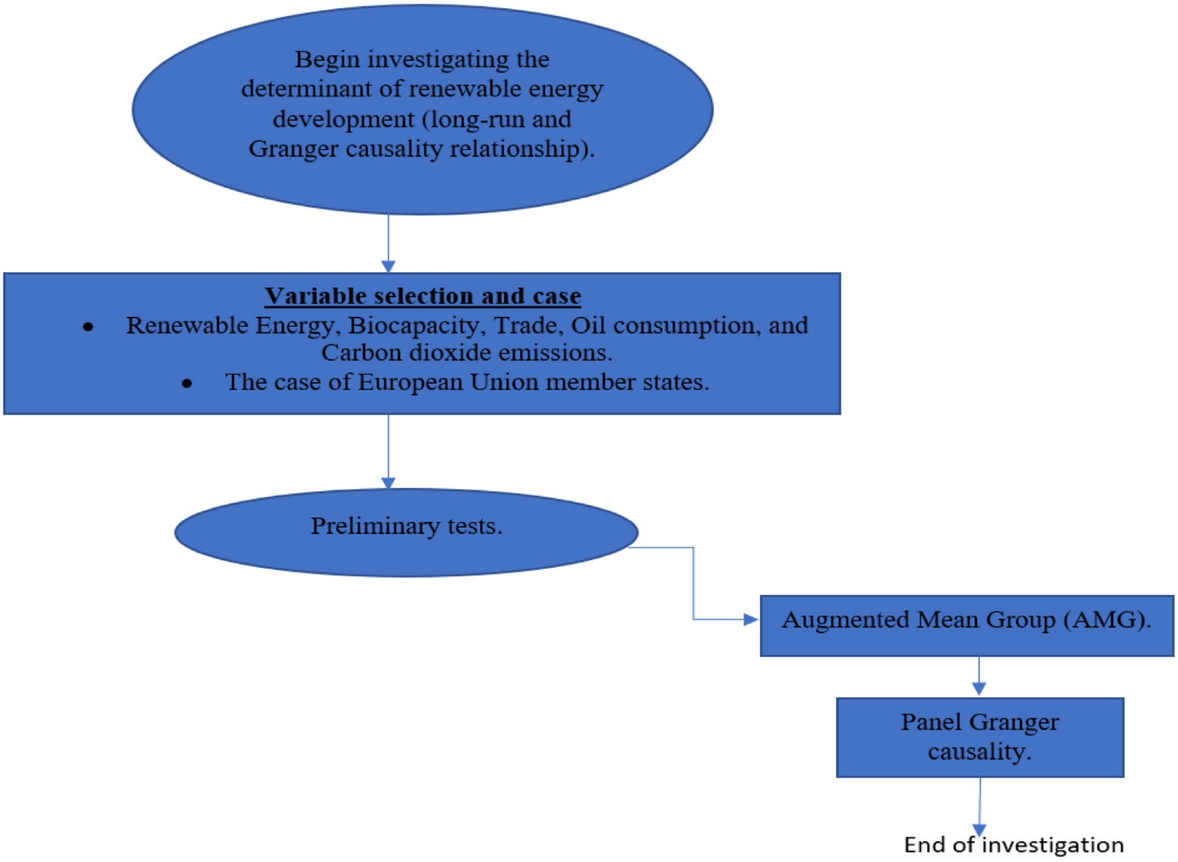

Fig. 1. The flow chart of the investigation procedure.

transportation, power generation, and infrastructure (Bianco et al., 2019).

Table 3–b presents the correlation matrix of all variables, including the level of significance (p-values). BIO is positively and significantly correlated to RE (0.797) from the correlation matrix, which may capture the key role of per capita biocapacity in the development of RE. Trade openness is negatively and significantly associated with RE (−0.577), which is contrary to our predictions. Indeed, our sample countries are technologically advanced, as a result, trade does not necessarily generate technology transfer from the rest of the world to improve the technological dimension of RE. Oil consumption is negatively and significantly associated with RE, capturing the substitution effect between oil consumption and RE. Unexpectedly, CE is negatively linked to RE, contrary to the most common hypothesis that environmental concerns are incentives for the expansion of RE. Overall, the correlation matrix in Table 3–b only describes the preliminary relationship between variables.

3.1. Empirical model

Based on previous studies as discussed in previous section, biocapacity indicator, oil consumption and carbon emissions, and trade openness were selected as independent variables and most likely determinants of renewable energy.

As a result, we specify the potential drivers of renewable energy as well into another model as follows:

$$lnRE_{it} = a_{0i} + a_{1i}lnBIO_{it} + a_{2i}lnOPEN_{it} + \alpha_{3i}lnOIL_{it} + \alpha_{3i}lnCE_{it} + v_{it} \tag{1}$$

where *lnBIO, ln TR, lnOIL, lnCE* denote the natural logarithms of the biocapacity, trade openness oil consumption, and, carbon emissions, respectively.

Based on Zhang et al. [56], biocapacity was used as a proxy for renewable natural capital. Biocapacity englobes the number of ecosystem goods and services generated within a country over a

Table 2
Descriptive statistics (1990–2016).

Variables	No. Obs.	Mean	Std. Dev.	Min	Max
lnRE	378	8.520306	1.217578	5.040783	10.56914
lnOIL	378	3.289369	.9875208	1.481605	4.922896
lnBIO	378	.947479	.8962189	-.2418397	2.64444
lnCE	378	4.870987	1.063421	3.370738	6.91095
lnOPEN	378	4.347852	.4003085	3.522779	5.420718

Notes: No. Obs.: indicates number of observations, Std. Dev.: indicates standard deviation, Min: minimum and Max: maximum. Compiled by the authors.

Table 3-a
Profile of RE, OIL, BIO, CE and OPEN per country.

