The energy efficiency of a country under the Green Deal Policy: the causal relationship between key determinants[1]

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Abstract: The paper aimed to check the impact of the core determinants on a country's energy efficiency policy. At the first stage of the investigation, the bibliometric analysis was used. It allowed identifying the determinants analysed by the scientists under the estimation of the country's energy efficiency policy. Thus, the following indicators were allocated: green investment; greenhouse gas emissions; share of the renewable energy in the final energy consumption. The study used the indicator energy efficiency for estimating energy efficiency policy of the country. The study used the bibliometrics analysis with instruments as follows as: Scopus and Web of Science Analysis Tools (to analyse the general tendency of publication activities); VOSviewer (to visualise the findings of meta-analysis); SciVal (for collaboration analysis). For the checking of the casual relationships between selected indicators, the following methods were applied: panel unit root test, Pedroni panel cointegration tests, the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) panel cointegration techniques, Granger causality test. The data from the following databases were used: the Eurostat, Ukrstat and the European Environmental Agency. The findings confirmed the bi-directional causality between energy efficiency and renewable energy, unidirectional causality from greenhouse gas emissions to energy efficiency. Besides, considering the results of cointegration analysis, increasing the share of renewable energy in the final energy consumption provoked: the increasing the energy efficiency by 46% (FMOLS) and 32% (DOLS). The increasing of greenhouse gas emissions by 1% initiated declining of energy efficiency by 16% (FMOLS) and 28% (DOLS); growing of green investment by 1% allowed the increasing of energy efficiency of the country by 71% (FMOLS) and 72% (DOLS). In this case, the government should implement effective instruments and policies to decline air pollution. Thus, under the transition process to the carbon-free economy, the additional green investment for renewable energy and green technologies reduces greenhouse gas emissions.

Keywords: energy policy, energy gap, energy efficiency gap, sustainable development.

JEL: P18; P28; P48; Q43; Q48

Introduction

The strengthening of energy efficiency issues and countries' energy dependency provokes the analysis and allocation of the main parameters that influence its changes. The Sustainable Development Goal (SDGs) 2030 (which contained 17 goals) involved seven goals focused on the affordable energy recourses for everyone. The 7th goal includes five main targets. One of the SDGs targets is increasing energy efficiency by developing green energy and clean technologies. Besides, in 2019, EU and Ukraine started to implement the "Green

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Deal Policy" which aimed to transition into the carbon-free economy and increase the country's energy efficiency. The analysis results showed that for the developing countries, the increase in energy efficiency was the consequence of the declining of industrial production in the country. Besides, the developing countries had inefficient technology, which limited energy production.

Moreover, countries had imbalances in all sectors, which justified spending financial sources on the essential areas. In this case, the emerging economies do not have enough financial sources to develop renewable energy and green technologies, increasing the country's energy efficiency. Thus, it is necessary to analyse the main parameters and determinants of the government's energy efficiency policy.

Theoretical premises

The findings proved that scientists identify the massive range of the parameters that influence a country's energy efficiency. In this case, to highlight the scientific trends in the energy efficiency investigations and core parameters that influenced energy efficiency, the study provided the bibliometric analysis. For the bibliometric analysis, the study combined the methodology described in the papers: [Akhundova et al., 2020; Ziabina & Pimonenko, 2020; Mikhnevych et al., 2020; Bilan et al., 2020; Panchenko et al,. 2020; Pereira et al., 2019]. The core requirement was that all papers should be published in a Scientific Journal that indexed in Web of Science and Scopus. Besides, the list of the documents was trimmed (105 357 papers) to eliminate the duplication. In general, the study used limitations as follows as:

- time 1991-2020;
- published in English;
- indexed in the scientific databases Web of Science and Scopus;
- keywords: energy efficiency, energy policy and carbon-free economy.

