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RESEARCH ARTICLE

The energy transition in Europe—a solution for net zero carbon?

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Abstract

Climate change has generated intense concerns from public authorities and international institutions with regard to shaping the behavior of companies, consumers, investors, and other stakeholders so as to manage this challenge as efficiently as possible. In order to address the climate emergency in the post-pandemic era, recovery plans need to trigger decarbonization, and a green transition, including specific investments and providing a more adaptive structure of the sources of energy in different regions, able to meet the need for a systemic shift towards a more sustainable economy that works for both people and the planet. The main measurable effect of energy production and consumption is by far represented by carbon emissions. In the present paper, we aim to identify the statistical significance of several factors influencing the carbon dioxide emission per capita in the European countries—level of economic development, level of globalization, trade openness, and the intensity of energy transition measured by the share of renewable energy in total energy consumption. The results show an increased interest of the experts in energy consumption model shift through green energy increased share, with relatively high differences among the 42 European countries analyzed. The analysis was conducted for the period 1990–2018 and policy differences depending on variables (GDP/capita, globalization index, trade openness, and renewable energy share in total energy consumption) were identified. The results showed that the carbon dioxide emission per capita evaluation designed model is representative of the European countries. The fact that the targets set by European non-EU member states for reducing CO2 emissions are lower than for the EU is influencing the dynamics of the energy transition, with implications for the size and destination of funds to finance the development of renewable energy.

Keywords Energy transition · Renewable energy · Fossil fuels · Carbon neutrality · Decarbonization · CO2 emissions · Panel regression

Introduction

Climate change has created challenges at the international level, with public authorities and international bodies trying to find solutions to improve the impact of human activity on the environment. The efforts are notable, but still insufficient, with different categories of stakeholders being involved in reducing the negative externalities generated by human activity. Thus, at both international and regional levels, concrete targets and objectives were established, and policies and strategies were elaborated for different fields of activity and for certain categories of stakeholders. The 2015 Paris Agreement is a reference document through concrete measures and targets aimed at reducing carbon emissions (Gurtu et al. 2016; Pianta and Lucchese 2020; Adebayo et al. 2021; Chunling et al. 2021; Ponce and Khan 2021). The European Green Deal, 2019, and recently, the Glasgow Climate Pact 2021, point out the need for

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integrated measures able to reduce climate change risks. The energy transition is one of the solutions to reduce the impact of human activity on the environment. The transition from fossil fuels to renewable energy will reduce carbon emissions but will generate specific challenges and problems that need to be addressed. For this reason, energy transition is considered a "multidimensional, complex, nonlinear, nondeterministic, and uncertain phenomenon" (Blazquez et al. 2020). The absolute reduction of carbon emissions cannot be achieved given the actual predominant models of economic growth that characterize most countries in the world. For this reason, more and more researchers are raising the issue of increasing carbon emission efficiency (economic value generated per unit of carbon emissions), which can be achieved through better coordination between economic growth and carbon reduction (Dong et al. 2022).

The complexity of the phenomenon of energy transition requires a holistic approach, with objectives and tools' measures on different levels of economic activity but also the initiation and implementation of public–private partnerships. In fact, the idea of partnerships is promoted also through the Sustainable Development Goals (SDGs), this being one of the objectives set by the UN (SDG 17). The partnerships between public authorities and private companies, on the one hand, but also between countries and international bodies, on the other hand, are necessary, given the new financing mechanisms specific to the transition to a low carbon economy, the interdependencies between national and regional economic agents (D'Orazio and Löwenstein 2020; Khan et al. 2020; Shahbaz et al. 2017; Cheng et al. 2021; Chunling et al. 2021; Kirikkaleli and Adebayo 2021; Raza et al. 2021), EU Green Deal (EC 2019) and more recently the enforcement of energy transition as a pivotal element in delivering climate change targets—COP26 Climate Pact (UN-Climate Change 2021). So, the main solution to reduce the negative impact of human activity on the environment is the energy transition, which comes with new approaches to energy production and consumption (Jahanger et al. 2022; Jiang et al. 2022; Usman and Balsalobre-Lorente 2022).

The results of the studies identified in the literature demonstrate the complexity of the energy transition phenomenon, the main determining factors being the level of economic development, the political will to manage environmental protection and climate change, the existence of public–private partnerships, the level of financial development, the level of technological innovation, the connection of countries to the international system (Ho and Iyke 2019; Liu et al. 2020; Khan et al. 2021a, b; Khaskheli et al. 2021; Tang and Tan 2015; Sinha et al. 2020b; Wang et al. 2020; Jahanger et al. 2022; Shahbaz et al. 2020; Cheng et al. 2021; Chunling et al. 2021; Kirikkaleli and Adebayo 2021; Raza et al. 2021; Shahbaz et al. 2020; Usman and Balsalobre-Lorente 2022). This paper contributes to a better understanding of the complex process of energy transition in the European countries; the EU is a world leader in this field both by trying to manage this phenomenon by creating a specific legal and institutional framework and by the results obtained by member countries that have set bold goals that they have often achieved. From the multitude of determinants of increasing the volume of carbon emissions, the present research aims to identify the influences of factors like renewable energy consumption, such as the percentage of total energy consumption, GDP/capita, the globalization index, and trade openness.

The main objective of this paper is to verify the statistical significance of the factors influencing the carbon dioxide emission per capita in the European countries, as well as evaluate the results gained by the model.

To achieve the main objectives, the following partial objectives were established:

– To identify the aspects of interest for specialists in the analysis of factors and the impact of the energy transition, based on the content analysis of the existing literature;
– To analyze the statistical significance of the relationship between variables by implementing the panel regression model; it is followed by the conclusion and recommendations.

Based on these objectives, the following hypotheses were set up:

H1: Energy transition is related to climate change, technology, investment policy, and development.

H2: Energy transition is influenced by renewables and economic factors.

Literature review

Recent energy transition challenges and policy measures

Internationally, the most important steps in the energy transition process have been taken within the European Union, which has established concrete measures such as the EU Infrastructure Investment Plan, Clean Energy for All Europeans Package, or European Green Deal, and the establishment of the Energy Union. Therefore, the current energy transition is a policy-driven process, this being the major difference from the previous energy transitions (Radulescu Irina and Popescu 2015; Blazquez et al. 2020; Bompard et al. 2020; Pianta and Lucchese 2020).

The financial challenge generated by the energy transition is considerable, and "innovative schemes between public and private finance" are needed. There are specialists who draw attention to the importance of economic aspects that can generate additional pressure in the process of energy transition and can even lead to the adoption of suboptimal technical solutions, which are cost-effective (Johnson 2015). Therefore, energy transition is a technically and politically feasible process, but the great challenge is economic feasibility—the existence of adequate financing methods and the profitability of investment projects (Polzin and Sanders 2020; Khan et al. 2021a, b).

In an increasing number of countries, the interest of public authorities has shifted from promoting economic growth to sustainable development with low carbon emissions. The sustainable development goals launched by the UN in 2015 have become an integral part of national strategies and economic policies, but they have also been incorporated into the strategies of corporations through various instruments in order to reduce their carbon footprint and improve non-financial performance, especially the environmental component. Ensuring sustainable and modern energy is one of the 17 SDGs, the energy thus gaining international recognition for its importance in people's lives but also in economic activities. More and more researchers acknowledge the pivotal role of energy both in people's current lives and for the future sustainability of the world development, especially taking into account that energy demand is expected to intensify under the impact of factors such as population growth, urbanization, economic development, increasing living standards (Isik and Radulescu 2017; Andrei and Andreea 2018; Marinaș et al. 2018; Popescu et al. 2018; Armeanu et al. 2021; Rehman et al. 2021; Shahzad et al. 2021). Promoting sustainable energy sources is the solution to ensure the new energy transition that will generate the decarbonization of the world economy. Renewable energy is the solution, the studies focused on the numerous economic, social, and technical challenges generated by the predominant use of green energy sources (Cristea and Dobrota 2014; Chudy-Laskowska et al. 2020; Remenyik et al. 2020).

The current energy transition comes with many challenges and solutions that can reduce the impact of energy production and consumption on the environment and also reduce energy poverty that affects many consumers, in both developed and emerging economies (Druică et al. 2019; Neacșa et al. 2020). Therefore, carbon neutrality (Cheng et al. 2021; Umar et al. 2021) is a new goal pursued by all countries, the measures and instruments used being very diverse. The market imperfections can be covered by fiscal incentives or subsidies (D'Orazio and Löwenstein 2020) so that research and development is promoted by companies in the field of renewable energy.

Internationally, researchers recognize the role of leader assumed by the European Union in the decarbonization concern of the economy, the member countries being considered renewable energy pioneers and climate change leaders (Jacobs 2016; Solorio and Jörgens 2017). At the level of the European Union, the efforts of the authorities to facilitate the energy transition process are notable, both the legal and the institutional framework having been created. Moreover, specific financing mechanisms have been designed in view of the financial challenges posed by the energy transition. Companies need tools to finance green energy investments given the high costs and associated risks. For this reason, for the time being, the main investor in the green energy market is the state (Ji et al. 2021; Petrović et al. 2021), but the interest of private companies is growing given the potential of the renewable energy market and the involvement of institutional investors looking for new tools for placing available funds. Therefore, in the future, the balance of forces on the financial level will change radically in the sense of increasing the share of private funds that will support the decarbonization process of the European and world economy (Andoura and d'Oultremont 2012).