Country	lnRE	lnOIL	lnBIO	lnCE	lnOPEN
Austria	8.864421	2.528066	1.139366	4.16992	4.4512
Belgium	7.005066	3.416229	-.0697998	4.880475	4.918029
Denmark	7.740954	2.223831	1.520006	4.012653	4.427802
Finland	8.951363	2.338515	2.602755	4.077785	4.224998
France	9.785757	4.486624	1.031439	5.891967	3.941393
Germany	9.504571	4.820483	.5174939	6.733928	4.138599
Ireland	5.841596	1.955262	1.325849	3.679839	5.048291
Italy	9.489921	4.408657	.0380994	6.014436	3.856282
Netherlands	7.468224	3.743892	-.0908537	5.390035	4.802129
Norway	9.379674	2.308258	2.117682	3.580437	4.249415
Spain	9.111764	4.171513	.3670009	5.671725	3.942843
Sweden	9.569351	2.796555	2.352679	4.054972	4.316954
Switzerland	8.41144	2.487313	.1954357	3.743926	4.582284
Portugal	8.160187	4.365964	.2175521	6.291723	3.969707
Total	8.520306	3.289369	.947479	4.870987	4.347852

Note: This table displays the mean value of renewable energy (RE), per capita biocapacity (BIO), trade openness (TR), oil consumption (OIL) and carbon emissions (CE). All the variables are converted in natural logarithmic forms (ln).

Table 3-b
The correlation matrix.

	lnRE	lnOIL	lnBIO	lnCE	lnOPEN
lnRE	1				
lnOIL	−0.353***	1			
lnBIO	0.797***	−0.609***	1		
lnCE	−0.269***	0.977***	0.600***	1	
lnOPEN	−0.577***	−0.528***	−0.0626	−0.505***	1

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

year. In other words, biocapacity measures the maximum biological capabilities available (land and sea area) to provide low-entropy raw materials and absorb high-entropy wastes [57]. BIO is measured in global hectares per capita (gha). Since BIO includes factors such as total land surface, forestland, waterfalls, forest bioenergy, solar irradiation, animal products, and waste, wind, which needs to be sufficiently enough to make RE production competitive, we explore the linkage between BIO and RE.[2] Accordingly, we expect a positive sign of a_{1i} across European countries, indicating a positive association between biocapacity and RE supply.

Another essential determinant of RE we consider in this study is trade openness. The degree of openness is critical for the development of RE sectors. For instance, Amri (2019) showed that trade openness positively influences renewable energy. Similar results have been reached by Sebri and Ben-Salha (2014), but some studies have found that improvements in the trade do not facilitate the deployment of RE Murshed (2018). Using trade openness, Ben Aïssa et al. (2014) found no causal relationship between trade openness and renewable energy.

Oil consumption is used to capture the role of fossil fuel consumption in the development of renewable energy. The EU's higher reliance on oil consumption (which accounts for more than 70%), could pose important challenges, including global warming, current account imbalances, delays in the transition to a RE production mix. The inclusion of oil consumption as a driver of RE provides a picture of the substitution effect of oil consumption and renewable energy.

Following previous studies, we analyze the relationship between environmental pollution and renewable energy. studies suggest that carbon dioxide emissions mitigation through carbon capturing and sequestration could offer co-benefits from renewable energy and environmental quality perspectives, thus an important factor that affects RE supply [25,44]. Since an increase in carbon dioxide emissions leads to prominent environmental pollution and global warming issues and driving clean technologies, we anticipate a positive linkage between environmental pollution and RE consumption.

4. Estimation method

The determinants of renewable energy are examined by following a robust estimation strategy. Firstly, we investigate the presence of cross-sectional dependence (CSD) and slope homogeneity in our model by considering the merits and demerits of various tests. Secondly, we investigate the stochastic properties of our model by accounting for cross-sectional dependence across panel members. Thirdly, we examine the long-run relationship between variables by performing robust panel cointegration tests. Fourthly, we estimate the coefficients of the regression model by using various estimation techniques. Lastly, the causal relationship between variables is investigated by using the heterogenous Granger-causality tests.

4.1. CSD and homogeneity tests

Given the current state of cooperation and joint policies to curb emissions among European countries, there is a higher chance of CSD across panel members. This study employs the CSD tests advanced by Breusch and Pagan [60], Pesaran [61], and Pesaran et al. [62], to check the presence of CSD in our panel dataset. Furthermore, we check the possible heterogeneity across European countries by applying the slope homogeneity test proposed by Hashem Pesaran and Yamagata [63].

The Lagrange multiplier (LM) statistics proposed by Ref. [60] for cross-sectional testing dependence can be specified as:

$$\mathrm{CSD}_{\mathrm{BP}} = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{\rho}_{ij}^{2} \tag{2}$$

where $\widehat{\rho}_{ij}$ represents the sample estimated correlation coefficient of the residuals from Ordinary Least Squares (OLS) estimations. Under the null hypothesis of no cross-sectional dependence, the LM test is valid for panels in which $\mathrm{T} \to \infty$ with fixed N. For macro panels whereby N and T are large, Pesaran [61] proposed the scaled version of the LM test as follows:

$$\mathrm{CSD}_{\mathrm{LM}} = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T\widehat{\rho}_{ij}^{2} - 1 \right) \sim N(0,1) \tag{3}$$

where, $\widehat{\rho}_{ij}$ denotes the sample correlation coefficients obtained from OLS estimations. More so, T is the time dimension, and N is the

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[2] Biocapacity englobes some critical raw materials required for the implementation of renewable energy.

number of countries under investigation.

However, the CSD_{LM} suffers from serious size distortion problems as T becomes large. Pesaran [61] proposed a more general cross-sectional dependence test that is valid for the panel where T→∞ and N→∞.

$$CSD_{LM} = \sqrt{\left(\frac{2T}{N(N-1)}\right)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{\rho}_{ij} \right) \sim N(0,1) \tag{4}$$

where $\widehat{\rho}_{ij}$ represents the sample estimated correlation coefficient of the residuals from Ordinary Least Squares (OLS) estimations. T is the time dimension, N is the number of countries. The CSD_{LM} the statistic is normally distributed.