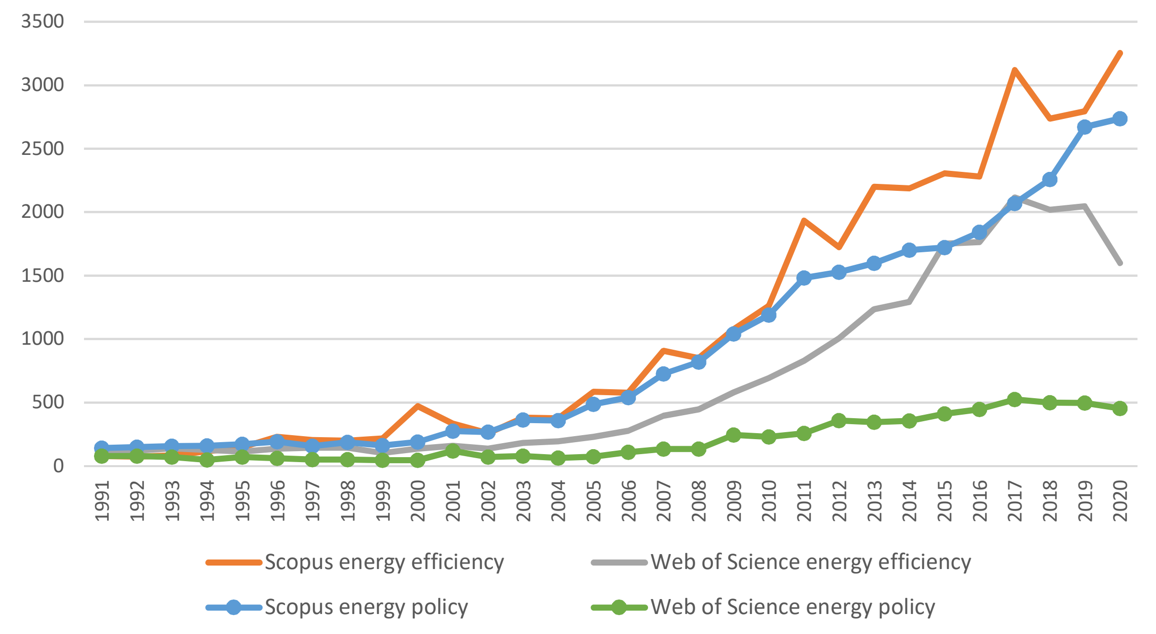
After the first stage, the 105 357 papers were selected. In the next step of the analysis, the subject areas of the papers were limited to identify the perspective direction in economics areas on energy efficiency analysis. The study excluded all engineering and technical subject areas. After the limitation, 1,380.0 were left for further research. The Scopus and Web of Science Tools Analysis allowed identifying the publication activities' general tendency, allocated the core sponsors and subject areas. Scopus and Web of Science Tools Analysis highlighted the most cited papers and scientists that analysed energy efficiency. The SciVal showed the collaboration between researchers and their impact on scientific background in the energy efficiency and energy policy. The last stage focused on the visualising of the co-occurrence analysis using software VOSviewer.

The publication activities (Table 1) showed that Scopus contained more papers that focused on the analysis of energy efficiency than Web of Science.

Table 1. Publication activities on energy efficiency in Web of Science (WOS) and Scopus for 1991-2020 years

Parameters	Numbers of the documents	
	WOS	Scopus
Keywords: Energy efficiency	20 240	32 966
Keywords: Energy policy	6 013	27 345