The studies demonstrated the importance of the level of development of countries on the exploitation of the renewable energy potential that each country has (Simionescu et al. 2019), through the existence of financial funds available on the market and which can be directed to green projects. Moreover, financial institutions have intensified the process of financial innovation and diversified the range of products and services that finance or cover the risks specific to renewable energy projects (Polzin and Sanders 2020). According to specialists, important factors in the financial market are also state investment banks or state-owned finance institutions that can ensure the cofinancing of large projects in the field of renewable energy (Macfarlane and Kumar 2021).

Statistical indicators measuring energy transition

Reducing the impact of human activity on the environment is the subject of numerous scientific researches, the interest gradually shifting from studying the Kuznets curve for different periods and countries, respectively, groups of countries, or regions (Dogan and Turkekul 2016; Khan et al. 2016; Armeanu et al. 2018; Panait et al. 2019; Sinha et al. 2020a; Gyamfi et al. 2021; Balsalobre-Lorente et al. 2022) to analyze the impact of energy consumption, energy transition, and the use of renewable energy on the economic development and sustainability of this process (Jahanger et al. 2022; Jiang et al. 2022; Usman and Balsalobre-Lorente 2022).

According to the WB database, energy makes up nearly three-quarters of global emissions, followed by agriculture. Within the energy sector, the largest emitting sector is electricity and heat generation. On the one hand, increasing quality of life and urban development has led to increased energy consumption in households, and on the other hand, technological progress and the continued development of services as share in the business environment have led to reductions in GHG emissions.

Human-caused greenhouse gas (GHG) emissions measured in tCO2 equivalent are increasing at the world level and decreasing in Europe, especially after 1990 (Fig. 1). If we calculate on capita or on million $ GDP, the figures are divergent.

Worldwide per capita consumption has been increasing in the last 3 decades, and in Europe, it is declining until 2014, after which the evolution is oscillating. In terms of emissions per GDP, there is a similar evolution worldwide and in Europe, with the same change after 2014. The oscillations of recent years and the increasing impact on climate change have justified both the commitments after the Paris meeting and the redefinition, more realistic targeting at COP26. Compliance with the states and measures to adjust the business environment from the perspective of resource consumption that generates pollution is the main challenge for achieving the assumed objectives.

Recent studies on the energy transition impact on the environment have used indicators that measure globalization and trade openness as variables for analysis. (Haug & Ucal 2019; Ho and Iyke 2019; Liu et al. 2020; Chen et al. 2021; Khan et al. 2021a; Khaskheli et al. 2021; Taghizadeh-Hesary et al. 2021), foreign direct investment (Tang and Tan 2015; Sinha et al. 2020b), technological innovation (Wang et al. 2020; Jahanger et al. 2022), GDP, financial development, public–private partnerships (Shahbaz et al. 2020; Cheng et al. 2021; Chunling et al. 2021; Kirikkaleli and Adebayo 2021; Raza et al. 2021; Shahbaz et al. 2020; Usman and Balsalobre-Lorente 2022).

Adebayo et al. (2021) analyzed the relationship between carbon emissions and renewable energy, trade openness, and economic growth for Sweden for the period 1965–2019, using novel quantile-on-quantile regression. The results of the study demonstrated the negative effect of renewable energy, respectively, trade openness on CO2 emissions in all quantiles for this country that is one of the European leaders in the energy transition process (due to climatic conditions, lack of fossil fuels, and public policies to promote renewable energy). The study by Khan et al. (2020) is based on the dynamic common correlated effect (DCCE) method. The authors study for the Nordic countries (Denmark, Iceland, Sweden, Finland, and Norway), for the period 2001–2018, the impact of renewable energy, CO2 emissions, environmental management, and regulatory pressure on trade. The research results showed that renewable energy (REC) and environmental management (EM) have a negative association impact on international trade for the countries analyzed, while regulatory pressure and carbon emissions have an insignificant effect on international trade.

Asiedu et al. (2021) focused on the relationship between renewable, nonrenewable energy consumption, CO2 emissions (as independent variables), and economic growth for 26 European countries, the analysis being based on statistical data published by the World Bank for the period 1990–2018. The authors used the dynamic ordinary least square (DOLS) and fully modified ordinary least square (FMOLS) to determine the relationships between the variables of the proposed model. The results of the study suggest a "bidirectional causality between economic growth and renewable energy consumption."

Wang et al. (2020) conducted a study on the impact of factors such as financial development, GDP, technological innovation, and renewable energy consumption on carbon

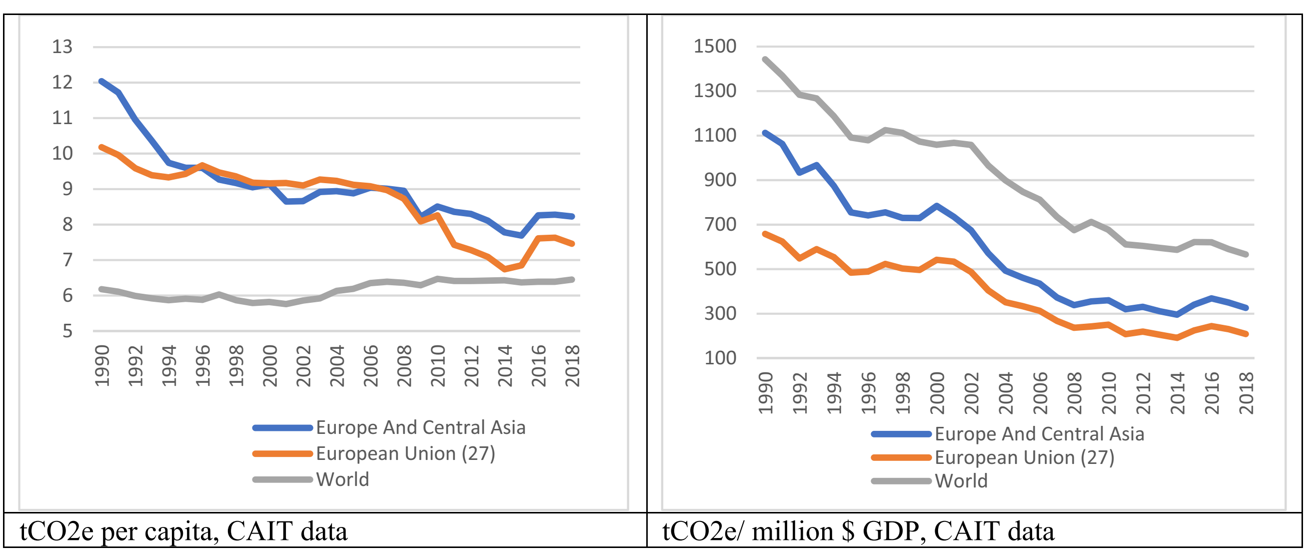


Fig. 1 GHG emissions after 1990, on capita and GDP. Source: based on https://www.climatewatchdata.org/ghg-emissions?breakBy=regions&calculation=PER_CAPITA&chartType=line&end_year=2018®ions=EUU%2CWORLD%2CECA&start_year=1990

emissions for N-11 countries from 1990 to 2017. The paper is based on empirical estimation, being use Pesaran unit root test, common correlated effect mean group, and augmented mean group. The research results showed a direct relationship between financial development, respectively, GDP and carbon emissions, while in the case of technological innovation, respectively, renewable energy consumption, the impact on carbon emissions is negative. The study by Cheng et al. (2021) focuses on China, given the environmental challenges facing this country due to the intense rates of economic growth. The analyzed period is 1991Q1 to 2017Q4, the authors being interested in investigating the impact of energy productivity, technological innovation, public–private partnerships on CO2 emissions while controlling GDP and renewable energy consumption. The results of the study suggest that among CO2 emissions and their determinants, there is a long-run equilibrium connection.

The study by Jiang et al. (2021) targets four categories of income-based countries (high-, upper-middle-, lower-middle-, and low-income countries) and is based on data for the period 1995–2017, panel smooth transition regression (PSTR) being used. The results obtained revealed the beneficial impact of economic growth and globalization; the use of renewable energy on carbon emissions for all categories of countries. Population growth has a negative impact on carbon emissions, in the sense that the relationship is directly proportional. Different results for the analyzed country groups were obtained for the effect of trade openness on carbon dioxide emission. Khaskheli et al. (2021) focused on the financial development impact (estimation through the financial system deposits and private credit by banks) the population, the international trade, and the economic growth on carbon emission for nineteen low-income countries. The analyzed period is 1990–2016, using data published by the World Bank and processed with the panel smooth transition regression technique. The conclusion of the study is that international trade and population increase carbon emissions. As the analyzed countries register a certain level of financial development and economic growth, their impact on carbon emissions is beneficial in terms of reducing them.

Simionescu et al. (2020) and focused the study on the countries of the European Union and Great Britain for the period 2007–2019, taking into account GDP, global competitiveness index (GCI), and renewable energy consumption. The authors used panel data models based on the FMOLS and demonstrated the manifestation of a "positive effect of renewable energy consumption progress on GDP and GCI growth and also a positive influence of economic growth on renewable energy consumption."

The economic development, the scarcity of fossil fuels, and the need to protect the environment are the main constraints of the new energy transition. Given the complexity of this phenomenon and its economic, social, technical, and environmental implications, in the specialized studies that focus on the energy transition, the approaches are diverse, and the indicators used are multiple, the main being identified and presented in Fig. 2.

The identification of indicators allows not only the understanding of the energy transition phenomenon from the perspective of the determining factors but also generates a good substantiation of the economic policies that have the role of supporting this process and generating a fair transition for all stakeholders.