Pesaran et al. [62], developed a modified version of the LM test to account for CSD when the factor loading is close to zero. This new version known as the bias-adjusted version of the LM test is calculated as follows:

$$LM_{adj} = \sqrt{\left(\frac{2}{N(N-1)}\right)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{\rho}_{ij} \frac{(T-k)\widehat{\rho}_{ij}^{2} - \mu_{Tij}}{\sqrt{\nu_{Tij}^{2}}} \sim N(0,1) \tag{5}$$

where μ_{Tij} and ν_{Tij}^2 are the respective mean and variance of $(T-k)\widehat{\rho}_{ij}^2$.

We used the slope homogeneity test proposed by Hashem Pesaran and Yamagata [63] to explore the degree of homogeneity of European countries. This test is valid for macro panel data with large T and N and does not impose any restrictions on the sample size when the error terms are normally distributed. The null hypothesis of homogeneity (H_0: $\beta_i = \beta$, for all i) is tested against the alternative hypothesis of slope heterogeneity (H_1: $\beta_i \neq \beta_j$) for a non-zero fraction of pairwise slopes for i ≠ j. The slope homogeneity test is based on the scale version of the Swamy [64] as described below:

$$\tilde{s} = \sum_{i=1}^{N} \left(\widehat{\beta}_i - \widehat{\beta}_{WFE} \right) \frac{x_i' M_\tau x_i}{\widehat{\sigma}_i^2} \left(\widehat{\beta}_i - \widehat{\beta}_{WFE} \right), \tag{6}$$

where $\widehat{\beta}_i$ is the OLS estimator and $\widehat{\beta}_{WFE}$ is the fixed-effect pooled estimator, M_τ is an identity matrix, and $\widehat{\sigma}_i^2$ is the estimator of error variance. The authors derived the slope homogeneity test from a standardized version of Swamy's test and developed the test denoted by Δ_{adj}:

$$\tilde{\Delta}_{adj} = \sqrt{N} \left(\frac{N^{-1}\tilde{s} - E(\overline{z}_{it})}{\sqrt{var(\overline{z}_{it})}} \right) \tag{7}$$

where $E(\overline{z}_{it}) =$ k and $var(\overline{z}_{it}) =$ 2k(T-k-1)/(T+1).

4.2. Stochastic properties of the series

Since there is evidence of both CSD and heterogeneity across European countries, we employ the panel unit root tests proposed by Pesaran [65]. The author developed a modified version of the Dickey-Fuller based panel unit root test to asymptotically eliminate CSD in the model. The new test denoted as a cross-sectionally augmented dickey fuller (CADF) can be calculated as follows:

$$y_{i,t} = (1-\delta_i)\mu_i + \delta_i y_{i,t-1} + \nu_{i,t} \tag{8}$$

where $\nu_{i,t} = \gamma_i f_t + e_{i,t}$, with f_t the observed common factor, $e_{i,t}$ is the individual-specific error. To account for unit root hypotheses Eq. (8) can be respecified as:

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i f_t + e_{i,t} \tag{9}$$

$\alpha_i = (1-\delta_i)\mu_i$, $\beta_i = -(1-\delta_i)$ and $\Delta y_{i,t} = y_{i,t} - y_{i,t-1}$. The null and alternative hypotheses can be specified as follows:

$$H_0 : \beta_i = 0 \text{ for all } i,\ H_1 : \beta_i < 0 \text{ for i} = 1, 2, \ldots.. N_1,\ \beta_i = 0 \text{ for i} = N_1 + 1, N_1 + 2, \ldots\ldots N.$$

The following CADF regression is used in Pesaran [65] to test the above hypothesis.

$$\Delta y_{i,t} = a_i + b_i y_{i,t-1} + D_0 \overline{y}_{t-1} + D_i \Delta \overline{y}_t + \varepsilon_{i,t} \tag{10}$$

where $\overline{y}$ is the proposed proxy of the unobservable common factor proposed by Ref. [65] to remove the cross-section dependence due to a common shock that affects all the units similarly [65]. derives a cross-sectional augmented version of the IPS-test

$$CIPS = \frac{1}{N} \sum_{\prime=1}^{N} CADF_i \tag{11}$$

4.3. Westerlund cointegration tests

As discussed earlier, ignoring CSD may lead to wrong inferences. For this reason, we study the cointegration nexus among variables based on Westerlund [66] cointegration tests. We estimate the cointegration test in a more efficient way through four statistics, including two group statistics (Group-τ and Group-α) and two panel statistics (Panel-τ and Panel-α). The error correction-based (EC) panel cointegration test advanced by Westerlund [66] can be estimated as follows:

$$y_{it} = \alpha_{0i} + \alpha_{1i} t + z_{it} \tag{12}$$

$$x_{it} = x_{it-1} + u_{it} \tag{13}$$

where i = 1 …..N and t = 1, …. ….T with z_{it} specified as

$$\delta_i(L) z_{it} = \delta_i \left(z_{it-1} - \gamma_1' x_{i,t-1} \right) + \beta_i(L)' u_{it} + \varepsilon_{it} \tag{14}$$

Westerlund [66] derived the EC by replacing (12) with (13) and generated the following equation:

$$\delta_i(L) \Delta y_{it} = \theta_{0i} + \theta_{1i} t + \delta_i \left(y_{it-1} - \gamma_1' x_{i,t-1} \right) + \beta_i(L)' u_{it} + \varepsilon_{it} \tag{15}$$

where the deterministic components are given by $\theta_{0i} = \delta_i(1)\alpha_{1i} - \delta_i \alpha_{0i} + \delta_i \alpha_{1i}$ and

$$\theta_{1i} = - \delta_i \alpha_{1i}.$$

From Equation (15), we test the null hypothesis $H_0 = \delta_i = 0$, for all i, against the alternative hypothesis $H_1 : \delta_i = \delta < 0$ for all i. This test is valid for the two-panel statistics and the rejection of the null hypothesis indicates that the whole panel is cointegration. In the case of the group statistics, the null hypothesis is also $H_0 = \delta_i = 0$ while the alternative hypothesis is specified as $H_1 : \delta_i < 0$ for at least one subgroup i.

