Article

Not peer-reviewed version

Economic Performance in Green Energy Transition Towards the New Normal Framework: Drivers and Blockers of Green Energy Productivity

Alina Zaharia * , Laura Brad * , Marius Bogdan Petre , Ioan-Daniel Chiciudean , Gabriela-Ofelia Chiciudean *

Posted Date: 7 May 2026

doi: 10.20944/preprints202605.0324.v1

Keywords: renewable energy productivity; energy efficiency; net zero emissions; sustainable development; policy; Europe

Article

Economic Performance in Green Energy Transition Towards the New Normal Framework: Drivers and Blockers of Green Energy Productivity

Alina Zaharia [1,2,*], Laura Brad [3,*], Marius Bogdan Petre [4], Ioan-Daniel Chiciudean [5] and Gabriela-Ofelia Chiciudean [6,*]

1 Department of Agrifood and Environmental Economics, Faculty of Agrifood and Environmental Economics, Bucharest University of Economic Studies, Bucharest, Romania
2 National Institute for Economic Research "Costin C. Kiriţescu", Romanian Academy, 050711 Bucharest, Romania
3 Department of Finance, Faculty of Finance and Banking, Bucharest University of Economic Studies, Bucharest, Romania
4 Bucharest University of Economic Studies, Romania
5 Department of Economic Sciences, Faculty of Horticulture and Business in Rural Development, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Cluj-Napoca, Romania
6 Department of Economic Sciences, Faculty of Horticulture and Business in Rural Development, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Cluj-Napoca, Romania
* Correspondence: alina.zaharia@eam.ase.ro (A.Z.); laura.brad@fin.ase.ro (L.B.); gabriela.chiciudean@usamvcluj.ro (G.-O.C.)

Abstract

In the context of SDG 7 and SDG 13 of the 2030 sustainable development agenda, a new performance indicator started to gain momentum in scientific research: the renewable energy productivity. Understanding the drivers and the challenges of green energy productivity could help add on to the classical focus of renewable energy research on infrastructure, technical and economic feasibility, environmental and social impacts, by considering more the performance indicators in this field. Only very few studies explored the influencing factors of the renewable energy productivity. Thus, this research aims to reveal the impact of social, economic, energy, and environmental variables on the green energy productivity. The methodological approach involves bibliometric analyses of the literature on green energy productivity (GEP), and panel data regression models involving 16 independent variables. The main findings indicate positive effects of green taxes, female participation in the workforce, and highly educated people on GEP, pointing out the importance of green taxation, education, and gender equality in sustainable development. On the other side, negative relationships of green energy productivity with economic growth, traditional energy variables, and air pollution were found for the European Union's member states over 2007 and 2023. The results suggest that the analyzed European countries based their economic growth on traditional resources, with less importance provided to the renewable resources and green technologies, as the share of renewable resources of GDP was also negatively correlated. While private financial resources increase the green energy productivity, questions about research and development investments, urbanization, and diversity index are still debatable.

Keywords: renewable energy productivity; energy efficiency; net zero emissions; sustainable development; policy; Europe

JEL: Q01; Q43; O11; C33.

 doi:10.20944/preprints202605.0324.v1

1. Introduction

Assessing energy productivity has been one way of exploring the status and the evolution of the green energy transition [1] and the possibility of achieving sustainable development [2,3], as its importance is directly related with the sustainable development goal (SDG) 7, which aims, among others, to ensure sustainable energy for all, and it is indirectly associated with many other SDGs, especially 13, 12, 9 and 8 [4,5].

Energy productivity is intensely investigated nowadays by using different research models, among which the panel data approach with regression models, which focuses on exploring the impact of different variables on the dependent one. In this regard, energy productivity is either part of the influencing factors which are analyzed to observe their impact on sustainability-related variables, such as green energy transition [1], air quality [2,3], and economic effects [6], either it is the dependent variable which is explored to see its drivers and blockers [7,8]. For example, [7] tested the following factors which might impact energy productivity: income, industrial value added, investment to capital ratio, energy price, perceived energy security index of energy imports, population growth, urbanization, female labor participation rate, and total degree-days, while [8] looked up to renewable energy use and other types of energy sources, and income.