An overview of renewable energy in Europe

Energy transition refers to the global energy sector's shift from fossil-based systems of energy production and consumption—including oil, natural gas, and coal—to renewable energy sources like wind and solar, as well as lithium-ion

Fig. 2 The main determinant factors of the energy transition. Source authors based on the studies

batteries. This shift is related to the economic status of the country (policy, development, investments' availability). Therefore, this transition will be realized differently for UE countries than for the other European countries due to the fact that at the UE level, there are implemented unitary reglementations. At the international level, the European Union stands out as a pole of excellence in the field of the energy transition, considering the created energy union that is based on complex instruments that allow a certain degree of convergence in this field between member countries taking into account the natural endowment with energy resources. The main aim of the European energy union is to assure secure, sustainable, competitive, and affordable energy for consumers and companies (Fig. 3).

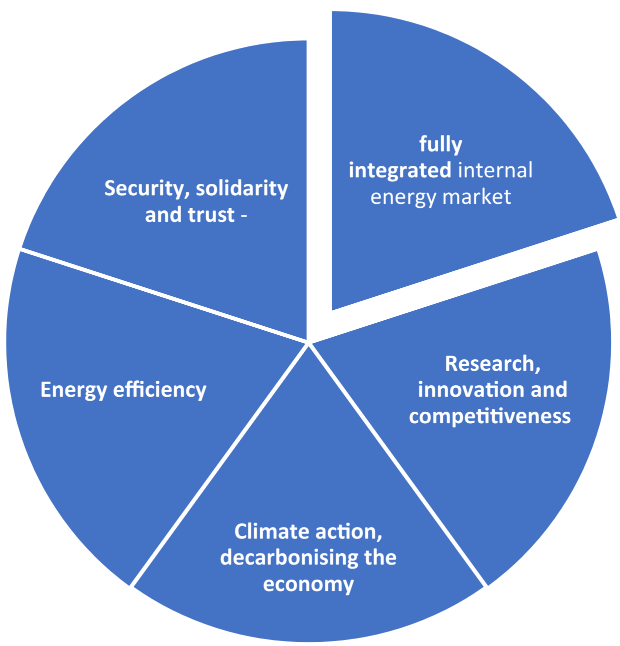


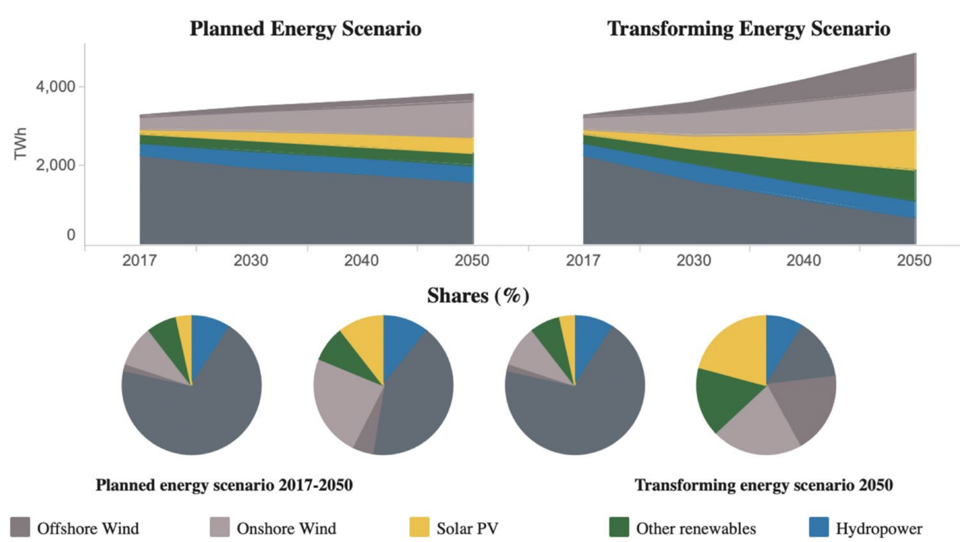
Fig. 3 Dimensions of the European energy transition. Source authors based on literature review

Through this strategy and based on Paris agreement commitments, the EU is a global leader in tackling global warming, achieving carbon neutrality, and implementing renewables. The renewable energy directive (2018) is the main regulation of this strategy because it is based on strong aims like removing barriers and stimulating investments, but most important is that citizens, consumers, and businesses are considered part of this clean energy transformation. These stakeholders must be informed, accountable, and educated so as to make the best possible decisions to help implement the economic policy measures adopted at the EU level. Moreover, the development and implementation of the Clean Energy for All Europeans package takes into account the need for a just transition for the stakeholders involved, given the negative effects (job losses in certain sectors such as coal mines, abandonment of cities due to mine closures, the bankruptcy of some companies or financial difficulties for other business, rising energy prices, which affects consumers and fuels energy poverty) of the transition from fossil fuels to renewable energy (Voicu-Dorobanțu et al 2021).

As it can be observed in Fig. 4 in the case of EU countries, the share of renewable energy (solar PV, onshore wind, and offshore wind) will increase significantly until 2050 regarding planned energy. Regarding transforming energy, the share of hydropower will remain constant, but the share of energy from renewable sources will increase at least four times until 2050.

Even if the policy of transit to renewable energy is not designed at the EU level, there is an increasing concern regarding all renewable sources in the case of planned energy in the European countries non-EU, the shift being much slower. In the case of transforming energy, the share of

Fig. 4 Planned energy scenario vs. transforming energy scenario EU 28. Source: IRENA 2022, http://irena.org



hydropower will increase, and the share of other renewables increasing significantly until 2050 (Fig. 5).

Although the transition is realized differently in the case of European countries, an ascending trend regarding renewable energy can be observed, reflecting measures in this concern, due to an increased interest in renewable sources of energy.

The increasing penetration of renewable energy into the energy supply mix, the onset of electrification and improvements in energy storage are all key drivers of the energy transition. Regulation and commitment to decarbonization have been mixed, but the energy transition will continue to increase in importance as investors prioritize environmental, social, and governance factors.

The turning point through which countries revisited climate pledges assumed by the Paris agreement was COP26 (2021), with major implications for the energy transition. This meeting was necessary given the complexity of the energy transition phenomenon and the need to find new directions and convergence of actions. The results of the meeting were marked by the divergence of economic interests and the diversity of national policies associated with the energy transition but also by the differences in natural and financial resources for energy production, including green energy. The USA and China pledged to cooperate for the ease of energy transition. The phasing out of fossil fuel subsidies was a common point agreed upon in Glasgow, which could help speed up the energy transition process. Moreover, representatives of poor countries, which are in a multidimensional way the most vulnerable to active actions for reducing gas emissions, called for redirecting funds from subsidies to climate finance, which can fund green energy and other low-impact environment projects.

Data and method

Taking into consideration the relevant studies identified in the main flow on this topic and the database and countries involved, our research includes European countries, for several reasons: (a) a relatively moderate economic development level gap between countries; (b) similar strategic approach to energy transition; (c) geographical conditions and natural resources for the production of various types of energy, which allow and presuppose an integrated approach, multi-energy types, with an important share of gross electricity generation in the world; (d) high population density and climatic conditions require energy consumption throughout the year for housing (either for heating or air conditioning in hot areas, with excessive continental temperate climate); (e) the economic structure with large service sector is associated with a reduced energy intensity, measured as the quantity of energy consumed to the level of economic output (EUROSTAT 2020).

Variables

Research variables used in this study are divided into two, namely factors related to renewable energy and economic factors. Renewable energy factors consist of variables reflecting the status of renewable energy (carbon dioxide emission per capita, renewable energy consumption as a percentage of total energy consumption), while the economic factors are variables reflecting the economic conditions influencing the transition to renewable energy (GDP/capita, globalization index, trade openness measured as sum of trade as percentage of GDP).

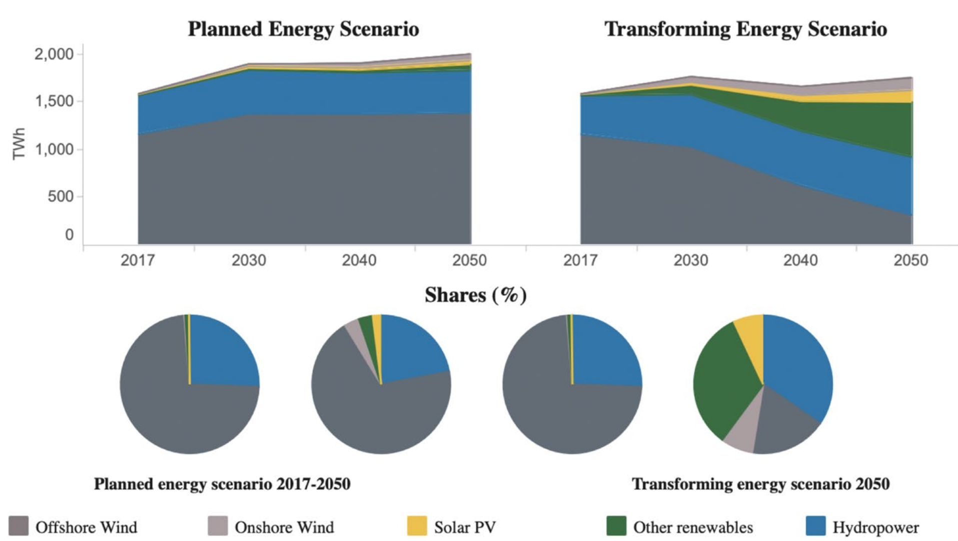


Fig. 5 Planned energy scenario vs. transforming energy scenario Europe, not EU. Source: IRENA 2022, http://irena.org

Variables such as carbon dioxide emission are estimated by carbon dioxide emission per capita (tonnes); renewable energy consumption is calculated by a percentage of total final energy consumption. The data of other variables such as GDP is estimated through constant prices; trade openness is measured by merchandise trade (percentage of GDP).