The four panels and group mean statistics can be specified as

$$P_\tau = \frac{\widehat{\delta}}{\widehat{\sigma}_{\widehat{\delta}}}\ P_\alpha = T_{\widehat{\delta}}\ ,\ \text{and}\ G_\tau = \frac{1}{N}\sum_{i=1}^{N}\frac{\widehat{\delta}_i}{\widehat{\sigma}_{\widehat{\delta}i}},\ G_\alpha = \frac{1}{N}\sum_{i=1}^{N}\frac{T\widehat{\delta}_i}{\delta_i(1)} \tag{16}$$

In which, $\delta_i(1) = \widehat{\omega}_{ui}/\widehat{\omega}_{yi}$ where $\widehat{\omega}_{ui}$ and $\widehat{\omega}_{yi}$ represent the long-run variances.

4.4. Augmented mean group (AMG)

Eberhardt and Bond [64] and Eberhardt [65] advanced the AMG model to consider cross-sectional dependence, country-specific heterogeneity, and serial correlation in macro panel datasets. The AMG model used two-step estimations techniques that incorporate a common dynamic process to account for cross-sectional dependency among units in the second stage. In the first step, Eberhardt and Bond [64] estimate the following equation:

$$\Delta y_{it} = \beta\Delta x_{it} + \sum_{t=2}^{T} c_t\, \Delta D_t + v_{it} \tag{17}$$

In this standard pooled first-difference model, D_t represents time dummies with c_t the coefficients associated with the time dummies. c_t are turned into a variable shared across units $\widehat{\mu}_t$, so that, the coefficient estimate will exist for each time period ($c_t = \widehat{\mu}_t$). In the second stage, the estimated coefficient $\widehat{\mu}_t$ is incorporated in each of the panel unit regression, as below:

$$\Delta y_{it} = \alpha_i + \beta_i x_{it} + d_i\widehat{\mu}_t + v_{it} \tag{18}$$

$$\beta_{AMG} = N^{-1}\sum_{i=1}^{N}\widehat{\beta}_i$$

where d_i represents the time, dummy used to approximate the unobserved common dynamic process. β_{AMG} is used to capture the long-run relationship between the variables.

4.5. Panel causality tests

Testing for causality is the most important step when analyzing the relationship between variables. In this study, we used the Dumitrescu and Hurlin [69] Granger causality test to test for heterogeneous non-causality relationships among variables. The Dumitrescu and Hurlin (hereafter DH) panel causality test is based on the individual Wald statistic is valid under cross-sectional dependence. DH considers the following regression:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K}\theta_{ik}y_{i,t-k} + \sum_{k=1}^{K}\psi_{ik}x_{i,t-k} + \varepsilon_{it} \tag{19}$$

where $y_{i,t}$ and $x_{i,t}$ are stationary and the autoregressive parameter θ_i and the regression coefficient ψ_i differ across units. K represents the lag length.

$$H_o : \psi_{i1} = \ldots = \psi_{ik} = 0 \quad \forall\ \mathrm{i} = 1, \ldots.., N \tag{20}$$

The null hypothesis H_o assumes homogenous non-causality between variables.

$$H_1 : \psi_{i1} = \ldots = \psi_{ik} = 0 \quad \forall\ \mathrm{i} = 1, \ldots.., N_1$$

$$\psi_{i1} \neq 0\ or \ldots or\ \psi_{ik} \neq 0 \quad \forall \mathrm{i} = N_1 + 1, \ldots.., N$$

H_1 implies that the causality relationship between variables is heterogeneous. The corresponding individual Wald statistics ($W^{Hnc}_{N,T}$) generated by DH is given by:

$$W^{Hnc}_{N,T} = N^{-1}\sum_{i=1}^{N} W_{i,T} \tag{21}$$

with $W_{i,T}$ representing the Wald statistics for each subgroup.

5. Empirical results

The results of CSD and slope homogeneity tests are reported in Table 4. The null hypothesis of no cross-sectional independence is strongly rejected at the 1% level of significance, indicating that second-generation panel estimation techniques allowing for CSD are suitable for this study.

Table 4 suggests that the null hypothesis of slope homogeneity is strongly rejected at a 1% level. These findings imply that there is substantial heterogeneity across European countries. Therefore, the estimation strategy in this paper should account for both CSD and country-specific heterogeneity to avoid estimation bias.

5.1. CADF panel unit root results

We examine the stochastic property of the underlying variables by employing the CADF panel unit root tests proposed by Pesaran [65]. As discussed earlier, the CADF panel unit root tests have the advantage of accommodating both CSD and slope heterogeneity across panel members. The simulation results are presented in Table 5. The stochastic property of the variables can be summarized as follows: (i) For the dependent variable (RE) the null hypothesis of unit root is rejected for only three countries, including Austria, Sweden and Switzerland, while there is evidence that stationarity is reached after the first differencing for Belgium, Denmark, Finland, France, Ireland, Italy, Germany, Netherlands and, Spain; (ii) Biocapacity indicator also rejects the null hypothesis of unit root at level for six countries (Denmark, Finland, France, Germany, Switzerland and Portugal) and there is stationarity at first difference for Austria, Italy, Netherlands, Norway, Spain and Sweden; (iii) For Belgium, Denmark, Finland, Sweden and Portugal, we reject the null hypothesis of unit root at level, while first differencing oil consumption yields stationarity for the whole sample of countries; iv) Carbon emission seems stationary at level for Denmark, Finland, France, Netherlands, Norway, Spain, Sweden and Switzerland and becomes stationary at level for all the fourteen countries; v) trade openness is stationary for five countries out of fourteen (Austria, Finland, Spain, Switzerland and Portugal) while it appears stationary for all the fourteen countries after taking first difference. Another important finding is that all variables are stationary at first

Table 4
CSD and homogeneity results.

Variables	lnRE	lnBio	lnOPEN	lnOil	lnCE
CSD_{BP}	1923.856[a]	1208.730[a]	1612.617[a]	864.060[a]	884.618[a]
P-value	0.000	0.000	0.000	0.000	0.000
CSD_{LM}	134.822[a]	81.813[a]	111.752[a]	56.265[a]	57.789[a]
P-value	0.000	0.000	0.000	0.000	0.000
LM-adj	134.496[a]	81.544[a]	111.428[a]	55.996[a]	57.519[a]
P-value	0.000	0.000	0.000	0.000	0.000
			Slope homogeneity		
			$\tilde{\Delta}$		$\tilde{\Delta}_{adj}$
LM Stat.			−6.062[a]		−4.503[a]
P-value			0.000		0.000

Notes: [a] indicates the level of significance at 1%.

