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Effects of policy induced uncertainty and geopolitical risk on renewable energy production: Econometric analysis

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ABSTRACT

Various human activities lead to the emission of greenhouse gases, which causes global warming and climate change with a wide range of negative consequences. Since burning of fossil fuels is the most important cause of anthropogenic emission of greenhouse gases, replacement of fossil fuels energy with renewable energy is recognized as one of the most significant tools for combating climate change. Bearing these facts in mind, many authors have analyzed numerous determinants that potentially affect various indicators of renewable energy. Nevertheless, it is obvious that available literature is very scarce when it comes to the impact of policy uncertainty and geopolitical risk on renewable energy production, as well as that the existing studies are burdened with certain methodical weaknesses. This research aims to analyze the impact of policy induced uncertainty and geopolitical risk on renewable energy production. The analysis was conducted on a fairly extensive panel data sample that incorporates 42 countries and time interval of 31 years (1990–2020). The panel data cointegration framework was used which is considered adequate because it eliminates numerous methodical shortcomings of the existing papers. According to the obtained findings, policy induced uncertainty and geopolitical risk do not have any long-term impact on renewable energy production. A positive short-term influence of geopolitical risk is present in 31 % of countries, and a negative one in 19 %. In addition, a positive short-run impact of policy induced uncertainty was detected in 21.4 % of countries, and a negative one in 31 %. Such heterogeneous effects cannot be linked to the geographic location and economic development. Average short-term influence of both variables is insignificant. Finally, the results of the analysis show that a positive average long-term effect has gross domestic product, final energy consumption structure, financial development, greenhouse gases emissions, gross domestic fixed investments and average annual crude oil price. Only international trade has a negative average long-run impact.

1. Introduction

There is no doubt that human activities, mainly through the emissions of greenhouse gases (GHGs), lead to global warming and climate change. According to the Intergovernmental Panel on Climate Change's Synthesis Report [1, p. 42], the global surface temperature had increased by 1.1 °C in the period 2011–2020 compared to 1850–1900. The increase in temperature is more pronounced over land (1.6 °C) than over the ocean (0.9 °C). Also, the human-caused increase in global surface temperature in the period 2010–2019 compared to 1850–1900 was estimated at 1.07 °C. If the first two decades of the 21st century (2001–2020) are observed, the global surface temperature had increased by about 1 °C compared to the period 1850–1900. There is a high probability that during the last 50 years (since 1970), faster global warming had been observed than in any other 50-year period for at least the last 2000 years.

The current extent of human-caused climate change generates a wide range of negative impacts that are reflected in the following facts [1, pp.

Abbreviations: GHGs, greenhouse gases; EPA, Environmental Protection Agency; RE, renewable energy; PU, policy uncertainty; GPR, geopolitical risk; FD, financial development; FE, financial efficiency; IMF, International Monetary Fund; WDI, World Development Indicators; R&D, Research & Development; DF, Dickey-Fuller; OLS, ordinary least squares; OPEC, Organization of the Petroleum Exporting Countries; PMG, pooled mean group; PB, pooled Bewley; MG, mean group; IFE, interactive fixed effects; CCEMG, common correlated effects mean group; CCEMG-GMM, common correlated effects mean group-generalized method of moments; HAC, heteroskedasticity and autocorrelation consistent; CCE, common correlated effects.

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5–6]: (i) global warming is very likely the main cause of global mean sea level rise since at least 1971; (ii) temperature rise is largely responsible for the increased frequency and strength of extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones; (iii) it is likely that since the 1950s human-caused climate change has increased the chance of complex extreme events, including an increase in the frequency of simultaneous heatwaves and droughts; (iv) there are about 3.3–3.6 billion people who are highly vulnerable to the impact of climate change, because increasingly frequent and powerful extreme events are exposing them to acute food insecurity and reduced water security; (v) climate change contributed to the fact that mortality from floods, droughts and storms in highly affected regions, in the period 2010–2020, was 15 times higher than in less vulnerable regions; (vi) climate change probably had a negative effect on agricultural production in mid and low latitude regions, but a positive impact in some high latitude regions; (vii) ocean warming and acidification are likely to have a negative impact on fisheries in certain regions; (viii) extreme heatwaves are very likely to cause increased mortality and morbidity; (ix) it is likely that climate change will lead to higher incidences of various medical diseases (for instance, mental health challenges are likely to be linked to warming, trauma from extreme climate events and loss of livelihoods); (x) climate change is likely to generate certain economic damages in sectors such as fishery, tourism, energy, agriculture and forestry, as well as annihilation of livelihoods by the destruction of infrastructure, property and income; (xi) climate change is likely to have an adverse impact on social and gender equality.

There is no doubt that climate change and all its negative consequences are a result of anthropogenic GHGs emissions. It is well-known that the main cause of anthropogenic emissions of all GHGs is the burning of fossil fuels. For example, according to the U.S. Environmental Protection Agency (EPA), burning of fossil fuels for energy generates 73 % of total GHGs emissions and 92 % of total U.S. CO_2 emissions.[1] Therefore, it is clear that the urgent replacement of fossil fuels energy with renewable energy (RE) is a very important means to stop further global warming.

A lot of empirical literature is dedicated to the research of different RE indicators. These studies are of great importance because they explain the most important determinants of various RE indicators and provide an overview of the most diverse methods that are relatively suitable for application. However, despite their great importance, the available papers offer very unconvincing and unreliable findings. The cause of this unreliability are numerous methodical shortcomings that are inherent in the available analyses. *That is why it is very important that these methodical weaknesses be precisely pointed out and explained.*

The first shortcoming is attributed to the fact that studies like Kim and Park [2], Ji and Zhang [3], Zhao et al. [4], Lei et al. [5], Borozan [6], Chu [7], Irfan et al. [8] and Pata et al. [9] were conducted on relatively small samples. Analysis based on relatively small samples can generate quite unreliable findings. Actually, it is well known that numerous statistical tests, such as unit root tests and cointegration tests, can be very biased and unreliable if applied to a small sample. Also, the statistical properties of regression model parameter estimates, such as unbiasedness and efficiency, are highly dependent on the sample size used for research. Therefore, it is important to conduct research on a significantly larger sample.

The next shortcoming is reflected in the fact that some researches were conducted using the techniques of econometric analysis of time series. The use of these techniques is quite widespread in empirical analyses, but it is also generally known that they are burdened with certain weaknesses. One of these weaknesses is that these techniques only take into account the temporal variations of the data, while completely neglecting the spatial variations (variations across countries). This feature leads to research being conducted on smaller samples (with lower information content) compared to panels, that results in unit root and cointegration tests having significantly less statistical power than panel counterpart. In addition, the use of a relatively small number of observations compared to panel data may result in obtaining less efficient estimates of regression parameters. Also, it is known that time series unit root and cointegration tests otherwise have low statistical power when time series are short [10]. The analyzes presented in Ji and Zhang [3], Zhao et al. [4], Lei et al. [5], Shafiullah et al. [11], Alola [12], Dutta and Dutta [13], Khan and Su [14] and Pata et al. [15] are based on time series analysis and are burdened by the mentioned weaknesses.

A very important omission of some previous studies is ignoring the potential presence of structural breaks in the variables. Structural breaks can occur as a result of various idiosyncratic and aggregate events (shocks) such as changes in existing public policy instruments, introduction of new public policy instruments, various forms of social changes and crises (political crises, epidemics, pandemics), global economic recessions, oil shocks, wars, etc. All these and similar events potentially affect the dynamics of the variables and the nature of the relationships between them, i.e., the parameters of the regression models. When analyzing panel data that includes several dozen countries and a relatively long period of time, there is a very high chance that some variables for some countries show structural breaks (sudden changes in dynamics). This risk is also great when analyzing time series. Ignoring structural breaks, during testing and model estimation, when they are present can cause wrong results and conclusions [16]. In order to increase the credibility of the obtained findings and conclusions, it is highly recommended to use econometric techniques that include structural breaks. Unfortunately, many studies such as Ji and Zhang [3], Lei et al. [5], Borozan [6], Chu [7], Irfan et al. [8], Dutta and Dutta [13], Yang et al. [17], Anton and Nucu [18], Abban and Hasan [19], Shahbaz et al. [20], Wang et al. [21], Trinh et al. [22], Alsagr [23] and Du et al. [24] ignore the potential presence of structural breaks in the data, which is a serious omission.

Also, very serious omission of some available studies, which can really lead to completely unreliable results and wrong conclusions, is ignoring the testing of the stochastic properties of the data. One of the important properties of many variables is having a unit root (one, and rarely two). This property must be taken into account if it exists, since further course of the econometric analysis largely depends on it. If the unit root is present in the data, the adequate framework for further analysis is cointegration, which significantly directs and limits the rest of the research. Therefore, it is very important to test the presence of a unit root in the data, because its neglect can very easily produce inconsistent estimates and spurious models that are not suitable for inference. However, some analyzes such as Kim and Park [2], Pata et al. [9], Khan and Su [14], Anton and Nucu [18], Kim and Park [25], Liu et al. [26], Feng and Zheng [27] and Wang and Fan [28] do not test the stochastic properties of the data.

The next problem is that a group of studies that includes Kim and Park [2], Borozan [6], Chu [7], Irfan et al. [8], Yang et al. [17], Abban and Hasan [19], Shahbaz et al. [20], Wang et al. [21], Trinh et al. [22], Alsagr [23], Du et al. [24], Kim and Park [25], Liu et al. [26] and Wang and Fan [28] ignores the necessity to take cross-sectional dependence into account or relies on econometric tests which assume stationary unobservable common factors. Analyzes based on panel data undoubtedly have great advantages over studies that rely on time series and cross-sectional data, primarily because they take into account both temporal and spatial variations of variables, which significantly increases the information content of the sample. Panel unit root and cointegration tests have significantly higher statistical power than time series counterparts, while the estimation of panel regressions produces more efficient estimates. Nevertheless, in the modern globalized world, there is a high degree of political and economic dependence between countries, which is the reason for the very frequent presence of

[1] More detailed information can be found at https://www.eia.gov/energyexplained/energy-and-the-environment/where-greenhouse-gases-come-from.php.

cross-sectional dependence in the data [29]. This requires first to test whether cross-sectional dependence is present, and if so, to use tests and estimators that allow it. The use of unit root and/or cointegration tests that do not allow for cross-sectional dependence when it is present leads to very unreliable and uncredible results. Also, estimating the models using methods based on the cross-sectional independence assumption can generate inconsistent estimates of regression parameters that we are not interested in.