Moreover, understanding the drivers and the challenges of green energy productivity could help add on to the classical focus of renewable energy research on infrastructure, technical and economic feasibility, environmental and social impacts, by considering more the performance indicators in this field. Recently, a new economic performance indicator is starting to be more and more discussed in the scientific literature, namely the green energy productivity (GEP) or the renewable energy productivity (REP) [5,9,10]. Most studies focus on the impact of GEP on environmental sustainability [11,12]. Some publications discuss GEP in relation with the social dimension of sustainability [5], while some research papers explore its relation with the economic aspects of sustainability [13]. However, until April 2026, the Web of Science, Scopus, and Google Scholar, the three main databases with scientific publications on social sciences and, specifically, economics, registered scarce research on how other influencing factors might impact the green energy productivity [9,14]. While [14] considers a mixed method analysis with a focus on qualitative approach as its research is based on experts' opinions, [9] focuses on using a quantitative approach based on data panel, as in this study. [9] considers the following variables of impact on the renewable energy productivity: domestic bank credit, inflows of foreign direct investment, government effectiveness, the World Uncertainty Index, labor force participation, capital formation, and non-renewable energy consumption.

Considering previously stated context, this research aims to investigate the impact of different economic, social, and environmental macroeconomic indicators on the green energy productivity, in order to better emphasize strategic options for achieving sustainability within the energy sector. Panel data and regression models were used to investigate data from Eurostat.

Compared with previous scientific literature, the novelty of this study lies in the different influencing factors considered for analysis, as well as the used methodology, which consists of modelling regressions to determine the effects on green energy productivity. Also, several models have been tested to emphasize the impact of different influencing factors on GEP, namely: GDP growth, domestic credit to private sector (% of GDP), research and development expenditure (% of GDP), diversity index of energy supply, primary energy consumption (PEC), energy price (EP), share of energy from renewable sources (%), total greenhouse gas emissions including LULUCF (t CO_2e/capita), total environmental taxes in GDP (%), total energy taxes in GDP (%), total taxes on pollution/resources in GDP (%), total transport taxes in GDP (%), proportion of seats held by women in national parliaments (%), ratio of female to male labor force participation rate (%), labor force with advanced education as % of total working-age population with advanced education, urban population (% of total population).

The structure of this paper is as follows. The literature review section provides quantitative and qualitative analyses of the literature in the field. The first sub-section – 2.1. – quantitatively explores the literature on green energy productivity by using the bibliometric technique. Then, the second

 doi:10.20944/preprints202605.0324.v1

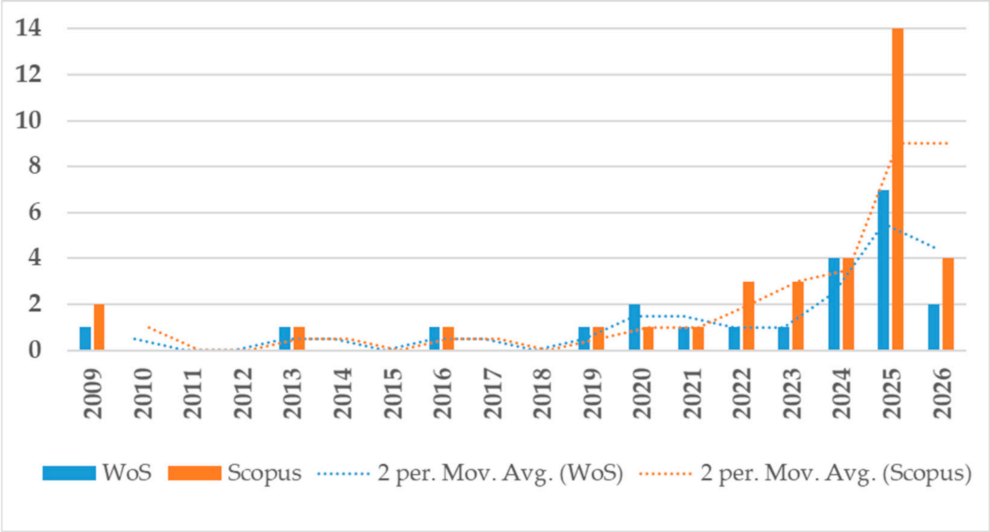
sub-section applies a mixed methods approach by discussing the most cited, the newest, and the most relevant research about green energy productivity, followed by the word network maps to emphasize main themes found in the titles and the abstracts of the scientific publications on green energy productivity. For both these two sub-sections, the information was collected from Web of Science (WoS), a scientific database of Clarivate [15], and from Scopus, a scientific database of Elsevier [16]. While Scopus and WoS are both curated and mainly used by researchers, Scopus has a broader coverage compared to WoS [17,18]. The search criteria for green energy productivity literature was: "green energy productivity" OR "renewable energy productivity". The third sub-section – 2.3. –, the final one, emphasizes the gaps in the literature on green energy productivity and presents the research hypotheses. Further, the methodological section provides information on the data used, the regression models, and the tests conducted before applying the panel data models. Then, the next section presents the results and their discussion, while the conclusions section illustrates the final remarks.