Table 5
CADF unit root tests.

Country	lnRE	ΔlnRE	lnBio	ΔlnBio	lnOPEN	ΔlnOPEN	lnOil	ΔlnOil	lnCE	ΔlnCE
Austria	-4.71^{c}	-6.15^{a}	−3.24	-4.68^{c}	-5.77^{a}	-6.58^{a}	−1.67	-3.84^{c}	−3.24	-4.46^{b}
Belgium	−2.45	-6.31^{a}	−3.05	-3.96^{c}	-3.75^{c}	-7.12^{a}	−2.08	-4.36^{b}	−3.45	-4.99^{a}
Denmark	−3.70	-4.98^{a}	-6.36^{a}	-5.96^{a}	−3.14	-6.45^{a}	-3.57^{c}	-5.93^{a}	-4.29^{a}	-5.59^{a}
Finland	−2.58	-5.36^{a}	-7.25^{a}	-5.79^{a}	-3.55^{c}	-6.45^{a}	-3.61^{c}	-6.23^{a}	-5.36^{a}	-7.88^{a}
France	−2.89	-4.95^{b}	-6.98^{a}	-5.19^{a}	−2.99	-5.62^{a}	−1.78	-4.94^{b}	-4.56^{b}	-6.63^{a}
Germany	−3.58	-4.04^{b}	-3.96^{c}	-4.25^{b}	-3.56^{c}	-4.77^{b}	-3.78^{c}	-4.23^{b}	-3.56^{c}	-4.77^{b}
Ireland	−2.15	-3.89^{c}	−2.99	-3.94^{c}	−1.89	-3.99^{b}	−2.17	-3.99^{b}	−2.23	-4.53^{b}
Italy	−2.09	-3.96^{c}	−2.80	-4.27^{b}	−2.55	-4.79^{b}	−3.49	-4.99^{b}	-3.89^{c}	-5.89^{a}
The Netherlands	−3.05	-3.99^{c}	−2.57	-4.39^{b}	−2.08	-5.33^{a}	−3.46	-5.69^{a}	-3.79^{c}	-5.19^{a}
Norway	−3.59	-3.59^{c}	−2.56	-5.25^{a}	-4.02^{b}	-7.89^{a}	−3.11	-5.96^{a}	-4.09^{b}	-6.87^{a}
Spain	−3.47	-4.66^{b}	−2.45	-5.89^{a}	-3.63^{c}	-6.08^{a}	-3.65^{c}	-5.63^{b}	-5.09^{a}	-6.73^{a}
Sweden	-4.92^{b}	-3.58^{c}	−2.97	-6.58^{a}	−2.56	-4.37^{b}	-3.77^{c}	-5.19^{b}	-4.56^{a}	-6.99^{a}
Switzerland	-4.56^{b}	-4.99^{a}	-3.93^{c}	−2.91	-3.97^{c}	-6.49^{a}	-3.58^{c}	-4.59^{b}	−3.53	-4.79^{b}
Portugal	−3.37	-5.09^{a}	-3.69^{c}	-3.76^{c}	-4.83^{b}	-5.31^{a}	−2.59	-4.26^{b}	−3.07	-4.22^{b}
Panel (CIPS)	−2.23	-4.66^{a}	-3.98^{a}	-4.24^{a}	−2.05	-4.56^{a}	−2.23	-5.92^{b}	−2.45	-6.53^{a}

Notes: ^{a}, ^{b} and ^{c} indicate 1%, 5% and 10% level of significance, respectively. 1%, 5%, and 10% critical values for individual units are −4.97, −3.99, and −3.55, respectively. 1%, 5%, and 10% critical values for the whole panel are −3.15, −2.92, −2.74, respectively. Critical values are obtained from Pesaran (2007). Δ denotes the first difference operator. The model includes both trend and intercept.

differences when one observes the CIPS statistics. Consequently, one may conclude that all variables are integrated of order one, which leads us to explore the possible cointegration relationship among variables.

5.2. Error correction-based bootstrap cointegration results

The results of the panel cointegration tests are illustrated in Table 6. Considering all statistics and the bootstrap p-values, we found that all the four statistics support the long-run cointegrating relationship.

This shows the presence of cointegration among the model parameters in Europe for the experimental period 1990–2016. After this stage, we estimate the long-run elasticities of the determinants of RE.

5.3. Augmented mean group (AMG) estimation results

Our study relies on the AMG methods developed by Eberhardt and Bond [67], Eberhardt [68] to estimate the long-run effects of biocapacity on RE. This approach perfectly addresses the cross-sectional dependency, country-specific heterogeneity and allows the examination of the parameters of nonstationary variables. Besides the AMG approach, we adopt the FMOLS and DOLS estimators suggested by Pedroni (2001 a,b) and Kao and Chiang (2001). These estimators account for heterogeneous panels and they are robust to substantial heterogeneity in cross-sections. Consequently, our findings are robust to various types of biases that may arise in panel data estimation. Table 7 displays the estimates computed to estimate the determinants of RE in Europe.

Table 6
EC bootstrap panel cointegration.

EC	Statistics	Asym. p-value	Boot. p-value
g_tau	-6.260^{a}	0.000	0.001
g_alpha	1.197	0.190	0.152
p_tau	-3.780^{a}	0.000	0.000
p_alpha	-3.951^{a}	0.010	0.000

Notes: ^{a} shows the rejection of no cointegration at the 1% level of significance. We used constantly with trend one lag and one lead. Our approach is based on the width of the Bartlett Kernel window in the semiparametric estimation of long-run variances. EC: error correction-based model.