The data for all variables were provided by the World Bank database. The data on globalization is estimated by using the KOF globalization index from KOF Swiss Economic Institute. The type and definition of each variable used in this study can be seen in full in Table 1.

Statistical analysis

Bibliometric analysis

For H1: Renewable energy transition is related to climate change, technology, investment, policy, and development.

In order to analyze the most common words regarding the transition to renewable energy, we used the bibliometric analysis, investigating the literature in a systemic and systematic process, structuring and ordering the results obtained converted from quantitative to qualitative.

Norton (2001) defines bibliometrics as the measurement of texts and information. Bibliometric analysis is rooted in the methodology, which involves the statistical analysis of scholarly documents (Garfield 1955), augmenting the analysis and helping unravel the intellectual structure of a domain with sufficient objectivity (Garfield 1979).

This analysis involves the identification of the literature content, being considered a state-of-the-art methodology, including components from all scientific domains (Glänzel 2003). Bibliometrics helps to explore, organize, and analyze large amounts of data helping researchers to identify "hidden patterns" that may help researchers in the decision-making process (Daim et al. 2006).

In order to identify the main topic of the content, we used the word clouds considering the words with the highest frequency. The relationships between words can be determined by investigating which words tend to follow others immediately, or that tend to co-occur within the same documents. Both types of analyses are complementary. If the word network reveals, which are the word pairs that co-occur most often, the correlation network reveals which words appear more often.

Panel regression

For H2: Renewable energy transition is influenced by both renewables and economic factors.

Table 1 Description of the variables used in the regression analysis

Variables	Description	Hypothesized relationship with renewable energy	References
Carbon dioxide emission per capita (CDE)	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during the consumption of solid, liquid, and gas fuels and gas flaring	Inverse	Bilgili and Ozturk (2015) Ch and Semenoh (2017) Tang and Tan (2015) Menegaki and Ozturk (2016) Youssef and Ben (2013)
Globalization index (GI)	The KOF Globalisation Index measures the economic, social, and political dimensions of globalization	Direct	Ahmed and Le (2021) Liu et al. (2020) Vlahinić and Fajdetić (2021) Khan et al. (2021a, b)
GDP/capita (GDP)	Gross domestic product (GDP) per capita shows a country's GDP divided by its total population. The table below lists countries in the world ranked by GDP at purchasing power parity (PPP) per capita, along with the nominal GDP per capita	Inverse	Vasylyeva and Pryymenko (2014) Kasperowicz et al. (2017) Bildirici (2013) Dogan and Turkekul (2016) Kharlamova et al (2016)
Renewable energy consumption as a percentage of total energy consumption (RE)	Renewable energy consumption is the share of renewable energy in total final energy consumption	Inverse	Chygryn (2016) Šinčāns et al. (2016) Masharsky et al. (2018) Slusarczyk et al. (2016)
Trade openness measured as the sum of trade as a percentage of GDP (TO)	Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product	Inverse	Sin-Yu and Iyke (2019) Chen et al. (2011) Ahmed and Le (2021)

In order to analyze the renewable energy transition from a transversal and longitudinal perspective, we proposed to use the panel data analysis. Panel data refers to data sets consisting of multiple observations on each sampling unit. This could be generated by pooling time-series observations across a variety of cross-sectional units (Baltagi et al. 2013). The spatial dimension refers to a set of transverse observation units, and the temporal dimension refers to periodic observations of a set of variables that characterize these cross-sectional units over a given period of time (Yaffee 2003). Panel data represents a set of cross-section data Y_{it} $(\mathrm{i} = 1, \ldots, \mathrm{n}$ şi $t = 1, \cdots, T)$ resulting from the statistical observation of the variables characteristic of a group of n regions periodically, for a defined time interval, T (Baltagi 2005).

For estimating the variation of a resultant variable according to the determinant factors in panel data analysis, the following model is considered:

$$y_{\mathrm{it}} = b_0 + b_1x_{1it} + \cdots + b_kx_{kit} + e_{it} \tag{1}$$

Notations:

b_0—cross sections which are considered constant over the time;

y_{it}—the values of the dependent variable;

$x_{k\mathrm{it}}$—are the values of the independent variable, X_k, where:

$i = 1, \cdots, n$—n represents cross sections;

$t = 1, \cdots, T$—t represents the periods of time, respectively the years;

e_{it} = is the error term over the time t.

In order to examine the existence of cross-sectional dependence among the cross-section units, the LMadj test can be used (Pesaran et al. 2008). The integration levels of the variables were examined with the Pesaran CIPS (cross-sectional augmented Im-Pesaran-Shin) unit root test (Pesaran 2007) due to probable spurious relations between variables (Gujarati and Porter 2009). The other test used to verify the existence of unit root is Levin, Lin, and Chu—LLC test (Levin et al. 2002), including three models (the first model without intercept, nor time trend; the second one includes intercept but no time trend; and the third model includes both intercept and time trend) (Jaroslava and Martin 2005). For testing stationarity, it can be also used: Im, Pesaran, and Shin W-Stat-IPS (Im et al. 2003), ADF-Fisher Chi-Square, and PP-Fisher Chi-Square tests.

In this study, we have considered four unit root tests, such as IMP, LLC, ADF, and Phillips–Perron test (PP). In order to investigate the existence of structural breaks, the robustness was checked both on single cross-section units and on the whole panel dataset.

The panel data model includes three different methods: common constant, fixed effects, and random effects.

a) The common constant method of estimation presents results considering no differences among the data matrices of the cross-sectional dimension (N).
b) The fixed effects model (FE) involves that differences between units can be accommodated from different intercepts. The fixed effect uses the ordinary least square principle, producing a constant intercept for each cross section, and the time period is considered less realistic, therefore in order to capture the difference, more models are needed (Zulfikar 2019). The fixed effects model can be written as follows:

$$y_{\mathrm{it}} = b_{0i} + b_1x_1 + \cdots + b_kx_{k\mathrm{it}} + e_{\mathrm{it}} \tag{2}$$

c) The random effects model (RE) estimates panel data where interference variables may be interconnected between time and units. In this case, the difference between intercepts is accommodated by the error terms of each unit (Zulfikar 2019). The random effects model can take the following forms:

$$y_{\mathrm{it}} = (b_0 + v_i) + b_1x_{1\mathrm{it}} + \cdots + b_kx_{k\mathrm{it}} + e_{\mathrm{it}} \tag{3}$$

$$y_{\mathrm{it}} = b_0 + b_1x_{1\mathrm{it}} + \cdots + b_kx_{k\mathrm{it}} + (v_i + e_{\mathrm{it}}) \tag{4}$$

The advantage of using the random effects model presents the advantage of eliminating heteroscedasticity, being called the error component model (ECM) or generalized least squares (GLS) technique. The difference between common constant and fixed effects is represented by the fact that random effects uses the principle of maximum likelihood or generalized least squares.

In the panel regression analysis, the Hausmann test was used for selection between random and fixed effects estimation methods, being detected the presence of statistically significant unobserved fixed effects (Hausman, 1978). The null hypothesis (H_0) considers the model is RE, meaning no correlation between independent variables and error terms in the panel data model (Mohamed et al. 2020). The alternative hypothesis (H_1) assumes that the appropriate model is FEM, and there is a statistically significant correlation between independent variables and error terms in panel data (Bell et al. 2019).

Robustness checks (heteroskedasticity of residues, the dependence of residues between the panels, and dependence of residues between the panels) can be conducted by the Wooldridge autocorrelation test (Wooldridge 2002) and Wald test (heteroskedasticity of residues), Pesaran test (dependence of residues between the panels) and Greene heteroscedasticity test (Greene 2003), and LM test (dependence of residues between the panels). One of the strengths of panel regression analysis is that it can make use of information about change between each pair of time points and not just between the start and end points of a panel survey (Headey 2013).

We used Eviews 13 student version to estimate the analysis models and Vos program in order to realize the bibliometric analysis.

Results and discussions

Experts' interest in renewable energy transition: a bibliometric analysis

In order to analyze the most relevant concepts in the field, we used bibliometric analysis, the principal source of scientific articles analyzing renewable energy transition being the academic platform Web of Science. A total number of 14,371 papers were identified in the period 1981–2021 (Fig. 6).

There has been a growing interest in renewable energy research in the last decade, with the main focus being on increasing global greenhouse gas emissions and large differences between regions and geographical areas.

From the total number of papers identified, we have explored the content of 600 research articles related to renewable energy transition on the Web of Science, in order to highlight the structure of the scientific field, using the content analysis to inspect the most common words and the relationship between words.

Analyzing the network of co-occurrences, co-occurrences with a frequency of at least 20 times have been taken into account, with a correlation degree greater than 0.5. The analysis has been done using Vos program.

Exploring the valuable information provided by the world clouds, we tried to respond to the following main research questions: What are the most common words found in the full scientific articles? In other words, we identified the aspects of interest for specialists in the analysis of factors and the impact of the energy transition, based on the content analysis of the selected literature.