Finally, the group of papers made up of Kim and Park [2], Lei et al. [5], Borozan [6], Chu [7], Irfan et al. [8], Pata et al. [9], Yang et al. [17], Anton and Nucu [18], Shahbaz et al. [20], Wang et al. [21], Alsagr [23] and Kim and Park [25] ignore the presence of potentially endogenous regressors, which is a very serious shortcoming. Many cointegration tests and estimators assume strictly exogenous (or, at least weakly exogenous) explanatory variables in order to produce reliable test results and consistent estimations. If such tests and estimators are applied in a situation where one or more regressors are endogenous, the test results will be completely invalid, and the obtained estimations will be inconsistent. Therefore, it is important to select tests and estimators that resolve this potential problem.

In addition to the explained methodical weaknesses, the empirical literature also has a large gap when it comes to the impact of policy uncertainty (PU) and geopolitical risk (GPR) on RE production. We were able to detect only one study analyzing the effect of PU on RE production [14] and no study examining the influence of GPR on the same variable. In other words, this topic is insufficiently researched and it would be useful, at least in a cognitive sense, to investigate it in more detail.

It is very important to point out that all the empirical studies presented in this paper suffer from at least one of the aforementioned weaknesses. It can be summarized that existing empirical literature is burdened with the following drawbacks: (1) using of relatively small samples; (2) application of time series analysis procedures that ignore the cross-sectional variation of data and employ unit root and cointegration tests with low statistical power; (3) neglecting the potential presence of structural breaks; (4) absence of unit root and possibly cointegration testing; (5) neglecting cross-sectional dependence and using econometric tests which assume stationary common factors; (6) disregarding potential endogeneity of regressors; (7) lack of researches on the influence of PU and GPR on RE production.

Therefore, it is necessary to conduct completely new research that will narrow the gap in the empirical literature and erase the inherent methodical weaknesses. *The aim of this study is to reduce the gap in empirical literature and to select econometric techniques that remove all explained methodical shortcomings, which will result in more credible and convincing findings and conclusions*.

The analysis of the impact of PU and GPR on RE production was conducted on a rather large panel sample that includes 42 countries and a period of 31 years (1302 observations), which is the largest possible sample considering the data availability at the time of the research. As explained, analyzes based on panel data have great advantages over studies that rely on time series and cross-sectional data, because they take into account both temporal and spatial variations of variables, which significantly increases the information content of the sample. The panel sample causes higher statistical power of panel unit root and cointegration tests, as well as more efficient parameters estimates. Based on the fact that this research on the impact of PU and GPR on RE production was carried out on a rather large panel sample, it can be concluded that the *first*, *second* and *seventh* omissions were thereby eliminated. In addition, cross-sectional dependence was examined using five econometric tests. Unit root was tested using two unit root tests that permit data heterogeneity and cross-sectional dependence, one of which allows for multiple heterogeneous structural changes and non-stationary common factors. Cointegration was examined by two tests that also take into account cross-sectional dependence, non-stationary common factors and endogenous regressors, one of which incorporates structural breaks. Finally, the model was estimated using six estimators, of which the last one is representative, while the others were employed to test the robustness of the findings. The representative estimator allows for static heterogeneous panels, cross-sectional dependence, structural breaks, cointegrated variables, and endogenous regressors. Given that the selected econometric techniques applied in this paper include: 1) cross-sectional dependence testing; 2) examination of the presence of unit root and cointegration using tests that allow for cross-sectional dependence, structural breaks and non-stationary common factors, whereby cointegration tests additionally permit endogenous regressors; and 3) application of estimator that allows for structural breaks, cross-sectional dependence, non-stationary common factors and endogenous regressors; it is clear that this research also rules out the *third*, *fourth*, *fifth* and *sixth* shortcomings. Therefore, such an analysis of the impact of PU and GPR on RE production, by applying the selected econometric techniques, shrinking the gap in the empirical literature and removed all observed methodical weaknesses. *Reducing the gap in the existing empirical literature, removing all detected methodical weaknesses and generating more credible results and conclusions, are the most important scientific contributions of this research.*

The research comprises seven parts. The second and third ones include a review of literature and explanations of employed methods and data. Empirical results are presented and discussed in the fourth and fifth sections, respectively. In addition, policy implication and recommendations are set out in the sixth part, while conclusions are given in the last section.

2. Literature review

All available empirical studies concerning RE determinants can be classified into two groups according to their concept. The first group consists of research that includes the impact of PU and/or GPR on various RE indicators. For example, Pata et al. [9] analyzed the effect of PU and GPR on RE investments in a sample of G7 countries over the period 2004–2018. They concluded that PU and GPR exert a negative influence on RE investments, with the effect of PU being much stronger. Borozan [6], relying on a sample of G7 countries for the period 1997–2019, discovered an asymmetric long-term effect of PU on RE consumption, which suggests that a negative change of uncertainty increases RE consumption, while a positive change decreases it. Dutta and Dutta [13] investigated the impact of GPR on RE exchange traded funds volatility and found that the growth of GPR increases (decreases) the likelihood that volatility will be low (high). Feng and Zheng [27], examining the influences of PU on RE innovation on a panel of 22 countries over the period 1985–2019, concluded that this influence is positive in high institutional quality countries, which is not the case if the institutions are of low quality. Khan and Su [14] found on a sample of G7 countries over the period 2000–2020 that the sustainable development (production) of RE requires a greater degree of economic stability. Their findings indicate a varying effect of PU on RE production, as it declines in Germany when the relationship changes from short-term to long-term, which is completely opposite in the UK, Italy, USA and Japan. Lei et al. [5] examined the presence of asymmetric influences of PU and financial development (FD) on RE consumption in China for the period 1990–2019. Their findings show that the growth of PU in the long-term leads to a stronger increase in RE consumption. Shafiullah et al. [11] revealed negative long-term impact of PU on RE consumption in the USA over the period 1986–2019. Liu et al. [26], using data for 52 traditional energy enterprises and 116 RE enterprises in China over the period 2007–2017, examined the effect of PU on different types of energy enterprises' investment. They concluded that PU negatively affects traditional energy enterprises' investment, which is not true in the case of RE companies. In addition, this paper concludes that PU has a negative effect on the investment of coal and petroleum enterprises, but positive influence on the investment of solar energy, geothermal energy and other RE enterprises. This research suggests that ownership concentration can amplify the negative impact of PU on RE enterprises' investment.

The second group of studies includes papers analyzing the influence of various determinants (but not PU and GPR) on different RE indicators. Alsagr [23] studied the impact of financial efficiency (FE) on RE production in 23 advanced and developing countries over the period 1996–2020. He found that an increase (decrease) in FE encourages (reduces) RE production, but with different intensity in developed and emerging countries. Also, Chu [7] investigated the effect of energy security and economic complexity on RE production in G7 countries over the period 1980–2017. He revealed that energy insecurity encourages RE production, while economic complexity reduces it. Du et al. [24] showed on a sample of 30 Chinese provinces over the period 2001–2019 that green financing initiatives increase RE consumption, which is particularly pronounced in regions where the market functions well. Irfan et al. [8] found a positive effect of mineral markets, and a negative influence of FD on RE production in G7 countries, but insignificant impact of FD in E7 economies. Wang and Fan [28] proved the positive effect of green finance on RE enterprises' investments in China, which strengthens if there is high-quality economic development, but weakens or even disappears if the financing constraints are very strong. Alola [12] found a positive effect of soybean and wheat prices and a negative effect of corn prices on the RE equity in the USA. Pata et al. [15] discovered that FD stimulates RE consumption in the US at high quantiles in the medium and long term. Trinh et al. [22], analyzing a large sample of 180 countries over the last three decades, proved the heterogeneous influence of various FD indicators on RE consumption. Abban and Hasan [19] investigated the influence of government system on RE investment using data for 60 developed and non-developed countries. Their results showed that both the left and central-oriented ruling party, especially with the parliamentary government system, have a positive effect on RE investments, while the effect of the right-oriented government is somewhat weaker. Shahbaz et al. [20] was revealed positive influence of FD on RE consumption, using data for 34 upper middle income developing economies over the period 1994–2015. Wang et al. [21] examined the effect of FD and economic growth on RE consumption in China over the period 1997–2017. Their results for China as a whole and western China indicate a positive long-term influence of economic growth and a negative long-term effect of FD, while the short-term impact is completely opposite. Anton and Nucu [18], examining the sample of 28 European Union economies over the period 1990–2015, found that the influence of FD on RE consumption is positive. Zhao et al. [4], investigating data for China during the period 1980–2016, showed that FD and per capita income have a positive impact on RE consumption, while the effect of trade openness is negative. Ji and Zhang [3] indicated that FD is a very important factor for the growth of RE production and consumption. Yang et al. [17] analyzed data for 92 RE companies in China over the period 2007–2016 and discovered that government subsidies have a positive threshold impact on RE investment, especially in medium, small, and micro-sized companies. According to their findings, the influence of tax incentive policies is more significant than the effect of monetary subsidies. Kim and Park [25], analyzing data for 64 countries during the period 2001–2014, concluded that the Clean Development Mechanism has a pronounced positive effect on RE deployment in countries with a less developed financial market. Finally, Kim and Park [2] showed on a sample of 30 countries for the period 2000–2013 that the RE sector grows much faster if the degree of FD is higher.