From the AMG results, oil consumption is inversely related to renewable energy, it is concluded that an increase in oil consumption by 1% will decrease RE by 0.079%. This finding suggests that oil consumption hampered renewable energy in Europe. This result is expected for the case of the EU giving the progressive nature of the region's clean energy development as reflected in its ability to meet the 20% renewable energy sources target in 2020. This empirical finding is similar to Ref. [70] who showed that oil consumption has a negative impact on RE consumption in Pakistan. In addition, it was found that carbon emanations negatively impact renewable energy; an increase in carbon intensity by 1% will decrease renewable energy by 0.245% for European countries. This indicates that greater environmental concerns through a decrease in carbon intensity positively affect renewable energy in Europe. Our findings are consistent with Marques et al. (2010); Valdés Lucas et al. (2016); Olanrewaju et al. (2019). Additionally, it can be observed that trade openness contributes to increasing renewable energy. Therefore, if trade increase by 1%, we would expect renewable energy to increase by 0.213% increase in renewable energy. This finding is comparable to those obtained by Tiba et al. (2016) and [58]. We find that the per capita biocapacity positively influences renewable energy, and this result is robust across various specifications. A 1% increase in the per capita biocapacity, increases RE by 1.153%. It is highly expected that RE will increase in response to the expansion of biocapacity.

Similarly, based on DOLS and FMOLS estimator, it can be concluded that our empirical findings show tiny differences. We get similar effects of biocapacity, trade, oil consumption, and carbon emissions on renewable energy. More importantly, the AMG model

Table 7
Determinants of RE.

Variables	AMG	MG-DOLS	MG-FMOLS
lnBIO	1.153^{a}	2.012^{a}	1.077^{b}
	(0.000)	(0.000)	(0.010)
lnOPEN	0.213^{c}	1.046^{b}	1.265^{a}
	(0.050)	(0.025)	(0.000)
lnOIL	-0.079^{b}	-0.540^{b}	-0.178^{c}
	(0.040)	(0.014)	(0.074)
lnCE	-0.245^{b}	-1.507^{a}	-1.474^{a}
	(0.015)	(0.001)	(0.000)

Note: ^{c}, ^{b} and ^{a} denote 10%, 5% and 1% significance level, respectively. The p-values are in parentheses.

yields the smallest regression coefficients compared to those obtained from the DOLS and FMOLS. In this analysis, we prefer the AMG estimator, given their superiority to provide reliable outcomes in the presence of cross-sectional dependence and slope heterogeneity in the panel data model.

5.4. Causality analyses

The directionality of the causality among variables is investigated for the whole panel and each country (see Tables 8 and 9). Table 8 displays the causal nexus based on the Z-bar statistics at the panel level, while Table 9 presents the individual Granger causality Wald statistics specific to each country.

Table 8 reports a significant bidirectional relation between renewable energy and per capita biocapacity. The same bidirectional link is found between renewable energy and oil consumption. There is statistically significant causation ranging from carbon emissions to RE, whereas the feedback effect exists between trade openness and renewable energy. In order to account for the possible heterogeneity across countries, we provide the causality results for each panel member (see Table 9).

As for the cross-section units, per capita biocapacity remains the most important predictor of renewable energy in several countries, including Belgium, Finland, France, Germany, Italy, Norway, Sweden, and Portugal. This finding supports our main hypothesis regarding the role of biocapacity in predicting the deployment of renewable energy in Europe. Our results show that trade openness significantly impacts renewable energy in Denmark and France. The results also show that RE is also caused by oil consumption only in Spain and Portugal. Finally, we can notice that causality is coming from carbon emissions to RE in Austria, Belgium, Denmark, and Spain.

Table 9
Dumitrescu and Hurlin [69] country-specific Panel causality.

Countries	$lnBIO \rightarrow lnRE$	$lnOPEN \rightarrow lnRE$	$lnOil \rightarrow lnRE$	$lnCE \rightarrow lnRE$
Austria	1.022	0.356	0.198	6.238^{a}
	(0.115)	(0.756)	(0.752)	(0.000)
Belgium	3.758^{a}	1.215	0.652	3.016^{b}
	(0.000)	(0.256)	(0.721)	(0.020)
Denmark	1.980	3.058^{b}	0.544	6.560^{a}
	(0.120)	(0.020)	(0.695)	(0.000)
Finland	2.523^{a}	0.236	0.452	0.078
	(0.002)	(0.895)	(0.774)	(0.165)
France	4.385^{a}	5.895^{a}	0.221	0.004
	(0.000)	(0.000)	(0.755)	(0.997)
Germany	3.523^{a}	0.225	0.356	0.001
	(0.000)	(0.766)	(0.500)	(0.989)
Ireland	0.896	3.756^{b}	0.496	0.011
	(0.591)	(0.044)	(0.650)	(0.967)
Italy	5.236^{a}	0.055	0.163	0.025
	(0.000)	(0.987)	(0.856)	(0.896)
Netherlands	1.256	1.756	5.872^{a}	0.020
	(0.345)	(0.562)	(0.000)	(0.875)
Norway	2.879^{b}	0.493	0.621	0.075
	(0.046)	(0.615)	(0.782)	(0.981)
Spain	1.122	0.789	2.982^{b}	3.560^{b}
	(0.345)	(0.963)	(0.035)	(0.015)
Sweden	3.756^{a}	0.056	4.950^{a}	0.010
	(0.000)	(0.985)	(0.000)	(0.962)
Switzerland	1.364	0.059	0.020	0.125
	(0.145)	(0.995)	(0.892)	(0.645)
Portugal	2.358^{a}	0.785	2.895^{c}	0.025
	(0.002)	(0.569)	(0.067)	(0.963)

Notes: ^{c}, ^{b} and ^{a} denote significance level at 10%, 5%, and 1% respectively. The p-values are in parentheses.