The empirical analysis proved that the most common words in the full content of selected articles apart from the keywords used are: "renewable energy," "transition," "technology," "investment," "community," "development," "policy," "government," "climate change," "demand," "impact," "change," "investment," "fossil," "demand," "Germany," and "China" (Fig. 7), confirming hypothesis 1.

The empirical results highlighted 4 significant clusters of the most common combinations in the selected 600 studies in the field. These are (1) renewable energy source-fossil fuel-climate change; (2) technology-renewable-electricity-demand-capacity; (3) climate change-power-role-importance-community; and (4) renewable energy-investment-energy transition-policy-development-government (Fig. 8). In order to highlight that these combinations of words are the most encountered, we explored the most correlated words within the selection of articles, using as a threshold the value of 0.5.

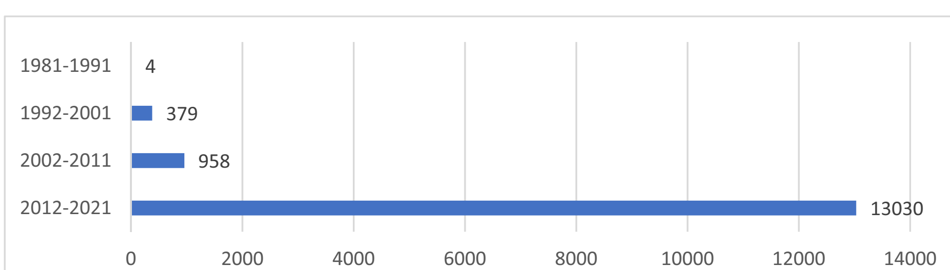
It is observed that the experts' approaches are diverse, from the analysis of the impact of resource consumption on the environment (cluster 1) to the relationship between renewable technologies and their development/diversification limits (cluster 2); from the binomial of climate change and the role of the community (cluster 3) to the multidimensional analysis between renewable sources, investment in energy transition and development (cluster 4). The latest cluster is also found in the latest scientific articles, which highlights the promising applicative nature of research and the link with development strategies and support policies, including investments for the energy transition.

Selected indicators evolution in the analyzed period and panel regression results

The statistical analysis of the economic indicators selected for the panel analysis refers to the period 1990–2018 and includes 42 European countries.

The selection of this geographical area aimed at highlighting the differences in policies and the diversity of the business environment, as well as the influence of the level of economic development of the states. The panel analysis at the level of the selected group of countries emphasizes the cumulative effect of the considered indicators. However, the

Fig. 6 Distribution of the number of studies identified by decennial intervals. Source: WoS database, authors extraction based on selected words



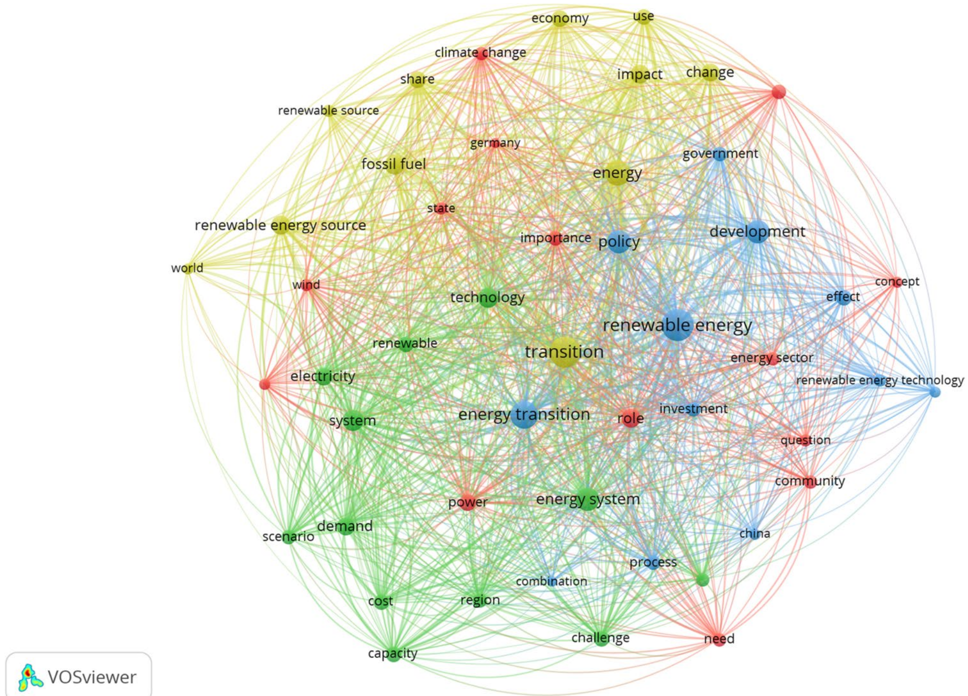


Fig. 7 Most common words and word networks in scientific publications' content. Source: authors' selection from the WoS database, based on selected words

national differences are significant, both from the perspective of the evolution of the selected indicators and also as a result of the application of the econometric analysis.

Descriptive analyses of the data were conducted to examine the sample characteristics. A summary of the descriptive statistics of each variable for the entire sample period and the countries used in this study can be seen in full in Table 2. From Table 2, it was known that the average CDE of European countries in the sample in this study is 7.25 tonnes/capita, the lowest CDE is 0.47 tonnes/capita, and the highest CDE is 30.44 tonnes/capita with a standard deviation of 3.61 tonnes/capita. The average globalization is 72.5 with the highest value of 90.98 and the lowest value of 27.83, the standard deviation being 13.46. The medium GDP/capita is 23,914.28, ranging from 953.19 to 116,644.80, with a standard deviation of 16,342.54. The average renewable energy consumption as a percentage of total energy consumption is 26.51, the lowest value is 2.41, and the highest value is 55.95, with a standard deviation of 12.14. Trade openness as the sum of trade as the percentage of GDP varies between 13.39 and 408.36, the medium value being 100.45 and a standard value of 53.98.

To answer the research objectives related to the determinant factor in the European countries related to the renewable energy transition, we used the panel data equation model as follows:

$$CDEit = \beta it + \beta 1GIit + \beta 2GDPit + \beta 3REit + \beta 4TOit + \varepsilon it.$$

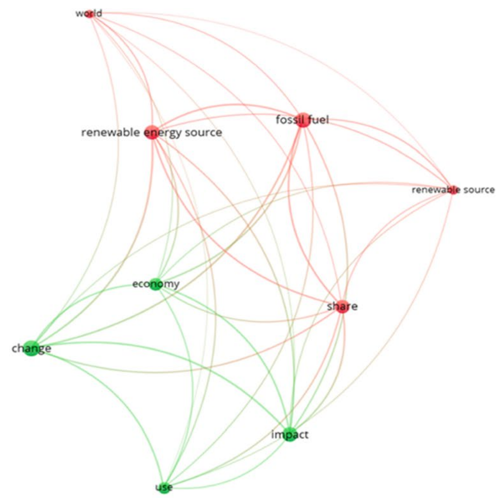
The dependent variable is represented by carbon dioxide emission per capita (CDE). The explanatory variables included in the regression equations are globalization index, renewable energy consumption as a percentage of total energy consumption, and trade openness measured as the sum of trade as a percentage of GDP.

Table 3 shows that the among variables is not reported a very high correlation, not indicating causality. In addition, carbon dioxide emission per capita shows a positive correlation with GDP/capita, globalization index, and trade openness measured as the sum of trade as a percentage of GDP, and a negative correlation with renewable energy consumption as a percentage of total energy consumption, hinting that renewable energy consumption contributes to reducing carbon dioxide emission although it does not indicate causality.

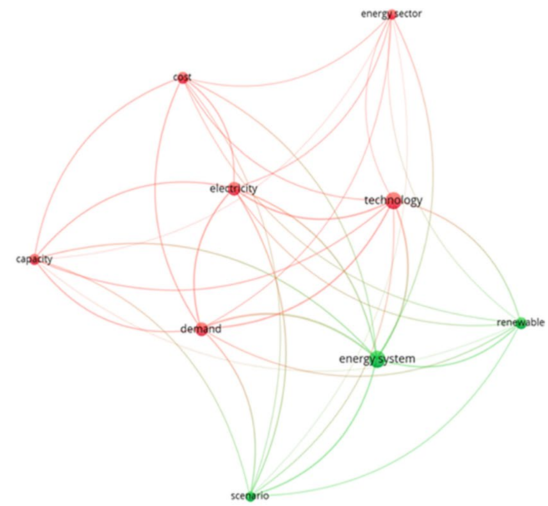
Using the panel analysis for 1990–2018, is estimated the influence of the variables: GDP/capita, globalization index and trade openness measured as the sum of trade as a percentage of GDP and renewable energy consumption as a percentage of total energy consumption on carbon dioxide emission per capita, from a cross-sectional and longitudinal perspective, based on the two models: with fixed effects and random effects.

The stationarity of the variables was tested through unit root tests using the augmented Dickey–Fuller and Im, Pesaran, and Shin unit root tests. All variables, except GDP/capita are stationary at a level, and GDP/capita is stationary after the first difference (Table 4).