As already pointed out in the introductory part, all these empirical studies have great importance, since they represent a rich collection of relatively appropriate techniques and offer a wide range of valuable results. Nevertheless, this empirical literature has a serious gap, because it does not examine enough the effect of PU and GPR on RE production, and is additionally burdened with numerous methodical weaknesses. These drawbacks are the generator of unreliable and unconvincing findings and conclusions. *Filling the gap in the available empirical literature, eliminating all detected methodical weaknesses and generating more credible results and conclusions, are the most important scientific contributions of this research.*

3. Material and methods

This research is based on extensive panel data sample that incorporates 42 countries and a time interval of 31 years (1990–2020). The number of countries in the sample (including their selection) as well as the time period covered are determined by the data availability. The analysis of PU and GPR effects on RE production was carried out using an empirical regression model that was built on the basis of representative literature, and can be presented as:

$$RE_{it} = \boldsymbol{\beta}_{0,i}\boldsymbol{D}_{it} + \beta_{1,i}GPR_{it} + \beta_{2,i}PU_{it} + \beta_{3,i}GDP_{it} + \beta_{4,i}TR_{it} + \beta_{5,i}UR_{it} + \beta_{6,i}REC_{it} + \beta_{7,i}FDI_{it} + \beta_{8,i}OPEC_{t} + \beta_{9,i}FD_{it} + \beta_{10,i}GH_{it} + \beta_{11,i}GF_{it} + \varepsilon_{it} \tag{1}$$

where *RE* denotes RE production per capita expressed in tons of oil equivalent; *D* is deterministic components vector; *GPR* is the geopolitical risk index constructed by Caldara and Iacoviello [30], whose higher value represents higher geopolitical risk and vice versa; *PU* is the world uncertainty index (policy induced uncertainty) constructed by Ahir et al. [31] whose higher value means higher uncertainty and vice versa; *GDP* represents a per capita gross domestic product quantified in constant 2017 USD by applying purchasing power parity rate; *TR* is the sum of exports and imports of goods and services calculated as a percentage of GDP; *UR* stands for people living in urban areas as a percentage of the total population; *REC* is RE consumption as a percentage of total final energy consumption; *FDI* is net inflows of foreign direct investment as a percentage of GDP; *OPEC* denotes the annual average Organization of the Petroleum Exporting Countries crude oil price; *FD* is the International Monetary Fund's financial development index; *GH* stands for total GHGs emissions including land-use, land-use change and forestry, expressed in metric tons of CO_2 equivalent per capita; *GF* denotes gross fixed capital formation measured as percentage of GDP; $\beta_{0,i}, \ldots, \beta_{11,i}$ are the heterogeneous parameters of the regression model; and ε_{it} is an error term. Logarithmic data were used in the analysis.

Data on RE production, geopolitical risk index and world uncertainty index are respectively taken from OECD database [32], personal website of Matteo Iacoviello [33] and world uncertainty index website [34]. In addition, data on crude oil price, financial development index, GHGs emissions were respectively taken from the *Statista* official website [35] and the International Monetary Fund's databases (IMF DATA access to macroeconomic & financial data [36] and IMF climate change dashboard [37]). All remaining variables were taken from the *World Development Indicators* (WDI) database [38]. Data sources, descriptive statistics and explanation of all variables are given in Table A.1.

According to Pata et al. [9] and Dutta and Dutta [13] geopolitical risk (*GPR*) was used to model the risk associated with geopolitical instability and conflicts in certain regions. There are opinions that a high degree of GPR, such as the one created by the conflict between Russia and Ukraine, could have both positive and negative effects on the EU energy transition [9, p. 2]. Since the EU is indirectly involved in the conflict and, at the same time, it largely depends on Russian oil and natural gas, the Russian-Ukrainian conflict and the growing GPR forced some EU (and some G7) countries to intensify the energy transition. France and Germany have stepped up efforts in the realization of their solar projects, while the US Congress debated the extension of RE long-term tax incentives [7, pp. 56075–56076; 9, p. 2]. Such activities are understandable, since the increased GPR shed light on numerous political and economic problems caused by dependence on imported fossil fuels. This put pressure on the G7 and some EU countries to increase efforts to develop RE sector and reduce energy dependence. Dutta and Dutta [13] showed that high GPR causes a decrease in the risk of green assets, because fossil fuels are more susceptible to strong shocks (caused by GPR), that results in an increased propensity for RE consumption. At the same time, Pata et al. [9] found a negative effect of GPR on RE investment (and possibly production) in G7 countries, which can be explained by the fact that high GPR worsens the investment climate (increases the concerns of business people, policy makers and financial markets) that potentially leads to a reduction in investment and the halting of entire RE R&D and other projects. Therefore, the impact of GPR on RE production can be both positive and negative.

According to Borozan [6, p. 413], policy-induced uncertainty (*PU*) can lead to a delay or, in a more extreme case, to a complete stop of further implementation of RE investment plans and projects. Also, a higher degree of PU may result in a reduction and delay in R&D expenditure aimed at increasing efficiency in RE production. Increased uncertainty may reduce expectations about future income and economic growth, decrease the willingness to take entrepreneurial risks, and delay or stop the implementation of plans for the purchase of RE. As pointed out by Pata et al. [9, pp. 1–2], PU caused by frequent changes in interest rates, high capital costs, reduction of public expenditures, pronounced financial tensions, is a factor that discourages investments in clean energy technology. Preventing the reduction of investment in RE technology requires mitigating market risks and PU. Also, the negative effect of PU on RE production and consumption was revealed in Khan and Su [14] and Shafiullah et al. [11]. On the other hand, Feng and Zheng [27] concluded that the influences of PU on RE innovation is positive in high institutional quality countries, which is not the case if the institutions are of low quality. In addition, Liu et al. [26] concluded that PU negatively affects traditional energy enterprises' investment, which is not true in the case of RE companies. These authors point out that PU has even a positive influence on the investment of solar energy, geothermal energy and other RE enterprises. Finally, Lei et al. [5] indicate a positive influence of PU on RE consumption (and possible production). Hence, it can be concluded that the impact of PU on RE production can be both positive and negative.

Gross domestic product (*GDP*) can directly and indirectly affect RE production. The indirect effect is achieved through other regressors. For example, per capita GDP growth can encourage higher gross domestic fixed investments (including investments in RE); higher foreign trade (imports due to growth in aggregate demand, and exports due to increased productivity); urbanization due to higher investments in the construction of cities and infrastructure; changes in the structure of energy consumption (if EKC effect works); FDI inflow (due to greater investments in transport infrastructure, science and education); raising the level of financial development (due to greater domestic and foreign investments in the financial sector, greater credit potential and intensification of activities on the financial markets); increase or decrease of GHGs emissions, etc. In addition, GDP also has a direct effect on RE production. The direct effect is realized in two ways. The first way concerns the so-called scale effect, which refers to the fact that greater GDP (with identical technology) requires greater consumption and production of (renewable) energy. The second way is based on the assumption that the demand for a clean environment increases with income growth, which leads to a tightening of environmental regulations and a reduction in the use of fossil fuels, i.e. an increase in the production and consumption of RE. Therefore, as pointed out in Alsagr [23], Chu [7] and Kim and Park [25], the expected effect of GDP on RE production is positive.

International trade (*TR*) can affect RE production in several ways [39, p. 116383]. The first is reflected in the fact that TR exerts strong competitive pressure on domestic companies, both on the domestic market (due to imports) and on the foreign market where domestic companies export and face global competition. Competitive pressure can have two effects. The first is a decrease in the consumption of input (energy) per unit of output, in order to increase price competitiveness, which would reduce the consumption and production of (renewable) energy. Competitive pressure also can act in the direction of increasing the quality of products and services, which can require higher consumption of inputs and RE. Also, according to Cole [40], the impact of TR on RE production is different across countries, which dominantly depends on the energy intensity of exports and imports. If export is energy-intensive and import is less energy-intensive, the expansion of TR can cause an increase in the consumption and production of (renewable) energy because more (renewable) energy would be consumed in production for export than would be saved by substituting part of domestic production by import. Regarding the energy intensity of exports and imports, different situations are possible that imply different effects of TR on RE production. Finally, TR can serve as a mechanism for the diffusion of advanced technological knowledge in RE and other economic sectors, which could have both positive and negative influence on RE production. Taking everything into account, the impact of TR on RE production is not predetermined.

Urbanization (*UR*) potentially affects RE production in several ways [39, p. 116383]. The fact that the traffic network is more developed and the use of electric and hybrid vehicles is greater in urban areas can be selected as the first way of positive influence on RE consumption and production. In addition, urban infrastructure as well as numerous institutions located in urban areas are large consumers of (renewable) electricity, which encourages its production. Also, products that consume a lot of electricity are used more in urban areas. The growth of the UR requires the transport of large quantities of agricultural products to such areas, which can additionally increase RE consumption and production. The growth of UR inspires industrialization process, which also affects the increase in the consumption and production of (renewable) energy. All the mentioned influence mechanisms suggest that a positive effect of UR on RE production can be expected.

According to Ji and Zhang [3, p. 119], the share of RE in total final energy consumption (*REC*) is included in the analysis in order to capture the impact of changing the structure of energy consumption (without changing its volume) on RE production.

The influence of *FDI* on RE production is achieved through several mechanisms [39, p. 116382; 41, pp. 63–64]. One of the channels of influence is achieved directly by the fact that the inflow of FDI from technologically superior economies can bring soft technologies such as systems, management practices, methods, knowledge, abilities, techniques and skills [42, p. 3]. The effect of such acquired soft technology may depend on which sectors of the economy host FDI. If it is the RE sector, advanced soft technology could influence the increase in efficiency and RE production. However, if other sectors are recipients of FDI, the increase in efficiency due to advanced soft technology could result in a decrease in consumption and production of (renewable) energy. According to Saggi [43, p. 209] the second mechanism of influence is achieved indirectly through demonstration, turnover of employees and vertical connection effects. The effect of demonstration is achieved by domestic companies adopting soft technology from more efficient and productive foreign companies through reverse engineering and the process of imitation. Turnover of employees works so that trained highly capable workers who have gained experience and have undergone training in efficient foreign companies have the opportunity to change employers and start their own businesses, which enables the further transfer of soft technology. The vertical connection effect is reflected in the possibility that vendors and clients of efficient foreign companies benefit from the adoption of their advanced soft technology. Also, depending on which sectors are the recipients of FDI, the indirect impact of FDI on RE production can be both positive and negative. Finally, the inflow of FDI can significantly increase competition on the domestic market, forcing domestic companies to raise the level of efficiency and quality of their products. Raising the level of efficiency could result in a reduction in the consumption and production of RE, while the production of higher quality products could act in the opposite direction. Bearing in mind all the above examples of influence, it can be concluded that the effect of FDI on RE production is ambiguous [8, p. 9].