2. Literature Review

2.1. Overview of the Literature on Green Energy Productivity – Bibliometric Approach

The search inquire – "green energy productivity" OR "renewable energy productivity" OR "productivity of renewable energy" OR "productivity of green energy" – was applied on both Scopus and Web of Science (WoS) platforms considering the title, the abstract, and the keywords of any document. It resulted a very low number of publications on both analyzed databases, namely only 26 papers on WoS, and 35 publications on Scopus. However, the literature on green energy productivity has just started to pique the interest of scientists, especially since 2024 for WoS, and since 2025 for Scopus, although the first paper on this topic has been published first in 2009 on both platforms. This increased interest is also demonstrated by the spike of publications on this topic on the Google Scholar platform [19] since 2025, which generated 28 results, considering a more specific search only on the titles of publications as it is the only more specific option on this platform, of which 16 documents were published since 2025 until March 2026, when the search was conducted. Also, there were many identical papers on these 3 databases. Thus, further, the focus will be on the publications from WoS and Scopus when conducting the bibliometric analysis.

Figure 1 illustrates the evolution of the literature on green energy productivity from Scopus and WoS databases.



 doi:10.20944/preprints202605.0324.v1

Figure 1. The number of documents published yearly on green renewable energy on Scopus and WoS until April 2026.

In both databases, almost all papers were written in English, except one in both cases. In terms of countries affiliated with the authors, the main geographic area where 53.85% of papers from WoS, respectively 31,43% of publications from Scopus, came from China. On the Scopus platform, China and India are on the first position both with the same number of publications on green energy productivity, namely 11 [16]. The next positioned regions represented less than half of the first placed countries, with 15.3%, respectively 14.2%, 11.4% and 11.4% of documents on WoS, respectively Scopus, coming from India, Pakistan, Turkey, and USA, respectively from Turkey, Pakistan, and USA. Thus, the regional interest was quite diverse, as, on average, WoS registered 1.04 documents per country on green energy productivity, while Scopus registered 1.25 documents per country on green energy productivity.

In terms of the document type, the majority of the papers were articles, with a percentage of 84.63% of the publications on WoS, and of 74/29% of the documents from Scopus. Other types of papers were conference papers (proceedings), review articles, and book chapters on both databases, while, supplementary, one editorial was registered on WoS.

In terms of the research areas, Figure 2 illustrates best the distribution of papers regarding this issue, pointing out that the majority of the papers in both databases focused on energy sector.