6. Discussion of results

Given the examination of the determinants of RE for 14 European countries by using biocapacity as a proxy of renewable natural capital, the result revealed that biocapacity has a positive and significant impact on renewable energy for the panel of European countries. Although the findings of this study are consistent with those of Gossens [46]; the argument behind is not the same. Former studies usually employed variables such as the surface of land available in windy areas and/or the total area in each class of wind or solar resources to estimate the effects of natural resource endowment on RE production. Despite the relevance of former studies, their measures of resource endowment used are arguably and provide limited information about the impact of renewable natural capital on RE. In this study, we report a positive impact of biocapacity on RE, as was expected. Based on our findings, we suggest policies to protect, preserve and enhance the local biocapacity. However, since most of the European countries are characterized by ecological deficit i.e. their ecological footprint of consumption exceeds the local biocapacity [20] mainly due to human pressure on ecosystems; policymakers must slow or reverse biodiversity decline and include the preservation of biodiversity when they make decisions regarding the deployment of RE in Europe.

It is worth noting that trade openness is an essential factor in RE supply. This result validates the argument that trade enhances national production, reduces the cost of investment in renewable sources, and expands its consumption. Theoretically, the effect of trade on RE can be positive or negative depending upon the magnitudes of the scales, technical and composition effects. According to this hypothesis, the trade will encourage renewable energy and

Table 8
DH [69] causality results.

Whole panel				
	$lnRE \rightarrow lnBIO$	$lnBIO \rightarrow lnRE$	$ln\ RE \rightarrow lnOIL$	$lnOIL \rightarrow lnRE$
Z-bar	14.178^{a}	8.297^{a}	18.191^{a}	9.264^{a}
p-value	(0.000)	(0.000)	(0.000)	(0.000)
Whole panel				
	$lnRE \rightarrow lnCE$	$lnCE \rightarrow lnRE$	$ln\ RE \rightarrow lnOPEN$	$lnOPEN \rightarrow lnRE$
Z-bar	1.279	3.014^{a}	3.658^{a}	3.884^{a}
p-value	(0.168)	(0.001)	(0.004)	(0.000)

Notes: Z-bar Statistics which show a standard normal distribution. ^{c}, ^{b} and ^{a} denote significance level at 10%, 5%, and 1% respectively. The p-values are in parentheses.

decrease carbon emissions if the composition and technical scale effect exerts a strong influence on trade and increase the deployment of RE, enhancing environmental quality. Our result is comparable to those obtained by Refs. [58,71]. Following this result, policymakers should adopt an approach based on trade openness in RE by removing potential barriers.

Following [15], we account for the impact of oil consumption on RE and report that oil consumption had a negative relationship with renewable energy consumption in Europe, and this implies that a decrease in oil consumption will lead to an increase in renewable supply. The main policy implication is that European countries need to diversify their oil price risks and use the additional funds to address the challenge of sunk costs for RE supply because of the uncertainty due to higher volatility in the international oil prices [72]. Relative to the environmental driver of RE, we found that carbon emanations are negatively related to RE. This finding is in line with the prediction of Marques et al. [15], Marques and Fuihas [16], and Papiez et al. [13] studies. Beyond its negative impact on the environment, carbon emissions decrease RE deployment.

Overall, we find bi-directional causality between RE and biocapacity, between RE and oil consumption, finally between RE and trade openness. The consideration of this two-way causal relationship among variables is essential in implementing RE policies. Furthermore, the results of panel Granger causality reflect that carbon emissions impact RE deployment in a one-way path. The country-specific Granger causality shows that biocapacity plays a critical role in predicting the deployment of RE in most of the countries under investigation. One might claim that, preserving and increasing the per capita biocapacity (renewable natural capital) is crucial to promoting RE supply in these countries. Trade openness seems to have a significant influence on RE in Denmark and France. This segment of results is in line with [73]. Following this finding, policies to sustain trade openness are required to further renewable energy. The results also suggest that there is causality from oil consumption to RE only in Spain and Portugal. This finding is consistent with [70], who showed that reducing oil consumption is necessary for the implementation of RE policy. We can notice a causal relationship from carbon emissions to renewable energy in Austria, Belgium, Denmark, and Spain. In this regard, policymakers of these countries should develop policies to mitigate carbon emissions and decrease the dependence on oil consumption, which is essentially responsible for carbon emissions.

7. Conclusion and policy matters

Our study aimed to establish a sound framework to investigate the determinants of renewable energy in 14 European countries between 1990 and 2016. In the context of the current study, we consider both CSD and cross-country heterogeneity in our estimation approach and explore new drivers of RE in Europe.

In conducting our empirical analysis, we consider a large set of potential factors that are likely to influence decisions in RE policy. The results of this study are concluded as follows; (i) There exists a long-term cointegration relationship among study variables. This means that, in the short term, a variation in per capita biocapacity, oil consumption, carbon emissions, and trade openness causes a slight change in RE supply; (ii) Per capita biocapacity and trade openness positively influence RE development across European countries by a respective elasticity of ~1.15 and ~0.21. This finding is highly consistent with the AMG, MG-FMOLS, and MG-DOLS estimations; (iii) Oil consumption and carbon emissions have a negative and significant effect on RE in Europe with a respective elasticity of ~0.08 and ~0.25.; (iv) The panel causality results show the existence of a feedback relationship between RE and BIO, between RE and OPEN, between RE and oil consumption, and between RE and CE. Notably.

7.1. Policy matters

The result of this investigation is timely especially because it offers more insight on the renewable energy ambitious target (attaining more than 32%' of renewable energy sources by 2030) of the EU (). Thus, we propose the following policy recommendations for consideration by the interest groups such as government and policymakers: (i) re-invent sustainable guideline for the preservation of the ecosystem vis-à-vis biocapacity so as to preserved and enhanced the development of RE. This can be done through environmental protection taxes, a certain degree of protectionism to preserve the forest and the renewable natural capital (ii) energy transition drive could be scaled up with proportionate scale down of the region's oil consumption, thus advancing the development of greener energy sources. (iii) trade openness is an essential part of the EU's economic policy. However, trade openness policies without the seriousness and implementation the region's energy efficiency directives (such as the smart meter data and emission trading scheme) is counterproductive to the development of RE in Europe. Despite the robustness of our findings, we identify an essential direction for further research. We think research should focus on disentangling the various aspect of RE (including wind and solar) and evaluate the EU's progress toward their renewable energy targets.