The influence of the average annual crude oil price (*OPEC*) is achieved through an indirect mechanism [44, p. 4]. In fact, there are no theoretical arguments based on which one would believe that an increase in the price of oil increases its consumption (Giffen good), but on the contrary, that an increase in the OPEC results in a decrease in oil demand and consumption (ordinary good). The decline in demand and consumption of oil indirectly stimulates the growth of demand and consumption of energy obtained from other sources that can substitute oil. For example, in the case of the hybrid vehicle, the increase in the OPEC can result in an increase in the consumption and production of (renewable) electricity. Therefore, a positive effect of OPEC on RE production is expected.

Financial development (*FD*) can directly and indirectly affect RE production, both positively and negatively, through diverse mechanisms [45, p. 6662]. Indirect mechanisms of influence are already captured by the regressors included in model 1. A higher degree of FD increases the depth and efficiency of financial markets and institutions and access to financial resources, reduces the costs of external financing (partly due to innovations in the financial sector), which enables companies to obtain the necessary raw materials easier and cheaper. This has a stimulating effect on GDP, which leads to higher consumption and production of (renewable) energy. Also, the growth of FD in a similar way makes it easier for enterprises to invest in the expansion of production capacities, thereby increasing GDP, consumption and production of (renewable) energy. According to Irfan et al. [8, pp. 4–6], FD increases FDI and consequently GDP, which raises the consumption and production of (renewable) energy. In addition, easier financing of investments enables companies to acquire new energy-saving technology, whereby the same volume of economic activity can be realized with less (renewable) energy consumption and production. Also, companies can more easily invest in new technology that allows them to produce better quality products in order to be more competitive in the market. The production of higher quality products may require higher consumption and production of (renewable) energy. Finally, greater FD can facilitate the financing of large investments in RE production capacities, which would create conditions for its growth [23, pp. 2–3; 3]. This is an important mechanism since investments in RE are more expensive than investments in conventional energy, which implies that public investment alone is insufficient to ensure a satisfactory pace of RE development [23, pp. 2–3]. An increase in FD can also result in TR growth (through an increase in aggregate demand and easier financing of production for export) which, as already explained, has an effect on RE production.

FD can also affect RE production directly. Higher degree of FD can encourage (discourage) industrialization. Since industry is an energy-intensive sector, increasing (decreasing) its share in the overall economy leads to greater (smaller) consumption and production of (renewable) energy. Also, easier and cheaper borrowing can allow citizens who do not have vehicles (or own vehicles that use fossil fuels) to buy a new electric vehicle, which would lead to an increase in the consumption and production of (renewable) electricity. In addition, easier access to finance enables the replacement of older electric cars with newer and more efficient ones, which would reduce the consumption and production of (renewable) electricity. Irfan et al. [8, pp. 4–6] believe that FD raises environmental standards with a positive impact on RE production. Also, greater FD provides financial resources for the realization of green projects that can have a stimulating effect on RE production. Finally, Kim and Park [25, pp. 2–3] believe that the low degree of FD results in inefficient allocation of funds by banks, unwillingness to finance RE projects, higher costs of credit financing, lack of efficient risk hedging and diversification tools, which together discourages RE production. All these examples of influence are only part of the diverse mechanisms that can exist.

Following Alsagr [23] and Ji and Zhang [3], GHGs emissions (*GH*) were included in model 1 in order to control environmental pressures. Actually, the higher GH leads to increasingly pronounced problems of climate change and air pollution, which exerts strong pressure on society to use all available capacities in order to significantly reduce GH. RE is a very important tool for achieving this goal. Hence, a positive effect of GH on RE production is expected.

Gross domestic fixed investments (*GF*) are a very important determinant of any economic activity and its growth [46,47]. They include the impact that tools, physical machines and equipment, i.e. new hard technology [42, p. 3] has on RE production. In fact, GF and new hard technologies increase technological knowledge and input productivity, which leads to a reduction in energy consumption per unit of output. If investments are focused on the RE sector, it could stimulate RE production. If the investments are realized in other sectors, the effect on RE consumption and production could be completely opposite. Therefore, the impact of GF on RE production is not predetermined.

Empirical analysis consists of several stages. The first step is cross-sectional dependence testing, which was done by employing five tests. The Breusch and Pagan [48] test is suitable for cases where the spatial dimension of the sample is small, and the temporal dimension is large. Obviously, the situation when we have a large spatial dimension makes this test less reliable. Therefore, the Pesaran scaled [49] procedure was applied, which allows both dimensions of the sample to be large. However, since this test expresses the size distortion for small time dimension, the Pesaran CD [49] procedure was also employed. Baltagi et al. [50] was used because it offers a simple asymptotic bias correction for the Pesaran scaled [49] test in the case of a small time dimension. Finally, Pesaran [51] procedure examines weak cross-sectional dependence in large panels. The application of these self-correcting tests provides robust results.

The second stage is testing the presence of unit roots in the variables, which was done using two unit root tests that permit data heterogeneity and cross-sectional dependence [52,53]. The Pesaran [52] test is an extension of the Dickey-Fuller (DF) auxiliary regression by including lagged cross-section averages and current difference of cross-section averages to control cross-sectional dependence. Also, it is possible to include lagged difference of variable and lagged difference of cross-section averages in auxiliary regression to control for serial correlation. This test has disadvantages since it allows only one (stationary) common factor, and neglects structural breaks. The shortcomings of this test were overcome by the application of the Bai and Carrion-i-Silvestre [53] test that allows multiple heterogeneous structural changes and vector of common factors that can be stationary, non-stationary or their combination.

Cointegration was tested by employing two tests [54,55] that take into account cross-sectional dependence, stationary and non-stationary common factors, as well as endogenous regressors. Bai and Carrion-i-Silvestre [54] test allows correlation between regressors, factor loadings and common factors, but ignores structural breaks. This was overcome by using the Banerjee and Carrion-i-Silvestre [55] test that allows for heterogeneous structural breaks.

Finally, equation (1) was estimated using six estimators. Three estimators such as Pesaran and Smith [56], Pesaran et al. [57] and Chudik et al. [58] are suitable for dynamic heterogeneous panels, of which two estimators [57,58] estimate homogeneous long-run effects, allow cointegrated variables, but not cross-sectional dependence. In addition, Pesaran et al. [57] also estimates heterogeneous short-run effects (including the error-correction coefficient). In contrast, Pesaran and Smith [56] estimates heterogeneous long-run effects and also allows cointegrated variables without cross-sectional dependence. None of these estimators allow for endogenous regressors (or reverse causality from dependent variable to regressors at the variable level). The fourth estimator [59] is designed for static homogeneous panels and allows cross-sectional dependence and cointegrated variables, but does not allow endogenous regressors. Finally, Pesaran [60] and Neal [61] are intended for static heterogeneous panels (with homogeneous or heterogeneous slope coefficients affecting the regressors) and allow cross-sectional dependence and cointegrated variables [62]. Pesaran [60] approach is simple and is based on the application of ordinary least squares (OLS) to the regression which is augmented by adding the cross-section means of the dependent and independent variables. Neal [61] procedure is an extension of the Pesaran [60] approach for the case that the regressors are endogenous and relies on the application of instrumental variables.

4. Results

As already explained, the first phase of the analysis is the cross-sectional dependence testing, which was done by employing five tests (Table 1). The Breusch and Pagan [48] test is suitable for cases where the spatial dimension of the sample is small, and the temporal dimension is large. Pesaran scaled [49] procedure was applied because it enables both dimensions of the sample to be large. Since this test expresses the size distortion for small time dimension, the Pesaran CD [49] procedure was also employed. Baltagi et al. [50] was used because it offers a simple asymptotic bias correction for the Pesaran scaled [49] test in the case of a small time dimension. Finally, Pesaran [51] procedure examines weak cross-sectional dependence in large panels.

The second stage of research is testing the presence of unit roots in the variables (Table 2). This phase was carried out by employing the two unit root tests [52,53]. The number of unobservable common factors was estimated using the Bayesian information criterion [63]. Bai and Perron [64] approach and modified Schwarz information criterion were employed to estimate the number and positions of structural breaks. A portmanteau (Q) test for white noise was used to estimate the number of lags in the Pesaran [52] CIPS auxiliary regressions. Also, testing of OPEC was conducted using Dickey and Fuller [65], Phillips and Perron [66], Kwiatkowski et al. [67] and Elliott et al. [68] tests. These results are available upon request from the authors.

The third step in the analysis is the cointegration testing and was carried out using two tests (Table 3). The Bai and Perron [64] approach was used to estimate the positions of the structural changes. Bai and Ng [69] method and the panel Bayesian information criterion were used to estimate unobservable common factors and their number. A model that includes only broken intercept without time trend is designated as *model 1*, while a model that includes a broken intercept with stable time trend is designated as *model 2*.