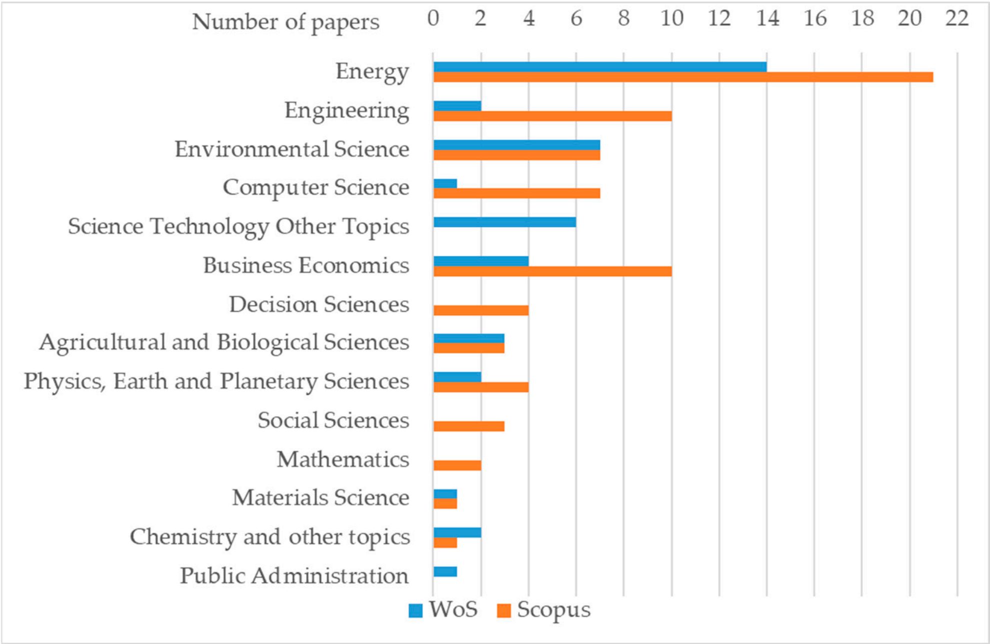


Figure 2. The number of documents on green renewable energy per research areas on Scopus and WoS until April 2026.

Supplementary, the WoS platform also provides information about the connection of each work with the sustainable development goals (SDGs). Thus, the majority of the papers were connected with the following SDGs: 09 Industry Innovation and Infrastructure, 13 Climate Action, 07 Affordable and Clean Energy, 12 Responsible Consumption and Production, and 08 Decent Work and Economic Growth, with the percentages: 69.23%, 65.39%, 61.54%, 53.85%, and 50.00% (Clarivate, 2026). Beside these only one or two papers were connected with the following SDGs: 11 Sustainable Cities and Communities, 02 Zero Hunger, and 06 Clean Water and Sanitation.

Further, the first 10 publications were the same for both databases with the same number of papers published, as it is illustrated in Figure 3.