Dynamics of the documents

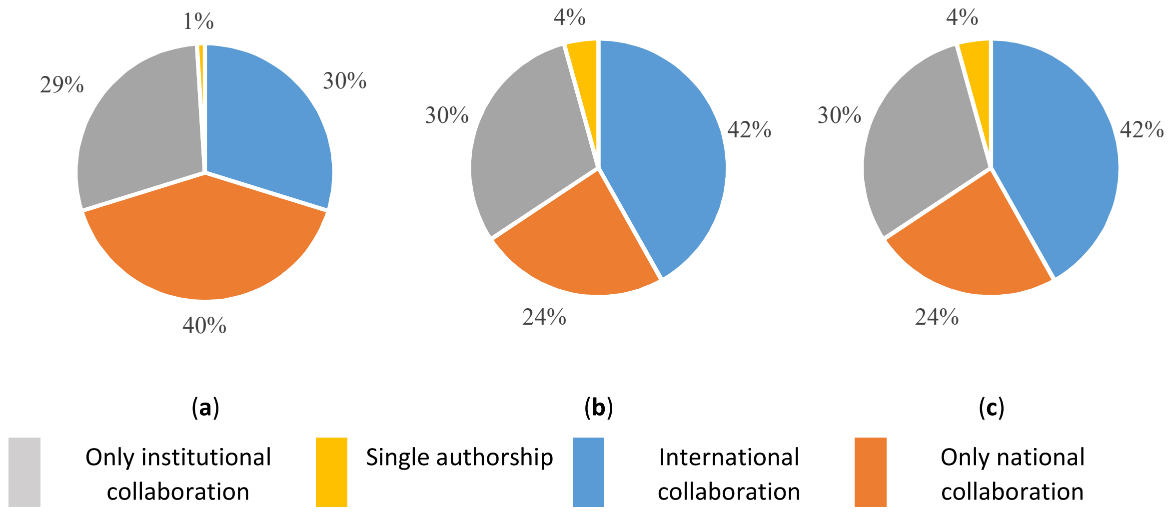


Sources: own work compiled by the authors using Scopus and Web of Science.

The findings in Table 1 confirmed the increasing tendency of publications on the energy efficiency in the scientific journals that indexed in Scopus and Web of Science for the years 1991-2020. The co-citations and co-authorship findings allowed concluding that the Chinese scientists were the most active in co-citations and had the prominent teams of authors. The results of collaboration under the investigation the energy sectors among three countries - the United States of America, China and Ukraine - showed that in the United States of America, many investigations were realised under the international cooperation – 46.6%

(Figure 1a). Simultaneously, the share of institutional collaboration (27.5%) is higher than national collaboration (20.5%). The opposite situation can be seen in China (Figure 1b), where the share of national collaboration is 40.4%, with an equal share for international (29.8%) and institutional collaboration (28.8%). In Ukraine, international collaboration is 41.8%, institutional – 30.0% and the lowest share belongs to the national cooperation – 23.8% (Figure 1c).

Figure 1. Scholarly output in the selected countries, by the amount of international, national, and institutional collaboration: (a) China; (b) Ukraine; (c) the United States.



Sources: own work compiled by the authors useing Scopus and SciVal.

The publication activities on the selected keywords in Scopus by affiliations for the years 1991-2020 are shown in Table 2. The findings confirmed that the significant sponsors of the investigation on the energy efficiency were National Natural Science Foundation of China, National Science Foundation, Department of Science and Technology, Japan Society for the Promotion of Science, Deutsche Forschungsgemeinschaft. Moreover, such results could be proved by the numbers of the documents by the countries.

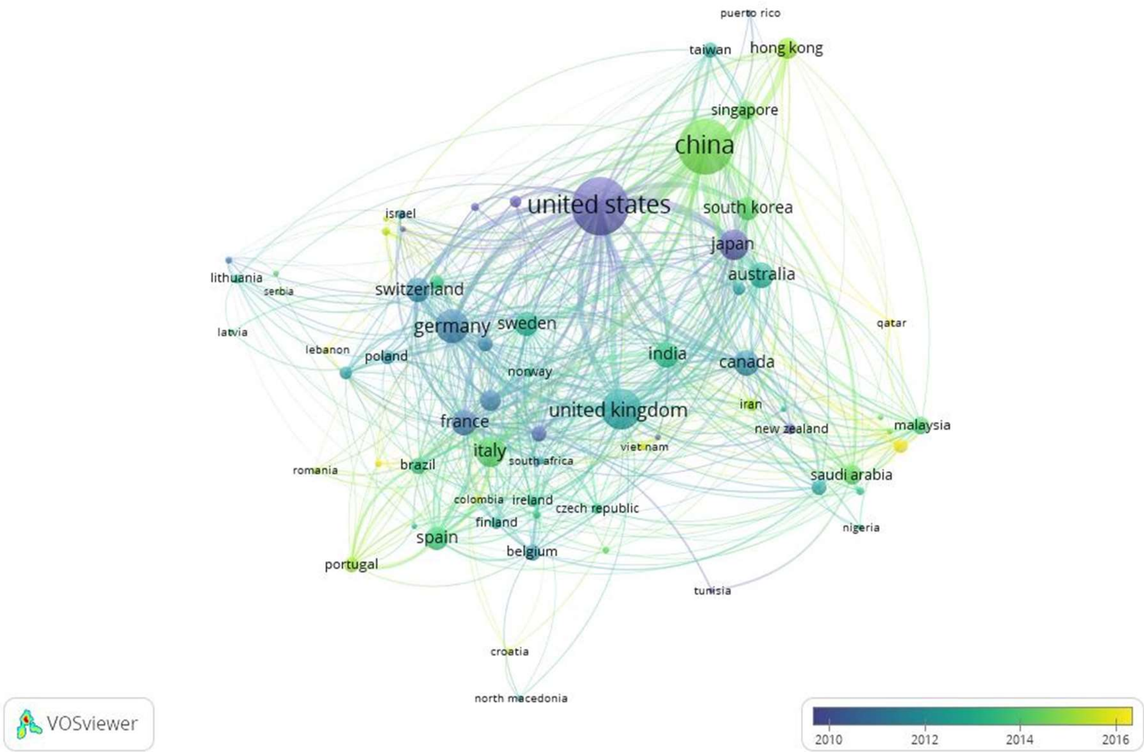
Table 2. Co-authorship citations analysis on the selected papers in Scopus for the years 1991-2019