Regression estimation results are shown in Table 4. The lower part of Table 4 contains the results of various diagnostic tests that need to be explained. Two unit root tests were applied to the residuals of the models estimated by the IFE, CCEMG and CCEMG-GMM estimators. It is well known that the stationarity of the residuals cannot be tested by simply applying any unit root test, since the residuals are not observable series. One should apply critical values that are greater in absolute value than the standard critical values of unit root tests. If testing based on standard critical values shows that the residuals are non-stationary, it is clear that the same result would be obtained with the application of true critical values. If the test result shows that the residuals are stationary, we cannot say with certainty that the same result would be obtained using the true critical values. Strictly speaking, if using unit root tests we conclude that the residuals are non-stationary, then there is certainly a conflict with the results of the cointegration tests, otherwise, if the results indicate the stationarity of the residuals, we can conclude that we did not detect a conflict with the cointegration tests results, but not that the conflict does not exist. In addition, the results of homogeneity slope testing should be understood only as an indication, because these tests do not allow cross-section dependence and I(1) processes. In fact, this analysis relies on Bersvendsen and Ditzen [73, pp. 5–6] extended version of slope homogeneity tests that allows for cross-sectional dependence. Although these tests are not constructed in a more theoretical fashion, it is important to point out that the simulation results show that they have satisfactory performance. Finally, diagnostic tests were not performed for some estimators because it would not make sense. For example, PMG, PB and MG estimators ignore the presence of unobservable common effects (including non-stationary ones) so residuals cannot be expected to be stationary and cross-sectionally uncorrelated. Also, by their construction, these estimators assume exclusively homogeneous or exclusively heterogeneous long-run slope coefficients. The IFE estimator takes into account unobservable common effects, but assumes homogeneous long-run influence. The only estimator that allows the possibility of homogeneous and heterogeneous influences for which Bersvendsen and Ditzen [73] constructed extended version of slope homogeneity tests is CCE.

Since CCEMG-GMM is an estimator that allows heterogeneous effects, structural breaks, cointegrated variables, cross-sectional dependence and endogenous regressors, this model with a linear trend (column 10) was selected as a representative one. The trend equation was chosen due to the fact that *model 2* (Table 3) shows cointegration in both cases (one and two breaks). This regression has good diagnostic test results and is consistent with the indication of slope homogeneity tests that the model parameters are heterogeneous (Table 4). Other estimators were employed to test the robustness of the findings.[2]

5. Discussion

As already explained, this analysis was conducted on a large panel sample that includes 42 countries and a period of 31 years. This kind of research has great advantages over studies that rely on time series and cross-sectional data, because it is based on a sample that has a large information content and takes into account both temporal and spatial variations of variables. The panel sample causes higher statistical power of panel unit root and cointegration tests, as well as more efficient parameter estimates. In addition, cross-sectional dependence was examined using five econometric tests. Unit root was tested using two unit root tests that permit data heterogeneity and cross-sectional dependence, one of which allows for multiple heterogeneous structural changes and non-stationary common factors. Cointegration was examined by two tests that also take into account cross-sectional dependence, non-stationary common factors and endogenous regressors, one of which incorporates structural breaks. Finally, the model was estimated using six estimators, of which the last one is representative because it allows for static heterogeneous panels, cross-sectional dependence, structural breaks, cointegrated variables, and endogenous regressors. Bearing all this in mind, the econometric methods employed in this paper include: 1) cross-sectional dependence testing; 2) examination of the presence of unit root and cointegration using procedures that allow for cross-sectional dependence, structural breaks and non-stationary common factors, whereby cointegration tests additionally permit endogenous regressors; and 3) application of estimator that allows for structural breaks, cross-sectional dependence, non-stationary common factors and endogenous regressors. *Therefore, by applying the selected econometric techniques, this analysis shrinks the gap in the empirical literature and removes all methodical weaknesses detected and explained in the introductory part of the paper.*

The results of testing of cross-section dependence very robustly show its presence in panel data sample (Table 1). In fact, all five statistical tests, for all variables, reject the cross-section independence null hypothesis at the 1 % significance level. Cross-section dependence is also revealed for differenced variables, but these findings are not presented to save space. This result is not surprising and is in line with expectations, since the world today is characterized by a very pronounced economic and political interdependence between countries. In such a complex constellation of interstate relations, any change in one country,

[2] Interactive fixed effects estimator was also applied with 3 and 5 common factors, but the results do not affect the conclusions. In addition, bias-corrected pooled Bewley estimator that allows arbitrary cross sectional dependence and relies on jackknife approach was also employed, but the obtained findings do not affect the conclusions. Also, CCE and CCE-GMM pooled estimators are applied but ignored because they have unsatisfactory diagnostic test results and because slope homogeneity tests indicate heterogeneous influences.

Table 1
Cross-section dependence test results.

Test	RE	GPR	PU	GDP	TR	UR
LM 1	10239.53*	4099.59*	1790.77*	20189.73*	10705.99*	19411.15*
LM 2	225.00*	77.03*	21.39*	464.77*	236.23*	446.01*
LM 3	224.29*	76.33*	20.69*	464.07*	235.53*	445.31*
CD	31.13*	49.76*	19.92*	138.22*	78.42*	111.25*
WCD	103.74*	136.92*	129.87*	163.33*	163.12*	163.33*
	REC	FDI	FD	GH	GF	
LM 1	10971.56*	3541.22*	14967.03*	9277.53*	4545.46*	
LM 2	242.63*	63.58*	338.92*	201.81*	87.78*	
LM 3	241.93*	62.88*	338.22*	201.11*	87.08*	
CD	8.60*	42.37*	114.23*	8.26*	7.30*	
WCD	120.00*	70.85*	154.20*	156.60*	163.12*	

Notes: The symbols *LM 1*, *LM 2*, *LM 3*, *CD* and *WCD* refer to Breusch and Pagan [48]; Pesaran scaled [49]; Baltagi et al. [50]; Pesaran CD [49] and Pesaran [51] tests. Asterisk indicates significance at the 1 % level.
Source: Authors' calculation

Table 2
Results of unit root testing.

	RE	GPR	PU	GDP	TR	UR	REC	FDI	FD	GH	GF
Pesaran (2007)											
Constant											
$CIPS_c^*$	−1.69	−3.10*	−4.00*	−2.17**	−1.86	−1.50	−1.29	−3.77*	−2.42*	−1.38	−1.79
Constant & trend											
$CIPS_t^*$	−2.26	−3.38*	−4.28*	−2.09	−2.24	−1.88	−2.44	−4.17*	−3.01*	−2.12	−2.22
Bai & Carrion-i-Silvestre (2009)											
Constant											
Z	0.10	−3.79*	−4.61*	−2.63*	1.76	−4.80*	−2.41*	−2.66*	−0.86	−0.01	−1.31***
P_m	−0.09	8.25*	14.76*	2.16**	−1.79	12.09*	1.22	6.25*	−0.64	−1.69	0.75
P	82.82	190.91*	275.33*	111.93**	60.75	240.69*	99.81	165.00*	75.67	62.06	93.67
Constant & trend											
Z	−0.72	−3.37*	−4.58*	1.14	1.99	19.06	−0.69	−2.33*	−0.40	4.83	0.25
P_m	0.18	7.65*	11.15*	−0.34	−2.41	−5.01	1.72**	6.41*	1.58***	−2.81	−0.94
P	86.39	183.19*	228.55*	79.64	52.78	19.06	106.28***	167.06*	104.47***	47.59	71.76
Z*	1.03	−3.11*	–	1.95	2.74	51.66	2.95	−2.44*	−0.26	4.07	1.78
P^*_m	0.003	7.60*	–	−0.75	−2.62	−6.16	1.54***	6.62*	1.32***	−3.44	−1.45
P*	84.04	182.57*	–	74.27	50.08	4.11	103.99***	169.82*	101.12***	39.38	65.15

Notes: Statistical significance at 1 %, 5 % and 10 % levels is indicated by *, **, and ***, respectively.
Source: Authors' calculation

Table 3
Cointegration test results.

Bai and Carrion-i-Silvestre (2013)		
	Constant	
Z	2.65	
P_m	-0.23	
P	81.06	
	Constant & trend	
Z	14.56	
P_m	5.65*	
P	157.21*	
Banerjee and Carrion-i-Silvestre (2015)		
	One break	*Two breaks*
Model 1	-5.14*	
Model 2	-6.67*	-15.58*

Notes: Asterisk indicates significance at the 1% level.
Source: Authors' calculation

especially if it is economically developed and politically influential, is quickly transmitted to other countries. Therefore, appropriate econometric techniques must be selected to take into account the presence of cross-section dependence.

The results of the application of unit root tests show that the GPR, PU, and FDI are stationary processes, as well as that the FD and REC are most likely non-stationary variables (Table 2). All remaining variables are certainly non-stationary.[3] Applying unit root tests to the first differences of variables, in order to determine the exact number of unit roots, reveals that all non-stationary variables are I(1) processes, except for UR, which has the possibility of being an I(2) process.[4] In addition, visual appearance of the variables and their correlograms support this conclusion. Since there is a strong possibility that UR is an I(2) process, UR is excluded from further analysis, because selected econometric framework does not allow for such variables.

Testing for cointegration using the first test [54], which does not take structural breaks into account, offers rather confusing and ambiguous findings (Table 3). In fact, testing with a constant indicates that the variables are not cointegrated, while testing with a linear trend gives a completely opposite result in the case of two test statistics. Nevertheless, the application of the second test [55], which takes structural breaks into account, very convincingly indicates that the variables are cointegrated.[5]The obtained results of cointegration tests show very well why it is important to take into account present structural breaks. In addition,

[3] Testing of OPEC showed that this variable is an I(1) process.
[4] Test results for differences are not shown to save space, but are available on request from the authors.
[5] All remaining model specifications suggested by the Banerjee and Carrion-i-Silvestre [55] were also used to test cointegration, but the obtained results cannot be accepted as valid due to the presence of cross-section dependence for certain time lags.

Table 4
Regressions estimation results.