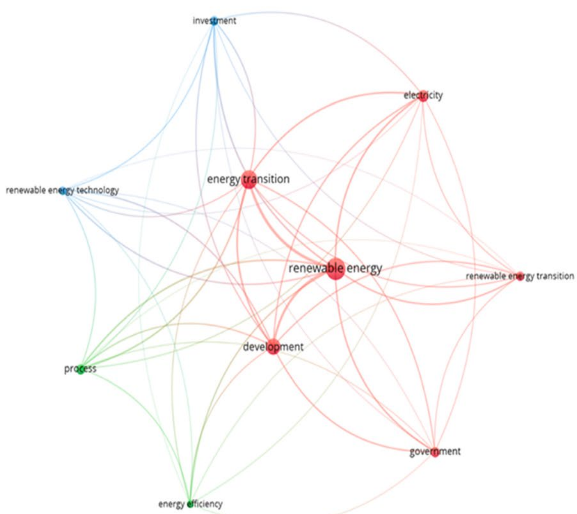
Based on the Hausman specification tests, the fixed effects model was favored over the random effects model. The results presented in this section are thus based on the fixed effects model (Table 5).



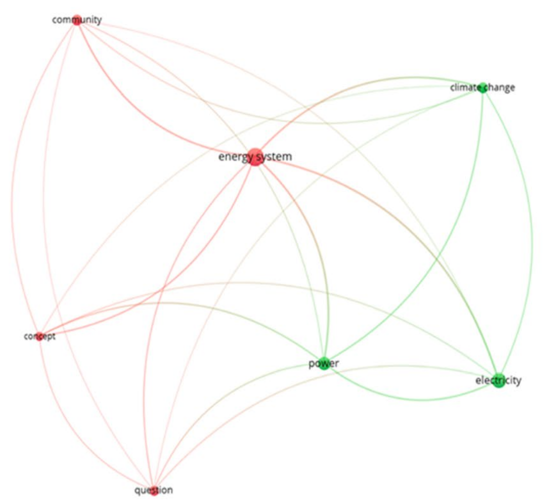
Cluster 1 renewable energy source - fossil fuel - climate change



Cluster 2 technology – renewable – electricity – demand - capacity;



Cluster 3 climate change – power – role -importance - community



Cluster 4 renewable energy-investment -energy transition – policy – development -government

Fig. 8 Most common combination. Source: authors' selection from the WoS database, based on selected words

Table 2 Summary statistics of dependent and explanatory variables

	Carbon dioxide emission per capita (CDE)	Globalization index	GDP/capita	Renewable energy consumption as a percentage of total energy consumption	Trade openness measured as sum of trade as a percentage of GDP
Mean	7.2522	72.5162	23,914.28	26.5142	100.4533
Min	0.4701	27.8347	953.1875	2.4102	13.3900
Max	30.4392	90.9839	116,644.8	55.9534	408.3600
Std. Dev	3.6137	13.4552	16,342.54	12.1443	53.9751

The correlated random effects-Hausman test results are interpreted on the basis of the chi-square value, and according to the chi-square value, we reject the null hypothesis. This means that there exists a significant difference in the statistical results of random and fixed effects; the fixed effects test will be applicable.

Table 3 Pearson's correlation among variables

	Carbon dioxide emission per capita	GDP/capita	Globalization index	Renewable energy consumption as a percentage of total energy consumption	Trade openness measured as the sum of trade as a percentage of GDP
Carbon dioxide emission per capita	1	0.4470	0.3649	−0.3117	0.3554
GDP/capita	0.4470	1	0.7296	0.1580	0.4281
Globalization index	0.3649	0.7296	1	0.0301	0.1758
Renewable energy consumption as a percentage of total energy consumption	−0.3117	0.1580	0.03007	1	−0.2168
Trade openness measured as sum of trade as percentage of GDP	0.3554	0.4281	0.1758	−0.2168	1

Table 4 Unit root tests for the full sample

Variables	Levin, Lin, and Chu		Im, Pesaran, and Shin W-Stat		ADF-Fisher Chi-Square		PP-Fisher Chi-Square	
	Statistic	Prob	Statistic	Prob	Statistic	Prob	Statistic	Prob
Carbon dioxide emission per capita	−3.7726	0.0001	−2.5510	0.0054	159.020	0.0000	199.7440	0.0000
GDP/capita	11.3639	1.0000	18.0924	1.0000	2.2092	1.0000	1.3830	1.0000
D(GDP/capita)	−7.2648	0.0000	−8.0977	0.0000	211.021	0.0000	336.2640	0.0000
Globalization index	−14.7978	0.0000	−8.2555	0.0000	231.387	0.0000	553.8790	0.0000
Renewable energy consumption as a percentage of total energy consumption	−3.5140	0.0002	−3.5771	0.0002	32.9771	0.0003	29.0044	0.0012
Trade openness measured as sum of trade as percentage of GDP	−2.8975	0.0019	−0.8023	0.2112	102.621	0.0614	140.2820	0.0001

Table 5 Correlated random effects-Hausman test

Test summary	Chi-Sq. statistics	Chi-Sq. d.f	Prob	
Cross-section random	228.7238	4	0.0000	
Cross-section random effects test comparisons				
Variables	Fixed	Random	Var (diff.)	Prob
GDP/capita	−0.0001	0.0003	0.0000	0.0000
Globalization index	0.0233	0.0426	0.0000	0.0000
Renewable energy consumption as a percentage of total energy consumption	−0.0815	−0.1199	0.0002	0.0062
Trade openness measured as sum of trade as percentage of GDP	−0.0003	0.0003	0.0000	0.0000

The sum of squares of errors (sum of squares errors-SSE) is 54.36. Based on the coefficient of determination (*R*-square) it can be observed that the fixed effects model obtained explains 87.82% of the carbon dioxide emission per capita variation is defined by GDP/capita, globalization index, and trade openness measured as the sum of trade as a percentage of GDP and renewable energy consumption as a percentage of total energy consumption on carbon dioxide emission per capita (Table 6).

Table 6 Statistics on the fixed-effects model evaluation

Regression model statistics	
Sum of squares of errors	54.3553
Standard error of regression	0.7264
Coefficient of determination (R^2)	0.8782

Source: authors' computation using Eviews

The study also tested the hypothesis of homogeneity.

The obtained results (Table 7) support as pertinent the estimation of carbon dioxide emission per capita based on GDP/capita, globalization index, and trade openness measured as the sum of trade as a percentage of GDP and renewable energy consumption as a percentage of total energy consumption in case of using models with fixed effects. Moreover, the variables have a constant influence over time on carbon dioxide emission per capita. Since for the European countries, the probability of having a calculated value of the test statistic *F* (Fisher) higher than its theoretical value is lower than the theoretical threshold of 0.0000, the null hypothesis of homogeneity is accepted. This attests the carbon dioxide emission per capita evaluation model is unique and representative of the European countries.

The results obtained from the CDE_{it} estimation using the fixed effects model are presented in Table 8. The values of the regression model estimates indicated that the variables, globalization index, and renewable energy consumption as a percentage of total energy consumption have a significant influence on the carbon dioxide emission per capita. Instead, GDP/capita and trade openness do not significantly influence the carbon dioxide emission per capita. The regression equation can be written as follows:

$$CDE_{it} = 4.9599 + a_i + d_t + 0.0234\ GI_{it} - 0.0815\ RE_{it} - 0.0003\ TO_{it} - 0.0001\ DGDP_{it}.$$

where a_i are the fixed effects determined by the individual size of the countries (differences between counties regarding the carbon dioxide emission per capita), and d_t represents the fixed effects determined by the temporal dimension (differences between years regarding the carbon dioxide emission per capita for European countries).

Since the use of the fixed effects model was validated using the Hausman test, in the case of panel analysis, it is considered that the influence of the variables globalization index and trade openness measured as the sum of trade as a percentage of GDP and renewable energy consumption as a percentage of total energy consumption on the CDE_{it} is similar for all countries, regardless of the period (1990–2018).

Panel data regressions were used to verify the hypotheses, while fixed effects are considered. The following assumptions had been verified:

1. Heteroskedasticity of residues (Wald test)
2. Dependence of residues between the panels (Pesaran test)
3. Autocorrelation of residues (LM test), (De Wachter et al. 2007)

The robustness checks revealed no autocorrelation and heteroscedasticity problems.

Table 7 Testing the homogeneity hypothesis based on the *F* test

F test for fixed effects		
Number of fixed effects	*F* value	Prob(*F*-statistic)
42	92.8000	0.0000

Source: authors' computation using Eviews

Research results and discussions

Overall, at the European level, the carbon dioxide emission per capita is significantly influenced by the variables GDP/capita, globalization index, and trade openness measured as the sum of trade as a percentage of GDP and renewable energy consumption as a percentage of total energy consumption in case of European countries for the period 1990–2018, therefore registering similar trends in order to achieve renewable energy transition, thus confirming hypothesis 2.