Country	Number of papers	The biggest sponsor	The most cited paper	Number of citations
China	2682	National Natural Science Foundation of China; Fundamental Research Funds for the Central Universities	Chen et al., 2009 Ong et al., 2016	2258 2074
The United States	2315	National Science Foundation; US Department of Energy; Office of Science	Joannopoulos et al., 1997	2546
India	921	Department of Science and Technology, Ministry of Science and Technology, India; Department of Science and Technology, Government of Kerala	Norman et al., 1998	878
Japan	842	Japan Society for the Promotion of Science; Ministry of Education, Culture, Sports, Science and Technology	Asahi et al., 2001	10320
Germany	537	Deutsche Forschungsgemeinschaft	Ohta et al., 2006	2449
The United Kingdom	492	Engineering and Physical Sciences Research Council	Eperon et al., 2014	1791

Sources: own work compiled by the authors using Scopus.

The latest publications deal with the energy efficiency analysis through compilations of three areas: economic, technical and energy. In the United States and the EU countries, most papers were published in the years 2010-2012, in China in 2014. Portugal, Lebanon, Iran, and Qatar had started to investigate energy efficiency after the 2014 year (Figure 2).

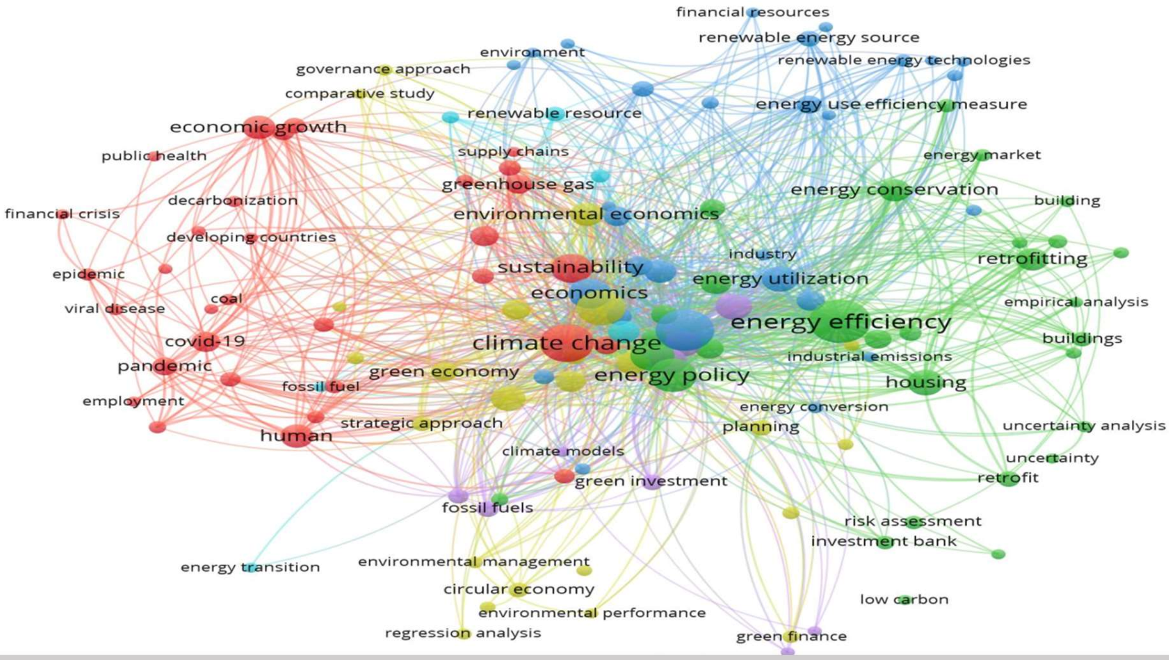
Figure 2. The visualisation of co-authorship analysis by the countries for the years 1991-2020



Sources: own work compiled by the authors using VOSviewer.