Col.	PMG		PB	MG		IFE	CCEMG		CCEMG-GMM	
	1	2	3	4	5	6	7	8	9	10
GPR	−0.0005	−0.03*	−0.01	−0.04	0.05**	−0.01	−0.002	−0.003	0.01	0.001
	(0.01)	(0.01)	(0.02)	(0.04)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)
PU	−0.02*	−0.004***	−0.02	−0.03	−0.01	−0.001	−0.002	−0.002	−0.003	−0.001
	(0.004)	(0.002)	(0.01)	(0.02)	(0.01)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
GDP	0.89	0.72	0.69	0.85	0.61	0.55	0.32	0.28	0.39	0.26
	(0.04)	(0.08)	(0.15)	(0.35)	(0.64)	(1.05)	(0.16)	(0.18)	(0.37)	(0.41)
TR	−0.06	0.09	0.09	−0.61	−0.40	0.01	−0.05	−0.04	−0.04	−0.02
	(0.04)	(0.03)	(0.08)	(0.34)	(0.14)	(0.17)	(0.09)	(0.09)	(0.08)	(0.11)
REC	0.86	0.69	0.85	0.82	0.70	0.83	0.83	0.84	0.89	0.88
	(0.02)	(0.01)	(0.04)	(0.09)	(0.15)	(0.23)	(0.08)	(0.08)	(0.10)	(0.14)
FDI	−0.01***	−0.01	0.002	0.01	0.04**	−0.003	−0.001	−0.001	−0.005	−0.004
	(0.01)	(0.005)	(0.02)	(0.05)	(0.02)	(0.005)	(0.006)	(0.006)	(0.006)	(0.01)
FD	−0.23	−0.11	−0.10	0.19	−0.001	0.02	0.06	0.05	0.10	0.09
	(0.03)	(0.04)	(0.14)	(0.20)	(0.19)	(0.13)	(0.07)	(0.07)	(0.06)	(0.06)
GH	0.14	−0.07	0.11	0.18	0.20	0.06	0.23	0.26	0.25	0.21
	(0.04)	(0.01)	(0.07)	(0.14)	(0.24)	(0.13)	(0.11)	(0.11)	(0.10)	(0.16)
GF	−0.10	−0.15	−0.45	−0.54	−0.23	−0.04	−0.08	−0.09	−0.02	0.08
	(0.04)	(0.03)	(0.17)	(0.29)	(0.15)	(0.29)	(0.06)	(0.06)	(0.07)	(0.11)
OPEC	−0.08	−0.08	0.02	0.03	0.05	−0.01	−0.0001	0.01	0.001	0.001
	(0.01)	(0.01)	(0.02)	(0.05)	(0.04)	(3.66)	(0.02)	(0.02)	(0.03)	(0.03)
Con.	−1.71	−3.04		−7.22	−7.74	−9.03	−1.08	−12.84	−0.45	−0.16
	(0.31)	(1.25)		(1.19)	(10.67)	(15.01)	(7.24)	(10.71)	(3.40)	(1.40)
Trend		0.0004			0.001			0.01		−0.001
		(0.51)			(0.01)			(0.01)		(0.003)
α	−0.14*	−0.22*		−0.78*	−0.82*					
	(0.03)	(0.04)		(0.07)	(0.07)					
$CIPS^*_c$						−3.38*	−5.95*	−5.92*	−5.95*	−5.84*
$CIPS^*_t$						−3.32*	−6.02*	−6.02*	−6.04*	−5.90*
IPS_c						−15.13*	−28.98*	−27.68*	−29.51*	−31.62*
IPS_t						−11.55*	−24.11*	−23.56*	−25.40*	−25.47*
PCD						0.19	−0.50	−0.07	−1.47	−1.51
WCD						0.19	−0.50	−0.07	−1.52	−1.57
$\widetilde{\Delta}$							5.29*	4.55*		
$\widetilde{\Delta}_{adj}$							7.89*	7.01*		
$\widetilde{\Delta}_{HAC}$							18.09*	108.9*		
$\widetilde{\Delta}_{HAC\ adj}$							26.96*	167.8*		

Notes: The labels PMG, PB, MG, IFE, CCEMG, CCEMG-GMM respectively represent the pooled mean group estimator [57] in error correction form for ARDL(1,…,1); bias-corrected pooled Bewley estimator [58] for ARDL(1,…,1) which relies on the bootstrap approach with 10,000 replications and allows arbitrary cross sectional dependence of errors; mean group estimator [56] in error correction form for ARDL(1,…,1); interactive fixed effects estimator [59] with 4 common factors and bootstrap standard errors obtained using 50 replications; common correlated effects mean group estimator [60]; and common correlated effects mean group-generalized method of moments estimator [61]. CCEMG and CCEMG-GMM estimates were obtained as an average of individual coefficients, where standard errors of individual estimates are used as weights. Coefficient α represents error-correction coefficient. $CIPS^*_c$, $CIPS^*_t$, IPS_c, IPS_t, PCD and WCD respectively represent Pesaran [52], Im et al. [70], Pesaran [49] CD and Pesaran [51] WCD tests that have been employed to individual specific errors. Pesaran and Yamagata [71] and Blomquist and Westerlund [72] slope homogeneity tests ($\widetilde{\Delta}, \widetilde{\Delta}_{adj}, \widetilde{\Delta}_{HAC}, \widetilde{\Delta}_{HAC\ adj}$) are also shown in the lower part of the table. Blomquist and Westerlund [72] test is based on Bartlett kernel and data driven bandwidth selection with prewhitened HAC. Statistical significance at 1 %, 5 % and 10 % levels is indicated by *, **, and ***, respectively.
Source: Authors' calculation

such results prove that all non-stationary variables included in equation (1) exert a long-run effect on RE production. However, it is very important to remember that the findings of unit root tests showed that PU, GPR and FDI are stationary variables. It is well known that the stationary variables included in the cointegration equation have no effect on the long-run equilibrium relationship between the non-stationary variables, which is why the effect of the stationary variables, if significant, can be interpreted exclusively as a short-term influence. Therefore, statistically significant estimates of slope coefficients for PU, GPR and FDI in cointegration model 1 can only be interpreted as short-run effects. Finally, it is clear that the results of unit root tests showed that PU, GPR and FDI theoretically cannot have any long-term effect on RE production, since stationary variables cannot determine non-stationary ones in the long run.

Inspection of the results obtained by estimating the representative model (Table 4-column 10) shows that the average short-term impact of GPR on RE production is insignificant. Therefore, the representative model does not suggest the existence of average short-run effect of GPR on RE production. Obviously, the absence of an average short-term impact does not imply that the short-run effect is lacking in all countries. A cross-country analysis (Table A.2) shows that the short-term effect is present in exactly half of the countries (21 countries).[6] A negative short-term impact (the strongest in Hong Kong and the weakest in Poland) is present in 8 countries (19 % of countries), while a positive short-run effect (the strongest in the United Kingdom and the weakest in Denmark) is estimated in 13 countries (31 % of countries). A 1 % increase in GPR in Hong Kong and Poland results in a short-term decrease in RE production by 0.65 % and 0.01 %, respectively. Also, a 1 % increase in GPR in the United Kingdom and Denmark leads to a short-run increase in RE production by 0.12 % and 0.01 %, respectively. Finally, the countries in all three groups (negative, positive and non-existent

[6] The results of a cross-country analysis are presented in Table A.2 only for the variables of interest (GPR and PU) to save space. Results for other explanatory variables can be obtained upon request to the authors.

short-term influence) are very heterogeneous in terms of economic development and geographic location (the continent they belong to).

The representative model (column 10) also indicates that the average short-run impact of PU on RE production is insignificant. In other words, PU does not, on average, exert a short-term influence on RE production. A cross-country analysis (Table A.2) shows that short-run impact is present in 52.4 % of countries (22 countries). A negative short-term influence (the strongest in Ukraine and the weakest in Poland) is present in 13 countries (31 % of countries), while a positive short-run effect (the strongest in Israel and the weakest in the Netherlands) is estimated in 9 countries (21.4 % of countries). A 1 % increase in PU in Ukraine and Poland results in a short-term decrease in RE production by 0.08 % and 0.003 %, respectively. Also, a 1 % increase in PU in Israel and the Netherlands leads to a short-run increase in RE production by 0.04 % and 0.005 %, respectively. Regardless of whether a positive, negative or insignificant short-term impact was discovered, the countries in all three groups are very heterogeneous in terms of economic development and geographic location. Khan and Su [14] analyzed the impact of PU on RE production in G7 countries. This study employs the wavelet quantile-on-quantile methods which are suitable to investigate the nonlinear association across different quantiles. They also tested the validity of the results through average quantile-on-quantile estimates and quantile regression. The findings suggest that PU has a negative impact on RE production in the medium to upper quantiles, although both the negative and positive effects were detected in the middle-upper quantile in France and the UK. It is clear that the results of this study, considering its conception and methodical approach, are not fully comparable with the findings of our analysis. Since the United States is the only country from the G7 group for which we detected a negative short-run influence, while for the remaining six countries the impact is insignificant, it can be concluded that the results obtained in our study are only partially consistent with the findings of Khan and Su [14]. Also, Borozan [6] used a symmetric and asymmetric PMG model to test and estimate the impact of PU on RE consumption. As in the previous case, the results of such designed study are not completely comparable with our findings. The main reason for this is the fact that in our analysis a symmetrical connection was detected, as well as the fact that the impact on RE production and not on RE consumption was investigated. Nevertheless, despite these differences, it can be pointed out that our results contradict those of Borozan [6], who suggest a negative asymmetric long-term and negative asymmetric average short-term impact of PU on RE consumption in G7 countries, since our analysis indicates a negative short-run influence for the US, while there is no effect for the remaining G7 countries.

The long-term effect of GDP on RE production is positive according to all estimated models. According to the estimation results of the representative model, an increase in GDP by 1 % results in a long-run increase in RE production by an average of 0.26 %. Borozan [6], using the symmetric and asymmetric PMG model, tested and estimated the effect of real GDP per capita on per capita RE consumption. The obtained findings show that this long-term impact is positive in both models. Also, Chu [7], using panel quantile regression as the primary estimation method, estimated the positive effect of real per capita GDP on RE production. Alsagr [23] estimated the positive long-run effect of GDP per capita on RE production using symmetric and asymmetric PMG. To the extent that the comparison of these studies with our analysis is possible, due to different methodical approaches, it can be pointed out that the results of our study are in agreement with Borozan [6], Chu [7] and Alsagr [23]. Our estimated impacts are smaller compared to Borozan [6], Chu [7] and symmetric effects in Alsagr [23], and larger in some cases when Alsagr [23] uses asymmetric PMG. Finally, Kim and Park [25], using the difference-in-differences approach as main strategy, failed to identify the influence of per capita GDP on RE production, while Irfan et al. [8], using the cross-sectional ARDL model, did not detect the average long-run impact of per capita GDP on the share of clean energy in the total primary energy supply. Therefore, our findings contradict to Kim and Park [25] and Irfan et al. [8].