doi:10.20944/preprints202605.0324.v1

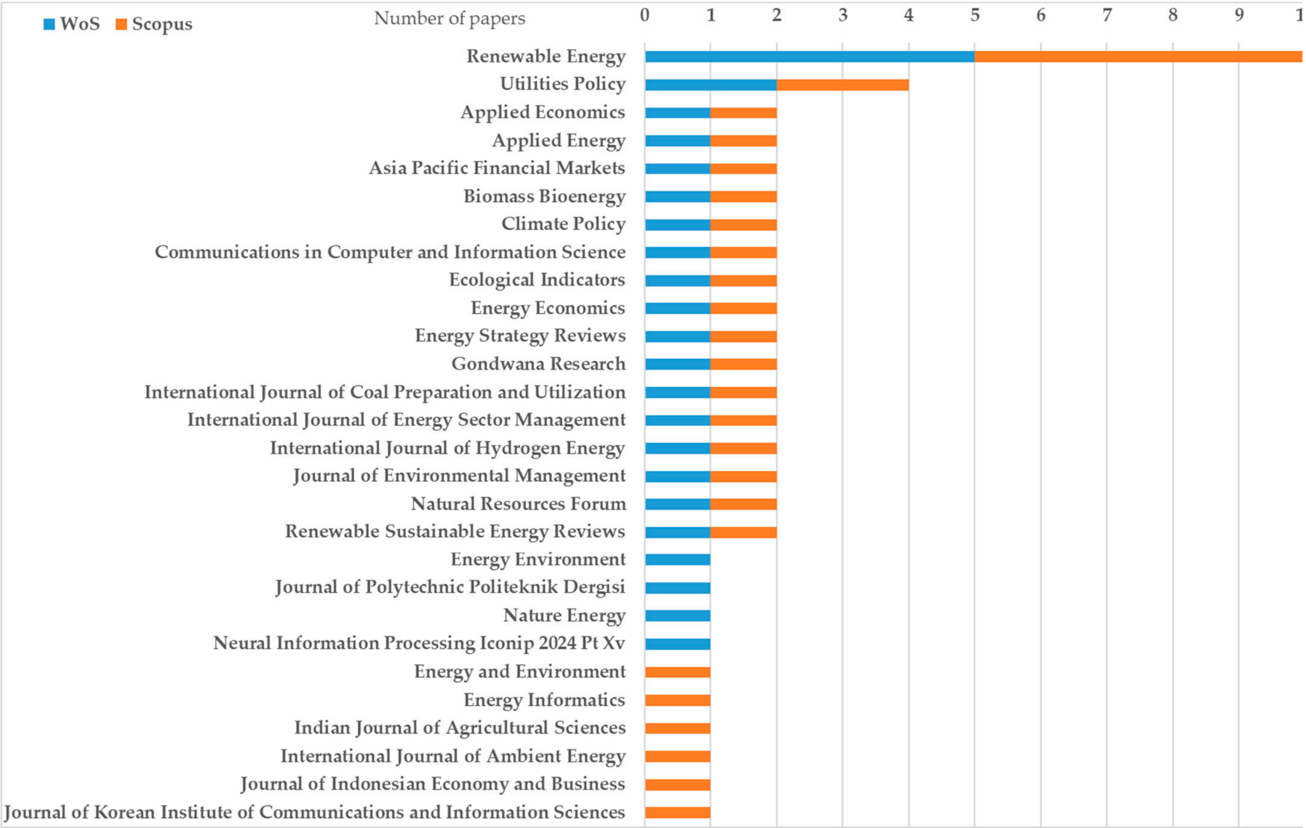


Figure 3. The number of documents on green renewable energy per publication on Scopus and WoS until April 2026.

The journals Renewable Energy and Utilities Policy published five and two papers, respectively, on both databases, while the rest of the journals published one paper each. Also, there were also some differences in journals published on the two platforms analyzed, which can be seen at the bottom of Figure 3.

Supplementary, WoS indicates on its platform the publishers and the conference titles for the topic analyzed, where data available. Thus, 61.5% of papers on green energy productivity were published by Elsevier until April 2026, 11.5% documents were published by Taylor & Francis, and 7.6% of publications from WoS were published by Springer, while each of the following publishers published one paper each: Emerald Group Publishing, Gazi University Journal of Science, Nature Portfolio, Sage, and Wiley. Next, only two conference titles were recorded on WoS, namely: 11th International Conference on Applied Energy, and 31st International Conference on Neural Information Processing. This information could be useful for researchers who aim topics such as green energy productivity.

Further, the authors of the papers on green energy productivity identified on both databases had the affiliations from Xiamen University, Hong Kong Metropolitan University, and Ilma University, with three papers each, while the rest of the affiliations registered two or one paper each. A total of 25, respectively, 79 affiliations were registered on the paper on green energy productivity from WoS, respectively, Scopus, meaning an average of 0.96 affiliations per document on WoS and of 2.26 affiliations per document on Scopus.

Finally, the main funding organizations with more than one paper published in both databases were: National Natural Science Foundation of China NSFC, and Key Projects of Philosophy and Social Sciences Research Ministry of Education, with three and two papers each on WoS [15] and Ministry of Education of the People's Republic of China, and National Natural Science Foundation of China with two papers each for Scopus [16]. A total of 27, respectively, 14 founding organizations were registered in the papers on green energy productivity from WoS, respectively, Scopus, meaning an average of 1.04 sponsors per document on WoS and of 0.40 sponsors per document on Scopus.