As the countries have a special specificity regarding the transition to renewable energy, we performed the regression analysis on groups of homogeneous countries regarding the share of renewable energy. Thus, we clustered the countries according to renewable energy consumption as a percentage of total energy consumption. Following the cluster analysis, 3 different clusters resulted:

– Cluster 1: Albania, Montenegro, Bosnia and Herzegovina, Austria, Denmark, Estonia, Finland, Croatia, Lithuania, Latvia, and Portugal;

Table 8 Estimation of the regression model parameters

Variables	Coefficients	Std. Error	*t*-Statistic	Prob
D(GDP/capita)	− 0.0001	0.0001	− 0.7446	0.4582
Globalization index	0.0234	0.0069	3.3949	0.0010
Renewable energy consumption as a percentage of total energy consumption	− 0.0815	0.0152	− 5.3749	0.0000
Trade openness measured as sum of trade as percentage of GDP	− 0.0003	0.0003	− 1.0618	0.2908
Intercept	4.9599	0.6548	7.5746	0.0000

- Cluster 2: Serbia, North Macedonia, Belgium, Bulgaria, Belarus, Switzerland, Cyprus, Czech Republic, Germany, Spain, France, UK, Greece, Hungary, Ireland, Italy, Luxembourg, Moldova, Malta, Netherlands, Poland, Romania, Russian Federation, Slovak Republic, Slovenia, Turkey, and Ukraine;
- Cluster 3: Iceland, Norway, and Sweden

  In the case of cluster 1, the summary of descriptive statistics can be seen in full in Table 12, Annex. Thus, it was known that the average CDE of European countries in cluster 1 is 6.08 tonnes/capita, the lowest CDE is 0.00 tonnes/capita, and the highest CDE is 14.88 tonnes/capita with a standard deviation of 3.62 tonnes/capita. The average globalization is 73.18 with the highest value of 88.71 and the lowest value of 37.54, the standard deviation being 12.55. The medium GDP/capita is 20,921.79, ranging from 953.19 to 57,462.78, with a standard deviation of 13,010.07. The average renewable energy consumption as a percentage of total energy consumption is 27.85, the lowest value is 0, and the highest value is 55.95, with a standard deviation of 10.34. Trade openness as the sum of trade as a percentage of GDP varies between 44.9 and 169.49, the medium value being 90.52 and a standard value of 25.59.

The obtained results (Table 9) support as pertinent the estimation of carbon dioxide emission per capita based on renewable energy consumption as a percentage of total energy consumption, globalization index, and trade openness measured as the sum of trade as a percentage of GDP in the case of using models with fixed effects. Moreover, the variables have a constant influence over time on carbon dioxide emission per capita. The R^2 is 0.92, and the probability of having a calculated value of the test statistic F (Fisher) higher than its theoretical value is lower than the theoretical threshold of 0.0000; the null hypothesis of homogeneity is accepted. This attests the carbon dioxide emission per capita evaluation model is unique and representative of the European countries.

The results obtained from the CDE_{it} estimation using the fixed effects model are presented in Table 10. The values of the regression model estimates indicated that the variables renewable energy consumption as a percentage of total energy consumption, globalization index, and trade openness measured as sum of trade as percentage of GDP have a significant influence on the carbon dioxide emission per capita.

The fixed effects model was validated using the Hausman test, considering that the influence of the variables renewable energy consumption as a percentage of total energy consumption, globalization index, and trade openness measured as the sum of trade as a percentage of GDP is similar for all countries in cluster 1, regardless of the period (1990–2018).

In the case of cluster 2, the summary of descriptive statistics can be seen in full in Table 13, Annex. Thus, it was known that the average CDE of European countries in cluster 2 is 7.61 tonnes/capita, the lowest CDE is 0.00 tonnes/capita, and the highest CDE is 29.36 tonnes/capita with a standard deviation of 3.96 tonnes/capita. The average globalization is 75.53 with the highest value of 90.98 and the lowest value of 33.93, the standard deviation being 12.34. The medium GDP/capita is 26732.82, ranging from 953.19 to 116,644.8, with a standard deviation of 17,447.95. The average renewable energy consumption as a percentage of total energy consumption is 17.08, the lowest value is 0, and the highest value is 78.21, with a standard deviation of 14.81. Trade openness as the sum of trade as a percentage of GDP varies between 13.39 and 114.98; the medium value is 111.98, and standard value is 15.3. The obtained results (Table 10)

Table 10 Estimation of the regression model parameters in the case of cluster 2

Variables	Coefficients	Std. Error	*t*-Statistic	Prob
D(GDP/capita)	$5.6 * 10^{-5}$	$3.65 * 10^{-5}$	1.3850	0.1664
Globalization index	0.0412	0.0075	5.5090	0.0000
Renewable energy consumption as a percentage of total energy consumption	0.0021	$5.10*10^{-5}$	42.0537	0.0000
Trade openness measured as the sum of trade as a percentage of GDP	− 0.0305	0.0023	− 13.3993	0.0000
Intercept	8.6801	0.4866	17.8376	0.0000

Table 9 Estimation of the regression model parameters in the case of cluster 1

Variables	Coefficients	Std. Error	*t*-Statistic	Prob
D(GDP/capita)	0.0001	$8.67 * 10^{-5}$	1.5205	0.1271
Globalization index	0.0811	0.0108	7.5026	0.0000
Renewable energy consumption as a percentage of total energy consumption	− 0.0376	0.0098	− 3.8151	0.0002
Trade openness measured as sum of trade as percentage of GDP	− 10.0215	0.0060	− 3.6047	0.0004
Intercept	3.0661	0.7393	4.1472	0.0000

support as pertinent the estimation of carbon dioxide emission per capita based on trade openness, globalization index, and renewable energy consumption as a percentage of total energy consumption in the case of using models with fixed effects. Moreover, the variables have a constant influence over time on carbon dioxide emission per capita. The R^2 is 0.99 and the probability of having a calculated value of the test statistic F (Fisher) higher than its theoretical value is lower than the theoretical threshold of 0.0000; the null hypothesis of homogeneity is accepted. This attests the carbon dioxide emission per capita evaluation model is unique and representative of the European countries.

The results obtained from the CDE_{it} estimation using the fixed effects model are presented in Table 10. The values of the regression model estimates indicated that the variables trade openness, globalization index, and renewable energy consumption as a percentage of total energy consumption have a significant influence on the carbon dioxide emission per capita.

The fixed effects model was validated using the Hausman test, considering that the influence of the variables GDP/capita, globalization index, and renewable energy consumption as a percentage of total energy consumption is similar for all countries in cluster 2, regardless of period (1990–2018).

In the case of cluster 3, the summary of descriptive statistics can be seen in full in Table 14, Annex. Thus, it was known that the average CDE of European countries in cluster 3 is 6.75 tonnes/capita, the lowest CDE is 3.54 tonnes/capita, and the highest CDE is 8.82 tonnes/capita with a standard deviation of 1.29 tonnes/capita. The average globalization is 80.88 with the highest value of 89.72 and the lowest value of 63.09, the standard deviation being 6.92. The medium GDP/capita is 40,308.37, ranging from 20,573.43 to 69,710.48, with a standard deviation of 13,267.69. The average renewable energy consumption as a percentage of total energy consumption is 55.43, the lowest value being 0, and the highest value is 31.35 with a standard deviation of 12.63. Trade openness as sum of trade as percentage of GDP varies between 50.77 and 104.09, the medium value being 75.91 and the standard value 10.34.

The obtained results (Table 11) support as pertinent the estimation of carbon dioxide emission per capita based on the globalization index and renewable energy consumption as a percentage of total energy consumption in case of using models with fixed effects. Moreover, the variables have a constant influence over time on carbon dioxide emission per capita. The R^2 is 0.94, and the probability of having a calculated value of the test statistic F (Fisher) higher than its theoretical value is lower than the theoretical threshold of 0.0000; the null hypothesis of homogeneity is accepted. This attests the carbon dioxide emission per capita evaluation model is unique and representative of the European countries.

The results obtained from the CDE_{it} estimation using the fixed effects model are presented in Table 11. The values of the regression model estimates indicated that the variables globalization index and renewable energy consumption as a percentage of total energy consumption have a significant influence on the carbon dioxide emission per capita.

The fixed effects model was validated using the Hausman test, considering that the influence of the variables GDP/capita, globalization index, and renewable energy consumption as a percentage of total energy consumption is similar for all countries in cluster 3, regardless of period (1990–2018).

Therefore, carbon emissions that reflect the transition to renewable energy are significantly influenced across the 42 European countries by the globalization index and trade openness measured as the sum of trade as a percentage of GDP and renewable energy consumption as a percentage of total energy consumption. When analyzing the transition to renewable energy at the level of homogeneous clusters regarding the share of renewable energy, trade openness does not have a significant influence on carbon dioxide emissions in the countries in cluster 3. Renewable energy significantly influence carbon emissions even in the case of cluster 1 which includes non-EU countries, and in their case, the target for renewable energy is lower than in the case of EU countries. Regarding cluster 3, trade openness does not significantly influence carbon emissions due to the fact that these countries are in a favorable position to embark on further openness-oriented policies at no cost of degrading the environmental quality.

Economic activity measured as GDP/capita does not impact the environment, which is consistent with some studies identified in the literature. The existence of the Kuznets curve

Table 11 Estimation of the regression model parameters in the case of cluster 3

Variables	Coefficients	Std. Error	*t*-Statistic	Prob
GDP/capita	$-1.74*10^{-5}$	$1.84 * 10^{-5}$	0.9430	0.3489
Globalization index	−0.031	0.01738	−1.7844	0.0787
Renewable energy consumption as a percentage of total energy consumption	−0.1140	0.0101	−11.2794	0.0000
Trade openness measured as sum of trade as percentage of GDP	0.0013	0.0075	0.1681	0.8670
Intercept	15.4545	1.2412	12.4511	0.0000

is demonstrated over different periods by countries and regions by specialists (Khan et al. 2016; Armeanu et al. 2018; Panait et al. 2019; Gyamfi et al. 2021). As the level of economic development increases, countries become increasingly aware of the negative externalities generated by human activity on the environment and through various instruments, mainly economic policy measures, try to manage and reduce the impact on the environment. However, the experience so far has demonstrated the importance of all categories of stakeholders in this complex process, their awareness and education being essential in order to implement the identified measures.