The estimated long-term effect of TR on RE production is both positive and negative depending on the used estimator. However, both CCEMG estimators (columns 7–10) suggest a negative average long-term effect. According to the representative estimator (column 10), an increase in TR by 1 % implies a long-run decrease in RE production by an average of 0.02 %. Therefore, the obtained results show that influence channels with a negative effect have a stronger intensity in the long-term. Alsagr [23] estimated the positive long-run effect of TR on RE production using symmetric and asymmetric PMG. At the same time, Chu [7], using panel quantile regression, estimated the negative long-term effect of TR on RE production for only one quantile, while in most of the remaining cases the estimated effect is positive. Therefore, our findings are contradictory to Alsagr [23] and partially consistent with Chu [7].

The impact of REC on RE production in the long-term is positive in all models. According to the estimate obtained by applying the representative estimator, an increase in REC by 1 % generates a long-term increase in RE production by an average of 0.88 %. Irfan et al. [8], using the cross-sectional ARDL model, estimated a positive average long-run impact of REC on the share of clean energy in the total primary energy supply, which is a consistent with our results. The size of the estimated effect is not directly comparable, because we estimated the elasticity coefficient, and Irfan et al. [8] estimated the multiplier.

Investments (FDI) is another stationary regressor, in addition to GPR and PU, which is insignificant in most models. According to the representative model (column 10), the average short-run effect of FDI on RE production does not exist. Our results are in agreement with the findings of Irfan et al. [8] who failed to identify the average long-term and short-run influence of FDI on the share of clean energy in the total primary energy supply.

Financial development (FD) has a variable long-term influence on RE production, depending on the estimator. However, according to the representative estimator, the average long-run effect of FD on RE production is positive. Growth of FD by 1 % increases RE production in the long-term by 0.09 % on average. Alsagr [23] estimated the positive long-term effect of FD on RE production using symmetric and asymmetric PMG. Our results are in agreement with the findings of Alsagr [23], with the fact that the positive long-term effect estimated in our study is significantly weaker. Irfan et al. [8], using the cross-sectional ARDL model, estimated a negative and insignificant average long-run effect of FD on the share of clean energy in the total primary energy supply in G7 and E7 countries, respectively. Finally, Kim and Park [25], using the difference-in-differences approach as main strategy, detected either a negative or no impact of FD on RE production, depending on the model. Obviously, our results are in contrast with the estimations of Irfan et al. [8] and Kim and Park [25].

The emission of greenhouse gases (GH) exerts a positive long-term influence on RE production according to most models, including representative ones. In fact, representative estimation shows that an increase in GHGs emissions by 1 % leads to a long-run increase in RE production by 0.21 % on average. The obtained finding is contrary to Alsagr [23], who detected a negative long-term effect of CO_2 emissions on RE production using both symmetric and asymmetric PMG estimators.

Gross domestic fixed investments (GF) have a negative long-term effect on RE production according to all models, except for the representative one. Based on the representative estimator, an increase in GF by 1 % causes a long-term increase in RE production by 0.08 % on average.

Finally, OPEC exerts a positive average long-run influence on RE production according to the representative model. The obtained estimation suggests that 1 % growth in OPEC results in a long-run increase in RE production by 0.001 % on average.

6. Policy implication and recommendations

Geopolitical risks and policy induced uncertainty have inevitable negative effects on the economy, both on a global and individual countries levels. Such phenomena can affect economic trends directly and indirectly through financial, trade and commodity price channels. These mechanisms reinforce each other and lead to the fact that countries face high inflation, slow economic growth or recession, unemployment and inequality growth, expansion of irregular economy, reduction of living standards, increase of corruption and other social problems. Bearing in mind that geopolitical risk and policy induced uncertainty are very negative phenomena in a broader sense, it is clear that the implication of this study is much more cognitive than practical. This study analyzes the hitherto insufficiently researched topic and offers fairly reliable findings and conclusions, thereby contributing to increased knowledge and a better understanding of the factors influencing RE production.

Nevertheless, since the findings of this study clearly show negative effect of geopolitical risk and policy induced uncertainty in some countries, certain recommendations for public and business policy makers can be suggested. Given that geopolitical risk and policy induced uncertainty are very undesirable phenomena in a broader sense that have negative effects on the economy, both on a global and individual countries levels, public policy makers should maximize efforts to increase the transparency of policies and reduce geopolitical tensions. However, many countries of the world are not generators of geopolitical risks, but are only exposed to their potential impact. Serious global and regional geopolitical risks and tensions are very often created by economically and demographically large and developed countries that are militarily powerful and internationally politically influential, while smaller countries suffer their influence. Therefore, it is desirable that the governments of the countries act preventively in the direction of the development of the renewable energy sector in order to increase the degree of energy independence and reduce the capacity of potentially negative impacts of increasing geopolitical risks and uncertainty.

One of the possible courses of action is greater support in the implementation of innovations in the field of renewable energy. In accordance with UNCTAD [74, pp. xv-xviii] and Petrović [75, p. 7; 39, pp. 116391–116392] countries should stimulate green innovations in areas such as concentrated solar power, biofuels, wind energy, biogas and biomass, green hydrogen and solar photovoltaic technology. Also, supporting projects that at first glance have nothing to do with renewable energy, such as nanotechnology and artificial intelligence, can also be very useful. For example, nanotechnology can significantly improve wind power generation by enabling the production of lighter rotor blades for wind turbines. Governments should be focused on the introduction of appropriate regulations that could encourage further development of the renewable energy sector. In addition, it is important that countries join international agreements and mechanisms related to climate change, because they can significantly stimulate green innovations and, potentially, RE production. Examples of innovations that may stimulate the development of the renewable energy sector are given by the Innovation for Cool Earth Forum (ICEF) based on their CO_2 emissions reduction potential, excellence in innovativeness, and feasibility.[7] These RE (or RE related) projects include: (1) 31.17 % solar sunroof triple-junction module efficiency; (2) New world record for thin-film solar cells; (3) the World's highest conversion efficiency of 26.33 % achieved in a crystalline silicon solar cell; (4) Water splitting–biosynthetic system with CO_2 reduction efficiencies exceeding photosynthesis; (5) High-power all-solid-state batteries using sulfide superionic conductors; (6) Long-lasting flow battery could run for more than a decade with minimum upkeep; (7) World's tallest wind turbine integrated with pumped storage hydro; (8) Demonstration of peer to peer electricity trading using blockchain technology; (9) Pioneering the networking of storage batteries with blockchain technology and (10) Demonstration of Positive Energy Building Begins in Lyon. Finally, a good example of a project that contributes to the development of the renewable energy sector is the ITER project, which has been implemented for more than three decades near Aix-en-Provence in southern France, and refers to the development of completely clean and safe fusion energy.[8]

Although this study suggests that the average short-run effect of FDI on RE production does not exist, the analysis across countries shows that this effect can also be positive. Therefore, it is important to attract quality FDI to the renewable energy sector in order to encourage its development and prevent the potentially negative effect of PU and GPR. For something like that, it is necessary to apply the following recommendations known in the literature [44, p. 9]: 1) to form an Investment Promotion Agency; 2) to encourage indirect spillovers (such as demonstration effects and labor turnover); 3) to supports the development of the domestic financial market; 4) to remove restrictions on FDI inflows as much as possible; 5) to develop infrastructure; 6) to encourage the development of foreign customers-local suppliers connections; 7) to select the RE sector as one of the priority destinations for FDI; 8) to stimulate the arrival of new companies appearing on the domestic market for the first time; 9) to strengthen the influence of FDI on domestic suppliers to become more competitive; 10) to use the benefits of Export Processing Zones; 11) to make the necessary efforts to interest investors from the diaspora; 12) to gradually conduct structural changes in the domestic economy; 13) to ensure good treatment for all companies.

Apart from adequate preventive measures that need to be undertaken by the governments of individual countries in order to develop the RE sector and increase energy independence and resistance to the potentially negative effects of upcoming geopolitical risks, it is also necessary to monitor geopolitical challenges and uncertainties at the level of RE companies. By moving from the approach based on the analysis and understanding of past events and geopolitical risks (backward-looking) to the monitoring and analysis of future geopolitical challenges (forward tracking), RE companies will be better placed to respond to threats and seize opportunities [76]. Given that geopolitical events have a very strong impact on the long-term value of RE companies, it is clear that companies must invest capital in developing capacities and capabilities to monitor and analyze not only geopolitical events but also the factors that cause them. In the fight against geopolitical risks and uncertainties, the management of RE companies should take the following steps and measures: 1) to establish compliance with existing sanctions, export controls and other regulations; 2) to assess the degree of exposure to current and potential geopolitical risks; 3) to identify steps to mitigate certain geopolitical risks and uncertainties; 4) to implement mitigation measures in accordance with the plan in the event of adverse events; 5) to consistently implement risk management initiatives in accordance with the insight into geopolitical events; 6) to practice planning different scenarios for potential geopolitical challenges; 7) to analyze and adapt corporate strategy in accordance with geopolitical trends; 8) to treat insight into geopolitical trends as input when analyzing and reviewing the company performance by the corporate board. Finally, it is important to bear in mind that geopolitical trends do not only carry downside risk, but also the possibility to significantly improve the business results of RE companies over the short, medium and long run by implementing the aforementioned recommendations.

[7] This information can be found at https://www.cmcc.it/article/top-10-innovations-that-will-help-the-world-to-cut-co2-emissions.

[8] Detailed facts about the ITER project can be found on the https://www.iter.org/proj/iterhistory.