The visualisation of the co-occurrence analysis (Fig. 3) allowed identifying 6 clusters of scientists with a robust background on energy efficiency.

Figure 3. The visualisation of co-occurrences analysis for the years 1991-2020



Cluster	Number of items	Core keywords	Links	Total link strength	Occurrences
Cluster 1 (red)	32	Climate change	108	335	59
Cluster 2 (green)	32	Energy efficiency	99	421	77
Cluster 3 (navy blue)	29	Investment	115	522	72
Cluster 4 (yellow)	24	Sustainable development	102	322	49
Cluster 5 (purple)	9	Emission control	78	202	27
Cluster 6 (blue)	6	Alternative energy	67	150	21

Sources: own work compiled by the authors using VOSviewer.

The most significant cluster contained 32 items and could be called "Climate change". The second biggest cluster focused on the analysis of energy efficiency. The third cluster focused on the analysis of investment as a key driver of increasing energy efficiency and contained 29 items. The findings showed that the three most significant clusters were connected by the three intermediator clusters: alternative energy, emission control and sustainable development.

The findings proved that energy efficiency analysed toward developing solar energy and energy conservations. Furthermore, the long-distance between clusters 1 and 2 meant that the links between them were rather weak. Clusters 1, 3–6 were located close to each other, which showed a considerable background on the investigations of the energy efficiency, renewable energy, investments and sustainability. In this case, the findings concluded that the new direction of the investigation should be focused on the analysis of the linking between energy efficiency, green investment, greenhouse gas emissions and renewable energy. Thus, the core element that led to an increase in energy efficiency was renewable energy, contributing to additional green investment. The scientists in the papers: [Chygryn & Krasnyak, 2015; Ibragimov et al., 2019a, b; Pavlyk, 2020; Pimonenko et al., 2017a; Lyulyov et al., 2020], proved that green investments increase energy efficiency. In the papers: [Cebula et al., 2018; Pimonenko et al., 2017b; Kostiukevych et al., 2020; Kwilinski et al., 2020], the authors confirmed that renewable energy positively impacted energy efficiency. The second parameter was innovation development. Thus, the innovation service and technologies lead to an increase in energy efficiency [Akimova et al., 2017; Bilanet al., 2019b; Kwilinskiet al., 2020; Lipkova & Braga, 2016; Kasztelnik & Gaines, 2019; Kendiukhov & Tvaronavičienė, 2017; Miskiewicz, 2020; Masharsky et al., 2018; Panchenko et al., 2020; Rubanovet al., 2019; Sotnyk et al., 2018; Bogachov et al., 2020; Borychowski et al., 2020; Chygryn et al., 2020; Czyżewski et al., 2019; 2020; Dalevska et al., 2019; Dementyev & Kwilinski, 2020; Dzwigol & Dźwigoł-Barosz, 2018; 2020; Dzwigol, 2019; 2020; Dzwigol et al., 2020; Kaźmierczyk & Chinalska 2018; Kharazishvili et al., 2020; Kuzior et al., 2020; Kwilinski et al., 2019; Kyrylov et al., 2020; Lyulyov et al., 2020; Miskiewicz, 2020; Pająk, et al., 2016; Saługa et al., 2020; Savchenko et al., 2019; Tkachenko et al., 2019a; 2019b; 2019c]. At the company level, the energy efficiency depended on the environmental management and implementing corporate social responsibilities [He, 2019; Kiss, 2018; Kwilinski, 2018; Leonov et al., 2017; Harafonova, Zhosan & Akimova, 2017; Wang et al., 2020]. At the country level, the efficiency of governance, reforms and financial policies provided impacted the country's energy efficiency. The authors confirmed that the environmental performance of the country [Bilan et al., 2018; Dkhili 2018; Pająket al., 2017], fiscal decentralisation [Bilanet al., 2019a; Tiutiunyk 2018; Wieland et al., 2020; Vasylieva et al., 2018], investment policy [Akimov et al., 2020; Lyeonov et al., 2019; Pimonenko, 2019], the law supporting energy innovations [Panchenko et al., 2020; Cebula & Pimonenko, 2015]. The findings proved that the scientists identified a huge range of the parameters that provoked the changes in a country's energy efficiency. Considering the bibliometric analysis, the scientists analysed the impact of green investment, greenhouse gas emissions and renewable energy on energy efficiency under the transition to the carbon-free economy.