Globalization has generated not only increasing interconnections between national economies and intensifying the production of goods and services but also negative externalities felt differently by developing and developed countries (Liu et al. 2020; Ahmed and Le 2021; Khan et al. 2021a, b; Vlahinić and Fajdetic 2021). The negative effects on the environment are felt especially in developing countries. The liberalization of capital movements internationally has led to the entry of considerable financial flows into poor countries, but most of the time, the technology brought by foreign-owned companies is level two, more polluting (usually transferring equipment that was no longer allowed to be used in developed countries due to the need to comply with environmental standards). Therefore, the more permissive regulations in emerging and underdeveloped countries, the desire of foreign investors to maximize their profits, and the lack of reaction of the public authorities have generated this situation in which these countries are the garbage dump of mankind.

The liberalization of the movement of goods after the Second World War was a factor that generated the intensification of trade. The opening of trade has bivalent effects on environmental pollution through various effects identified in the literature. In the first phase, the liberalization of capital movements generates an increase in the local production which through the effects of scale generates "high production and the consumption of energy at a lower revenue level" (Tachie et al. 2020). As demand for inferior products increases, the opening of trade generates environmental pollution. Studies conducted for different countries/groups of countries in Europe and Asia have shown the negative impact that trade opening has on the environment through greenhouse gas emissions generated by the production activity that must support growing exports. (Ozturk and Acaravci 2013; Shahbaz et al. 2017; Balsalobre-Lorente et al. 2018; Adebayo et al. 2021; Khaskheli et al. 2021) The comparative advantage of a country has its mark on the structure of exported goods, which has a direct influence on the type of greenhouse gases generated by industrial production. Therefore, in addition to the scale effect, the composition effect is another aspect that specialists consider when analyzing the impact of trade opening on the environment (Managi et al. 2009; Tachie et al. 2020). The opening of trade also favors the transfer of high-performance technology, and the less developed countries can have access to technology, at reasonable prices, thus improving their energy efficiency and the positive effects being felt on the environment. Therefore, the technical effect comes to complete the picture of the impact of trade opening on the environment. Renewable energy is a solution that comes to solve not only the problem generated by the decrease of fossil fuel resources but also the pollution generated by the use of classical energy sources. The low impact of the production and use of renewable energy on the environment is recognized in the international literature (Cristea and Dobrota 2014; Zhou et al. 2018, 2020; Khan et al. 2020; Adebayo et al. 2021; Shahzad et al. 2021).

Conclusions and policy implications

Climate change generated by the intensification of economic activity has a negative impact on people and companies both through extreme events such as storms, tornadoes or prolonged droughts, and by rising temperatures and falling rainfall, which even if somewhat low levels generate discomfort for citizens or losses for economic agents. Simple financial instruments such as weather derivatives contracts or insurance are no longer enough, the phenomenon requiring a holistic approach and complex solutions must be found, globally, in order to be embraced by all stakeholders. The global approach materialized in the Paris Agreement and the meeting in Glasgow, COP26, but the solutions adopted and implemented must take into account the specifics of each country, the endowment with natural factors, and the competitive advantages that each economy has on the international market, the involvement of public authorities, the responsibility of citizens, and the desire of companies to initiate and carry out public–private partnerships. The goals set at the international level are pursued differently by the countries of the world in terms of the level of development, and their involvement in the world economy through capital flows and trade flows. Developed countries have the financial resources, know-how, and the capacity to develop and implement complex technological, economic, and social policies so as to manage climate change and the energy transition. The progress made by EU countries is a testament to the importance of legal regulations, with the EU being a leader in managing climate change and achieving the energy transition.

Emerging and underdeveloped countries are forced to cope with both the pressure of transnational companies importing outdated technology and exporting various goods (contributing heavily to environmental pollution) and the lack of financial funds to implement economic measures to support consumers and local companies. The technological and economic dependence of these countries on transnational companies and international financial assistance generates a slowdown in the pace of energy transition, which undermines global efforts.

The European energy sector is in the process of transitioning to "clean green energy," facing the challenge of decarbonizing energy systems, reducing greenhouse gas emissions, and promoting renewable sources, while also to ensure the security of electricity supply at an affordable cost to the final consumer. In order to point out the research issues of great interest related to the energy transition, we have identified the most common words associated with the renewable energy transition, we realized a bibliometric analysis regarding 600 articles on this topic, in the WOS database. The empirical analysis proved that the most common words in the full content of selected articles apart from the keywords used are related to climate change, technology, investment policy, and development.

In order to establish the status at the level of European countries regarding the transition to renewable energy, we analyzed variables specific to this phenomenon for a period of 28 years, at the level of 42 European countries. The proxy variable that reflects the transition to energy is carbon dioxide emissions, the results indicating that the variables that significantly influenced are GDP/capita, globalization index, trade openness, and renewable energy consumption as a percentage of total energy consumption. At the level of clusters of homogeneous countries in terms of the share of renewable energy, in the case of all clusters GDP/capita does not significantly influence carbon dioxide emissions, although there are differences regarding the target for renewable energy in the case of cluster 1 (non-EU countries), with EU target being higher than the target in non-EU countries. At the level of cluster 3, the variable that does not significantly influence carbon dioxide emissions is trade openness, due to the favorable position to embark on further openness-oriented policies without degrading the environmental quality.

The results showed that, although the interest in the energy transition is recognized by European countries, their course differs not only in terms of economic potential and efficiency but also in international commitments and targets set to reduce the effects of human action on environmental factors. The fact that the targets set by European non-EU member states for reducing CO2 emissions are lower than for the EU is influencing the dynamics of the energy transition, with implications for the size and destination of funds to finance the development of renewable energy. So, the energy transition can help reduce the impact of human activity on the environment, and the production and consumption of renewable energy is environmentally friendly. The involvement of public authorities in regulating the energy transition provides the necessary instruments and financial funds for a fair transition for stakeholders, taking into account both the complexity of the phenomenon and the negative effects of the transition from fossil fuels to renewable energy. Given the complexity of the energy transition phenomenon and the economic, social, and technical challenges involved, policy measures are needed:

- The continuation of international meetings and negotiations to combat the effects of climate change and to achieve the energy transition because the problems are global and require a global approach, answers, and tools;
- The establishment of funds (public, managed by international institutions) for energy finance and climate finance through which developed countries support the process of energy transition from the rest of the world given the label of major pollutants that these countries have justifiably acquired at an international level;
- Rethinking the energy subsidy system by gradually giving up fossil fuel subsidies;
- Public–private partnerships, especially between the state and transnational companies so as to ensure an adequate transfer of the latest technology, in emerging and underdeveloped countries;
- Strengthening institutional capacity in emerging and underdeveloped countries because these partnerships can fuel corruption;
- Reconfiguration of the trade and investment policy in order to favor the import of up to date technology;
- Empowering consumers through education so that they consume responsibly but are also aware of the role they play as stakeholders of public companies and institutions.

Finally, all countries and regions should advance an energy transition that is just and inclusive, appropriate to national expectations for net-zero climate impact, for resilient and sustainable development. "Sharp adjustments in capital flows and a reorientation of investments are necessary to align energy with a positive economic and environmental trajectory" (IRENA 2021).

The authors are aware of the limitations of their research considering the sample of selected countries, the period of analysis, and the indicators used. In future research directions, the authors aim to focus the study on the impact of the energy transition on CO2 emissions only for EU countries given the common package of laws that these countries have adopted to create the energy union. In the context of the events generated by the conflict in Ukraine, the countries of the European Union have started to be more concerned about energy security, which is why a reconsideration of the European energy transition policy is observed, which has consequences for the energy mix to be used in the coming decades. As independent variables, the authors consider the selection of other indicators such as the degree of urbanization, the level of technological innovation, the aging of the population in developed countries, the FDI flows received, the level of development specific to the financial market measured either with the help of stock market capitalization, the volume of loans granted. or the level of financial inclusion.

Annex

Table 12 Summary statistics of dependent and explanatory variables in the case of cluster 1

	Carbon dioxide emission per capita	Globalization index	GDP/capita	Renewable energy consumption as a percentage of total energy consumption	Trade openness measured as the sum of trade as a percentage of GDP
Mean	6.08	73.18	20,921.79	27.85	90.52
Min	0.00	37.54	953.19	0.00	44.9
Max	14.81	88.71	57,462.78	55.95	169.49
Std. Dev	3.62	12.55	13,010.07	10.34	25.59

Table 13 Summary statistics of dependent and explanatory variables in the case of cluster 2

	Carbon dioxide emission per capita	Globalization index	GDP/capita	Renewable energy consumption as a percentage of total energy consumption	Trade openness measured as the sum of trade as a percentage of GDP
Mean	7.6073	75.5287	26,732.8200	17.0814	111.9779
Min	0.0000	33.9267	953.1875	0.0000	13.3900
Max	29.3603	90.9839	116,644.8000	78.2135	114.4128
Std. Dev	3.9572	12.3377	17,447.9500	14.8140	15.3022

Table 14 Summary statistics of dependent and explanatory variables in the case of cluster 3

	Carbon dioxide emission per capita	Globalization index	GDP/capita	Renewable energy consumption as a percentage of total energy consumption	Trade openness measured as the sum of trade as a percentage of GDP
Mean	6.752534	80.87573	40,308.37	55.42721	75.9059
Min	3.538009	63.09475	20,573.43	31.35442	50.77
Max	8.823570	89.,72036	69710.48	78.21350	104.09
Std. Dev	1.294801	6.918722	13267.69	12.62775	10.3386

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Availability of data and materials Data used are public information.

Declarations

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