7.2. Limitation and future directions

Although the current study is limited in not able to accommodate all the EU member states, it provides preliminary insights on whether natural capital can contribute to the deployment of renewable energy in Europe. We propose a benchmark regression model on nature-renewable energy nexus, which can be extended in several avenues. In future investigation, one could examine the channels through which natural capital could impact renewable energy by accounting for possible spatial interactions among countries. Furthermore, this study could be applied in specific countries by taking advantage of data at the finer resolution on natural capital and renewable energy supply data in future studies. Moreover, other empirical approaches such as machine learning as illustrated in the earlier studies of [83,84] could be adopted in future investigation.

CRediT authorship contribution statement

Yacouba Kassouri: Data curation, Writing – original draft, Conceptualization, Formal analysis, Investigation, Methodology. **Mehmet Altuntaş:** Visualization, Validation. **Andrew Adewale Alola:** Writing – review & editing, Investigation, Visualization, Corresponding.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

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[1] E. Statistics, EuroStat. https://ec.europa.eu/eurostat/web/energy/data.

Table A
Literature Review

Author (s)	Country	Period	Methods	RE determinants
Group 1: Political factors (international legislation, political institutions)				
Menz and Vachon [74]	US.	1998–2006	OLS	Renewable portfolio standards (RPS)
Carley [28]	US	1998–2006	Fixed effects	Renewable portfolio standards (RPS)
Stadelmann and Castro [75]	112 developing and emerging countries	1998–2009	Logit	Democracy, natural endowments, membership within the EU
Aguirre and Ibikunle [24]	BRICS	1990–2010	FEVD, PCSE	Supporting policies make renewable energy more competitive
Schaffer and Bernauer [29]	26 IEA countries	1990–2010	Logit	EU membership and a federalist structure of the political system are crucial to promote renewable energy
Kilinc [30]	EU countries and US states	1990–2008	Fixed effects	Electricity consumption, feed in tariffs, tenders and tax
Cadoret and Padovano [43]	26 EU countries	2004–2011	LSDV	Lobbying manufacturing industry, governance, political factors
Zhang et al. [76]	APEC countries	1992–2012	Panel quantile	Corruption
Nicoli and Vona [77]	28 OECD countries	1979–2007	Panel IV	Energy market liberalization, corruption, green lobbying
Group 2: Socio economic factors (prices of conventional energy, energy demand)				
Sardosky [33]	G7 countries	1980–2005	Panel cointegration	GDP, CO_2 emissions
Chang et al. [78]	OECD countries	1997–2006	PSTR	Energy prices
Marques et al. [15]	Europe	1990–2006	Fixed effects	Oil, coal, natural gas, GDP, CO_2 emissions
Apergis and Payne [38]	13 Eurasia countries	1992–2007	Panel cointegration	Feedback relationship between renewable energy and GDP
Gan and Smith [79]	OECD countries	1994–2003	Fixed effects	GDP, renewable energy and bioenergy deployment policies
Sebri and Ben-Sakha [39]	BRICS	1971–2010	ARDL	Renewable energy contributes to economic growth
Ackah and Kizys [80]	Oil producing Africa	1985–2010	Panel GMM	Income, energy prices, resource depletion, CO2 emissions
Bloch et al. [44]	China	1977–2013	ARDL	Oil consumption negatively affects renewable energy
Cadoret and Padovano [43]	EU countries	2004–2011	LSDV	Economic growth negatively affect renewable energy
Papiez et al. [13]	58 countries	1995–2014	PCA analysis	GDP per capita stimulates renewable energy development
Olanrewaju et al. [25]	SSA	1990–2015	Fixed effects	Energy intensity, natural gas rents, carbon intensity, oil rents
Eren et al. [41]	India	1971–2015	DOLS	Positive impact of economic growth on renewable energy
Luqman et al. [70]	Pakistan	1990–2016	Nonlinear ARDL	Oil consumption negatively affect renewable energy consumption
Bilgili et al. [27]	USA	1989–2016 (Monthly)	Wavelet analysis	Renewable sources contribute to economic growth

Author (s)	Country	Period	Methods	Results
Group 3: Country specific factors (international legislation, political institutions)				
Marques et al. [16]	EU countries	1990–2006	Panel data technique	Total surface area of each country may positively or negatively affect renewable energy deployment.
Aguirre and Ibikunle [24]	EU, OECD and BRICS	1990–2010	Panel data analysis	Negative effects for wind resources on RE and positive effects for solar resources on RE
Omri and Nguyen [23]	64 countries	1990–2011	Dynamic panel data	Trade openness positively influences renewable energy consumption
Gosens [46]	China, Germany and the US	1980–2014	Panel data analysis	Natural resource quality has a positive effect on wind and PV development
Sadorsky [34]	8 Middle East countries	1980–2007	FMOLS	Trade positively influence per capita energy consumption.
Ben Aissa et al. [55]	Africa	1980–2008	FMOLS, DOLS	Trade openness has no direct effect on renewable energy consumption
Sebri and Salha [39]	BRICS	1971–2010	ARDL	Bidirectional causality between trade and renewable energy consumption
Jebli and Youssef [53]	Tunisia	1980–2009	ARDL	Short-run unidirectional causality from exports, imports to renewable energy consumption.
Lin et al. [52]	China	1980–2011	VECM and cointegration technique	Trade openness improves the amount of renewable energy
Liu et al. [54]	Asia-Pacific region	1994–2014	Granger causality	Unidirectional causality from trade to renewable energy
Brini et al. [81]	Tunisia	1980–2011	ARDL	Bidirectional causality between renewable energy consumption and international trade
Murshed [59]		2000–2017	2SLS panel technique	Improvement in trade triggers renewable energy consumption

(continued on next page)

Table A (*continued*)

Author (s)	Country	Period	Methods	RE determinants
	Bangladesh, India, Pakistan, Sri-Lanka and Nepal			
Amri [58]	Developing and industrialized countries	1990–2012	GMM dynamic panel	Bi-directional linear links between trade and renewable energy consumption.
Alola and Saint Akadiri [82].	United States	1990: Q1-2018: Q2	ARDL	Increase in economic expansion and national security effectiveness spur cleaner energy development. Tightened trade policy and high economic uncertainty are detrimental to the development of clean energy.

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