In this case, the paper aimed to check the causality between energy efficiency and the key determinants: green investment, greenhouse gas emissions and renewable energy.

Methodology

Considering the findings, the indicator level of energy efficiency was selected to estimate the country's energy efficiency. Besides, the bibliometric analysis results identified the core determinants of energy efficiency that were selected for the further causality relationship analysis: green investment, greenhouse gas emissions, and share of the renewable energy in the final energy consumption. For the analysis, the EU countries and Ukraine (as a potential candidate for EU) for 2009-2018 were chosen. The data for analysis were obtained from the Eurostat, Ukrstat and the European Environmental Agency. A similar methodology of analysis was used in the papers: [Ibragimov et al., 2019 a,b; Vasylieva et al., 2019]. With the purpose to check the hypothesis, the study used the following model:

(1) $$EE = f(GHG; RE; GI)$$

where EE – level of energy efficiency of the country; GHG – greenhouse gas emissions; RE – share of the renewable energy in the final energy consumption; GI – green investment.

Thus, for the investigation, the modified function (1) could be written as a panel cointegration equation:

(2) $$lnEE_{it} = \delta + \alpha lnGHG_{it} + \beta lnRE_{it} + \gamma lnGI_{it} + \varepsilon_{it}$$

where α, β, γ – regression parameters, which were evaluated and explain the elasticity of output relate on a level of energy efficiency of the country, green investment, greenhouse gas emissions and share of renewable energy in the final energy consumption; ε – the error term; i=1, ..., N; t=1, ..., T.

At the first stage, the study checked the stationarity of the date using the panel unit root test. In this case, the null hypothesis was that selected variables were non-stationary (H0). Next, the cointegration between variables was checked. Thus, the hypothesis assumed non-cointegration between the selected variables (H1). At the next stage, the long-run relationship was checked using the Fully Modified Ordinary (FMOLS) Least Square and

Dynamic Ordinary Least Square (DOLS) panel cointegration techniques. Therefore, the following hypothesis was checked:

H3: GHG, RE and GI had an impact on EE;

H4: EE, RE and GI had an impact on GHG;

H5: EE, GI and GHG had an impact on RE;

H6: EE, GHG and RE had an impact on GI.

If the long-run relationships between variables existed, the Granger causality test could be performed to check the causality among selected variables for analysis. In this case, it was the hypothesis on the absence of Granger causality between EE, RE, GHG and GI (H7). The study used the Dumitrescu-Hurlin Test: Panel Granger Causality Test. In general, the model could be presented as in formula (3):

$$Y_{i,t} = \beta_i + \sum_{i=1}^{N} \gamma_i^{(n)} y_{i,t-k} + \sum_{i=1}^{N} \delta_i^{(n)} x_{i,t-n} + \epsilon_{i,t} \tag{3}$$

where β_i indicates constant term, $\gamma_i^{(n)}$, $\delta_i^{(n)}$lag parameter and coefficient slope, $y_{i,t}$, $x_{i,t}$ are times series.

Thus, if the p-value < 0.05, the null hypothesis (absence of Granger causality) could be rejected and the alternative hypothesis accepted – the existence Granger causality. Besides, the resulting conclusions could be:

- if causality existed between two variables, it was the bi-directional causality;
- if causality from one variable to other – unidirectional causality;
- no causality.

The study used the EViews software for the analysis.

Results

Considering the abovementioned methodology, the first stage was checking the stationarity of the selected variables. The findings of the panel unit root test are shown in Table 3.