7. Conclusions

It is an indisputable scientific fact that human behavior resulting in GHGs emissions is a dominant contributor to global warming and climate change. According to the Intergovernmental Panel on Climate Change's Synthesis Report, GHGs emissions, caused by human behavior, has greatly intensified during the last decades. Of the cumulative net CO_2 emissions recorded between 1850 and 2019, slightly less than half was emitted in the last three decades. Also, average annual GHGs emissions over the period 2010–2019 were higher than in any previous decade for which this data is recorded. Consequently, the concentrations of N_2O and CH_4 very likely reached a level not recorded in at least the past 800,000 years, while the concentration of CO_2 is very likely at the highest level in at least the past two million years.

Climate changes bring a whole series of negative consequences such as: global mean sea level rise; increased frequency and strength of extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones; increased the likelihood of complex extreme events; extremely high mortality from floods, droughts and storms in highly affected regions; probably a negative effect on agricultural production in mid and low latitude regions; ocean warming and acidification; increased mortality and morbidity due to extreme heatwaves; potentially higher incidences of various medical diseases; economic damages in some sectors, etc.

Since the main cause of GHGs emissions is the burning of fossil fuels, it is clear that RE production is a very important tool in the fight against global warming and climate change. Great importance of RE has led to the fact that a large number of empirical studies are dedicated to the analysis of different RE indicators. However, despite the substantial methodical and cognitive contribution of these papers, their results and conclusions are very unreliable, primarily due to the numerous methodical shortcomings inherent in them. Apart from these weaknesses, the empirical literature also has a large gap when it comes to the impact of policy uncertainty and geopolitical risk on RE production. The literature inspection detected only one paper analyzing the effect of policy uncertainty on RE production and no study examining the influence of geopolitical risk on the same variable. *The aim of this study is to reduce the gap in literature and to select econometric techniques that remove all methodical shortcomings, which results in more credible and convincing findings*.

Empirical analysis of policy induced uncertainty and geopolitical risk effects on RE production is based on a fairly extensive panel data sample that incorporates 42 countries and a time interval of 31 years (1990–2020). The most important conclusions could be summarized as follows. Firstly, policy induced uncertainty and geopolitical risk do not have any long-term impact on RE production. Secondly, the short-term impact of these determinants exists and is very heterogeneous across countries. A positive influence of geopolitical risk is present in 31 % of countries (the strongest in the United Kingdom and the weakest in Denmark), a negative effect in 19 % of countries (the strongest in Hong Kong and the weakest in Poland), while in the remaining 50 % of countries there is no short-term impact. Also, positive short-run influence of policy induced uncertainty was detected in 21.4 % of countries (the strongest in Israel and the weakest in the Netherlands), a negative effect in 31 % of countries (the strongest in Ukraine and the weakest in Poland), while in the remaining slightly less than 48 % of countries no short-term impact was observed. Thirdly, if the entire group of 42 countries is in focus, the average short-run influence of geopolitical risk and policy induced uncertainty does not exist, which implies that positive and negative effects cancel each other out. Fourthly, regardless of whether the short-term impact of geopolitical risk or policy induced uncertainty is detected, countries belonging to any group (with positive, negative or no impact) are very heterogeneous in terms of geographic location and economic development. Therefore, based on our findings, it cannot be concluded that the existence and nature of the studied relationship are related to these properties. Finally, the fifth conclusion is that the average long-term effect of gross domestic product, structure of final energy consumption, financial development, emission of greenhouse gases, gross domestic fixed investments and average annual crude oil price is positive, while international trade is the only determinant that has a negative average long-run impact.

This study is based on the application of econometric techniques that eliminate the shortcomings of currently available research related to the analyzed topic. *In addition, bearing in mind that the topic has been insufficiently researched so far, the most important scientific contribution of this research is reducing gap in the existing literature, removing all detected methodical weaknesses and generating more credible results and conclusions*. However, this study also has certain limitations. In fact, the econometric techniques employed in this paper really enable a more comprehensive and credible analysis, which undoubtedly has positive implications for the findings and conclusions we have reached. At the same time, it is very important to keep in mind that the applied econometric methods require large panel samples in order to produce reliable findings. The sample used in this study is quite large and enables pretty reliable use of selected econometric framework. At the same time, it must be emphasized that additional analysis on even larger sample would be a desirable challenge for the results of this research. Applying the same econometric methods to larger panel sample would test the robustness of the presented findings and conclusions. Such an examination would further strengthen confidence in the obtained results. In addition, the exploitation of a larger panel sample would potentially enable the employment of additional econometric techniques, which would permit the analysis to take into account completely new dimensions of the observed relationship that cannot be considered for now. Since this analysis is based on the largest available sample at the time of its implementation, such additional examinations remain as a recommendation for future research.

CRediT authorship contribution statement

Predrag Petrović: Validation, Software, Methodology, Formal analysis, Conceptualization. **Ivana Ostojić:** Writing – original draft, Data curation.

Data availability

The data is available at https://data.mendeley.com/datasets/6hhtgxb324/1.

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Declaration of competing interest

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Appendix A

Table A.1
Explanation, sources and descriptive statistics of variables used in the research

Variable	Explanation	Mean	Median	Maximum	Minimum	Std. Dev.	Source
RE	Ln(RE production per capita expressed in tons of oil equivalent)	−1.792388	−1.680588	1.099594	−8.547147	1.546816	https://data.oecd.org/energy/renewable-energy.htm
GPR	Ln(Geopolitical risk index)	−2.485332	−2.650089	1.470110	−5.628696	1.275906	https://www.matteoiacoviello.com/gpr_country.htm
PU	Ln(World uncertainty index)	−2.206001	−1.903915	0.294817	−11.512930	1.671207	https://worlduncertaintyindex.com/data/
GDP	Ln(Per capita gross domestic product quantified in constant 2017 USD by applying purchasing power parity rate)	9.970452	10.187810	11.155160	7.261152	0.815506	https://databank.worldbank.org/data/source/world-development-indicators/
TR	Ln(Sum of exports and imports of goods and services calculated as a percentage of GDP)	4.137124	4.110236	6.092712	2.621261	0.567345	https://databank.worldbank.org/data/source/world-development-indicators/
UR	Ln(People living in urban areas as a percentage of the total population)	4.223788	4.326197	4.605170	3.008500	0.309860	https://databank.worldbank.org/data/source/world-development-indicators/
REC	Ln(RE consumption as a percentage of total final energy consumption)	2.210911	2.487398	4.329548	−4.605170	1.610366	https://databank.worldbank.org/data/source/world-development-indicators/
FDI	Ln(Net inflows of foreign direct investment as a percentage of GDP)	0.771217	0.843791	4.669029	−7.198535	1.229465	https://databank.worldbank.org/data/source/world-development-indicators/
OPEC	Ln(Annual average Organization of the Petroleum Exporting Countries crude oil price)	3.637476	3.707701	4.695468	2.507972	0.673596	https://www.statista.com/statistics/262858/change-in-opec-crude-oil-prices-since-1960/
FD	Ln(International Monetary Fund's financial development index)	−0.718980	−0.667867	0.000000	−2.384348	0.463990	https://data.imf.org/?sk=388DFA60-1D26-4ADE-B505-A05A558D9A42&sId=1479329132316
GH	Ln(Total GHGs emissions including land-use, land-use change and forestry, expressed in metric tons of CO_2 equivalent per capita)	2.002219	2.093128	3.594994	−0.993861	0.676638	https://climatedata.imf.org/pages/access-data
GF	Ln(Gross fixed capital formation measured as percentage of GDP)	3.116655	3.103113	3.795911	2.481622	0.209268	https://databank.worldbank.org/data/source/world-development-indicators/

Source: Authors

Table A.2
Impact of GPR and PU across countries

GPR		PU	
Negative effect of GPR		***Negative effect of PU***	
Hong Kong, China	−0.64565*	Ukraine	−0.07891**
Mexico	−0.15145*	United States	−0.03128*
Chile	−0.11071*	Hungary	−0.02368*
Türkiye	−0.03967*	Sweden	−0.02209*
Colombia	−0.02837**	Switzerland	−0.02203*
India	−0.02346*	Türkiye	−0.02141**
Italy	−0.01995***	Hong Kong, China	−0.02056**
Poland	−0.01431*	Viet Nam	−0.01026*
Positive effect of GPR		South Africa	−0.00944*
Denmark	0.013376**	Malaysia	−0.00871*
France	0.018585**	Thailand	−0.00734***
Finland	0.02564*	Indonesia	−0.00442**
Portugal	0.029526***	Poland	−0.0027*
Thailand	0.03529*	***Positive effect of PU***	
Russia	0.039914*	Netherlands	0.005382**
Netherlands	0.041958***	Portugal	0.00762*
Peru	0.04632**	Chile	0.008295*
Canada	0.051296***	Argentina	0.009761*
Germany	0.07769***	Australia	0.014563***
Switzerland	0.080983*	Philippines	0.014804*
Australia	0.084784*	Denmark	0.016496**
United Kingdom	0.120728*	Mexico	0.023051*
No GPR effect		Israel	0.036816***
Argentina	−0.00121	***No PU effect***	
Belgium	0.021861	Belgium	0.007629
Brazil	−0.02518	Brazil	−0.00569
China	0.017737	Canada	−0.00619
Egypt	0.035536	China	0.001826
Hungary	0.016288	Colombia	0.009929

(*continued on next page*)

Table A.2 (*continued*)

GPR		PU	
Indonesia	−0.00976	Egypt	0.007946
Israel	−0.02081	Finland	−0.000004
Japan	−0.08295	France	−0.00086
Korea	0.008878	Germany	0.011264
Malaysia	−0.00505	India	0.005023
Norway	−0.02924	Italy	−0.00158
Philippines	0.009122	Japan	−0.00804
Saudi Arabia	0.254731	Korea	0.008446
South Africa	−0.01219	Norway	0.008379
Spain	0.060973	Peru	−0.00462
Sweden	0.000815	Russia	−0.00092
Tunisia	0.031886	Saudi Arabia	−0.03695
Ukraine	−0.00234	Spain	0.014724
United States	0.138234	Tunisia	0.029559
Viet Nam	−0.00852	United Kingdom	0.013132

Notes: Statistical significance at 1 %, 5 % and 10 % levels is indicated by *, **, and ***, respectively.
Source: Authors' calculation

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