2.2. Main Themes from the Literature on Green Energy Productivity

This section provides a mixed method analysis of the literature on green energy productivity by using the bibliometric technique and the word cluster analysis. First, the most cited papers, the newest documents, and the most relevant publications from WoS and Scopus until April 2026 are being discussed. Then, a word cluster analysis for the title and the abstract of these documents is being conducted by using the VOSviewer software, versions 1.6.18 [20–22].

Following the same inquiring criterion, namely "green energy productivity" OR "renewable energy productivity", on the two analyzed platforms, Web of Science and Scopus, the most cited publications about green energy productivity are presented in Table 1.

Table 1. The most cited publications about green energy productivity on Web of Science (WoS) and Scopus databases until April 2026.

Top - hierarchy		Number of citations		The most cited publications on green energy productivity (until April 2026)	Publication year
WoS	Scopus	WoS	Scopus		
1	1	103	107	Zhao, J., Sinha, A., Inuwa, N., Wang, Y., Murshed, M., & Abbasi, K. R. (2022). Does structural transformation in economy impact inequality in renewable energy productivity? Implications for sustainable development. *Renewable Energy*, *189*, 853-864. [5]	2002
2	NA	85	NA	Orlov, A., Sillmann, J., & Vigo, I. (2020). Better seasonal forecasts for the renewable energy industry. *Nature Energy*, *5*(2), 108-110. [23]	2020
3	2	65	67	Cevik, E. I., Yıldırım, D. Ç., & Dibooglu, S. (2021). Renewable and non-renewable energy consumption and economic growth in the US: A Markov-Switching VAR analysis. *Energy & Environment*, *32*(3), 519-541. [24]	2021
4	3	52	62	Cui, Q., He, L., Han, G., Chen, H., & Cao, J. (2020). Review on climate and water resource implications of reducing renewable power curtailment in China: A nexus perspective. *Applied energy*, *267*, 115114. [25]	2020
5	4	49	60	Park, G. L., Schäfer, A. I., & Richards, B. S. (2013). Renewable energy-powered membrane technology: Supercapacitors for buffering resource fluctuations in a wind-powered membrane system for brackish water desalination. *Renewable energy*, *50*, 126-135. [26]	2013

 doi:10.20944/preprints202605.0324.v1

6	5	43	52	Mandal, K. G., Hati, K. M., & Misra, A. K. (2009). Biomass yield and energy analysis of soybean production in relation to fertilizer-NPK and organic manure. *Biomass and bioenergy*, *33*(12), 1670-1679. [27]	2009

*NA – not available.

The highest cited paper [5], presented on both analyzed databases, used the REP to determine an indicator of inequality in renewable energy productivity, which was investigated in relation with employment, trade openness, conflicts, TFP (total factor productivity), and economic complexity index. The main results suggest that structural transformation and technological innovation lower inequality in renewable energy productivity, while economic complexity index stimulate the increase of inequality and trade openness indicated statistically insignificance, by using a data panel for some OECD countries [5].

Additionally, the newest publications about green energy productivity on Web of Science (WoS) and Scopus databases in March 20, 2026, are presented in Table 2.

Table 2. The newest publications about green energy productivity on Web of Science (WoS) and Scopus databases until April 2026.

	The newest publications on green energy productivity (until April 2026)	**Citations**
Scopus	Rafipour, F., Tabibian, M., & Saati, M. (2026). An AI and multi-criteria framework for siting renewable energy systems enhanced by graphene photovoltaics in a coastal City. *Energy Informatics*, *9*(1), 40.	0
	Aggarwal, S., & Mahalik, M. K. (2026). The influence of domestic bank credit and FDI inflows on renewable energy productivity: an analysis of developing Asian economies. *Asia-Pacific Financial Markets*, *33*(1), 95-118.	2
	Shahbaz, M., Eti, S., Yüksel, S., Dinçer, H., & Çırak, A. N. (2026). A multi-criteria decision-making framework for enhancing renewable energy productivity. *Renewable Energy*, 124990.	1
	Aggarwal, S., & Mahalik, M. K. (2026). The role of urbanization in fossil fuel demand of developing Asian economies: understanding the moderating effect of renewable energy productivity. *International Journal of Ambient Energy*, *47*(1), 2623005.	1
	Aggarwal, S., & Mahalik, M. K. (2025). The nexus of urbanization and renewable energy productivity: implications for sustainable development in developing Asia nations. *International Journal of Energy Sector Management*, *19*(6), 1406-1426.	5
WoS	Shahbaz, M., Eti, S., Yüksel, S., Dinçer, H., & Çırak, A. N. (2026). A multi-criteria decision-making framework for enhancing renewable energy productivity. *Renewable Energy*, 124990.	0
	Lin, B., & Zhang, A. (2025). Digital finance and total factor productivity of renewable energy enterprises: role of capital reallocation and supply chain optimization. *Applied Economics*, 1-16.	0