Table 3. The finding of stationarity analysis using the panel unit root test

Type of tests	Statistic Characteristics	Variables							
		at base level				at 1st difference			
		EE	GHG	RE	GI	EE	GHG	RE	GI
Levin, Lin & Chu	Statistics	-4.79	-12.54	-2.71	-2.47	-1.04	-3.93	-8.65	-11.08
	probability	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Im, Pesaran and Shin W-stat	Statistics	-1.6	-2.87	2.13	0.76	-2.02	-1.94	-2.64	-4.94
	probability	0.05	0.002	0.98	0.78	0.00	0.00	0.00	0.00
ADF-Fisher Chi-square	Statistics	78.92	107.3	47.83	57.56	90.56	88.47	97.99	139.93
	probability	0.07	0.00	0.91	0.63	0.00	0.00	0.00	0.00
PP-Fisher Chi-square	Statistics	91.26	68.89	51.07	68.07	267.27	205.38	164.93	230.85
	probability	0.00	0.26	0.84	0.28	0.00	0.00	0.00	0.00

Source: own work

The findings in Table 3 allowed concluding that at a base level only a few variables were stationary: all variables in Levin, Lin & Chu test; greenhouse gas emissions in Im, Pesaran and Shin W-stat; energy efficiency and greenhouse gas emissions in ADF-Fisher Chi-square; energy efficiency in PP-Fisher Chi-square. Therefore, all variables become stationarity in all tests at the first level. It allowed rejecting the null hypothesis of non-stationarity at 1% significance. At the next stage of the analysis, the study conducted the cointegration between variables using the Pedroni panel cointegration test.

Table 4. The findings of cointegration between the energy efficiency of the country, green investment, greenhouse gas emissions and share of the renewable energy in the final energy consumption using the Pedroni residual cointegration test

<table>
<tr><th colspan="2">Dimensions</th><th>Test</th><th>panel v-statistic</th><th>panel rho-statistic</th><th>panel PP-statistic</th><th>panel ADF-statistic</th></tr>
<tr><td rowspan="4">Within-dimension</td><td rowspan="2"></td><td>Statistics</td><td>0.39</td><td>-0.06</td><td>-10.95</td><td>-11.73</td></tr>
<tr><td>Probability</td><td>0.35</td><td>0.47</td><td>0.00*</td><td>0.00*</td></tr>
<tr><td rowspan="2">weighted</td><td>Statistics</td><td>-2.46</td><td>2.34</td><td>-6.61</td><td>-5.65</td></tr>
<tr><td>Probability</td><td>0.99</td><td>0.99</td><td>0.00*</td><td>0.00*</td></tr>
<tr><td colspan="2" rowspan="3">Between-dimension</td><td>Test</td><td>group rho-statistic</td><td>group PP-statistic</td><td colspan="2">group ADF-statistic</td></tr>
<tr><td>Statistics</td><td>3.91</td><td>-10.54</td><td colspan="2">-7.92</td></tr>
<tr><td>Probability</td><td>1.00</td><td>0.00*</td><td colspan="2">0.00*</td></tr>
</table>

*Note: * represents significance at the 1% level.*

Source: own work

The empirical results in Table 4 confirmed that six out of eleven probabilities of the test had the statistical significance at 1% level. It allowed rejecting the hypothesis of non-cointegration between a country's energy efficiency, green investment, greenhouse gas emissions, and the share of the renewable energy in the final energy consumption. Besides, the findings confirmed the long-run relationship among analysed variables. In this case, the Fully Modified Ordinary Least Square (FMOLS) and Dynamic Ordinary Least Square (DOLS) panel cointegration techniques were used. The empirical results of FMOLS and DOLS were presented in Table 5.

Table 5. The results of the long-run relationship between variables using the FMOLS and DOLS panel cointegration techniques

Variables		FMOLS		DMOLS	
Dependent	**Independent**	**Coefficient**	**Probability**	**Coefficient**	**Probability**
EE	GHG	-0.16	0.05**	-0.28	0.00*
	RE	0.46	0.00	0.32	0.00*
	GI	0.71	0.00	0.72	0.00*
GHG	EE	-0.24	0.02**	-0.35	0.00*
	RE	-0.41	0.00*	-0.28	0.00*
	GI	-0.53	0.00*	-0.64	0.00*
RE	EE	0.35	0.00*	0.38	0.00*
	GHG	-0.3	0.00*	-0.26	0.00*
	GI	0.34	0.00*	0.37	0.00*
GI	EE	1.01	0.00*	0.98	0.00*
	GHG	0.57	0.33	0.68	0.56
	RE	0.53	0.00*	0.42	0.00*

*Note: * and ** represents significance at the 1% and 5% levels.*

Source: own work

The findings of long-run relationship analysis confirmed that both tests, FMOLS and DOLS, had similar results. The empirical results were statistical significance at 1% and 5% for analysed parameters, excluding two cases in DOLS and FMOLS models for greenhouse gas emissions' impact on green investment and vice versa. An increase of 1% of greenhouse gas emissions led to the decline of energy efficiency by 16% (FMOLS) and 28% (DOLS). At the same time, the increase in the share of renewable energy in final energy consumption by 1% provoked: an increase of the energy efficiency by 46% (FMOLS) and 32% (DOLS); a declinine of greenhouse gas emissions by 16% (FMOLS) and 28% (DOLS). What is more, the growth of green investment by 1% allowed: an increase of energy efficiency of the country by 71% (FMOLS) and 72% (DOLS); an increase of renewable energy by 34% (FMOLS) and 37% (DOLS); a decline of greenhouse gas emissions by 53% (FMOLS) and 64% (DOLS). The findings (Table 3) proved the hypothesis of the long-run relationship between selected variables. It allowed concluding that attracting green investment and extending renewable energy led to a decline in greenhouse gas emissions and an increase in a country's energy efficiency. The findings of the Granger causality test are shown in Table 6.

Table 6. The empirical results of Granger causality test between the energy efficiency of a country, green investment, greenhouse gas emissions and share of the renewable energy in the final energy consumption

Null Hypothesis	Zbar-statistic	W-statistic	Probability	Confirmation	Type of causality
GHG→EE	2.72	2.03	0.04**	reject	Unidirectional causality from GHG to EE
EE→GHG	2.43	1.55	0.12	accept	
GI→EE	2.61	1.85	0.06***	reject	Bi-directional causality between EE to GI
EE→ GI	1.8	0.5	0.02**	reject	
RE→EE	4.89	5.63	0.002*	reject	Bi-directional causality between EE and RE
EE→RE	1.67	0.29	0.04**	reject	
GI→GHG	2.60	1.83	0.04**	reject	Bi-directional causality between GI to GHG
GHG→GI	1.17	0.55	0.06***	reject	
RE→GHG	3.68	3.62	0.0003*	reject	Unidirectional causality from RE to GHG
GHG→ RE	1.67	0.28	0.78	accept	
RE→ GI	2.57	1.78	0.03**	reject	Unidirectional causality from RE to GI
GI→ RE	1.55	0.08	0.93	accept	

Note: → – no Granger causality; accept or reject – mean the decision on null hypothesis;

, **, * – represent significance at the 1%, 5% and 10% levels.*

Source: own work

Thus, the findings in Table 6 confirmed that unidirectional causality was directed from greenhouse gas emissions to energy efficiency. Simultaneously, the unidirectional causality was confirmed from share of renewable energy in the final energy consumption to green investment and greenhouse gas emissions. Therefore, the empirical results confirm the bi-directional causality between: energy efficiency and share of renewable energy in the final energy consumption; energy efficiency and green investment; greenhouse gas emissions and green investment.

Summary, recommendations

The transition to the carbon-free economy under the "Green Deal Policy" justified developing the mechanisms and tools for increasing a country's energy efficiency. The bibliometric analysis results proved that a country's energy efficiency through the efficiency of the policy to attract green investment, extend renewable energy, and decline greenhouse gas emissions. The Granger causality test's findings confirmed the bi-directional causality between energy efficiency and the share of renewable energy in the final energy consumption. Moreover, considering the results of cointegration analysis (using DOLS and FMOLS), the increase of the share of renewable energy in the final energy consumption provoked an increase in the energy efficiency by 46% (FMOLS) and 32% (DOLS). The results of Granger causality test allowed to confir the unidirectional causality from greenhouse gas emissions to energy efficiency. Simultaneously, an increase by 1% in greenhouse gas emissions provoked a decline in energy efficiency by 16% (FMOLS) and 28% (DOLS). In this case, the government should implement effective instruments and policies to reduce air pollution. Besides, the stimulating policy on spreading renewable energy allowed an increase in energy efficiency and a decline in air pollution. The developing positive business climate allowed attracting the additional green investment for renewable energy and green technologies.

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