 doi:10.20944/preprints202605.0324.v1

	Soto, G.H., Zambrano-Monserrate, M. A., Pilatin, A., & Martinez-Cobas, X. (2025). Energy resource productivity and environmental quality: A quantile-on-quantile study of Latin America from 1990 to 2022. *Utilities Policy*, *95*, 101944.	1
	Yaman, H. Measuring renewable energy productivity in EU countries with the Hicks-Moorsteen index. Journal of Polytechnic - *Politeknik Dergisi*, 29(4):290406:1-7.	0
	Yan, X., & Raza, M. Y. (2025). Decoupling the traded coal and its factors under the sustainable energy changeover in South Korea. *International Journal of Coal Preparation and Utilization*, 1-21.	4

Table 2 indicates only one common study found in the top five newest publications about green energy productivity on both databases. This study [14] revels the main factors which could stimulate renewable energy productivity for BRICS countries, among which was found: the quality of technology and infrastructure, energy storage capacities, financial support, high investments in R&D, specialized and trained personnel, and good management of risks.

Also, some of these newest studies are the most relevant for this research.

Thus, one of these recent studies and the most relevant paper on the topic [9] investigates the impacts of domestic bank credit, inflows of foreign direct investment (FDIi), government effectiveness, the World Uncertainty Index, labor force participation, capital formation, and non-renewable energy consumption on the renewable energy productivity by using Generalized Method of Moments (GMMs) estimation technique for a data panel of 23 Asian countries during 1996–2020. Its main results suggest that effective government, labor force participation, capital formation, non-renewable energy consumption positively influenced renewable energy productivity, while world uncertainty influenced it negatively [9]. Additionally, at robustness checks, the impacts of domestic credit bank, of FDIi, of the cumulative effect of domestic credit bank with world uncertainty (BCWU), and the cumulative effect of FDIi with world uncertainty (FDIWU) on renewable energy productivity were statistically insignificant, although the the domestic credit bank and the BCWU seemed to register a positive influence, and FDIi and FDIWU appeared to have negative ones [9].

Another one of these recent studies [28], presented in Table 2, considers renewable energy productivity (REP) as an independent variable to test its impact on fossil fuel demand. The main results of this study [28] suggest that REP, and the cumulative effect between urbanization and REP reduced fossil fuel demand in 20 Asian countries during 1996–2020. Also, considering another study from the top of the newest publications [12], renewable energy productivity seemed to stimulate as well the achievement of the sustainable development goals, by registering a positive impact on SGD score.

Another one of the newest publications [29] focused on investigating Chinese listed renewable energy companies during 2007-2021 to find out that digital finance stimulates the TFP of these companies. Additionally, an EU focused study [10] measured REP between 2013 and 2022, by comparing the energy efficiency of different member states. Further, another approach [30] investigates REP as a decoupling factor of CO_2 emissions for South Korea over 1990–2023, indicating its low contribution on pollution.

Next, the most relevant five publications about green energy productivity on Web of Science (WoS) and Scopus databases in March 20, 2026, were the same for both platforms, as presented in Table 3.

 doi:10.20944/preprints202605.0324.v1

Table 3. Top relevant publications about green energy productivity on Web of Science (WoS) and Scopus databases until April 2026.

Top	Number of citations		Relevant publications on green energy productivity (until April 2026)	Publication year
	WoS	Scopus		
1	1	2	Aggarwal, S., & Mahalik, M. K. (2026). The influence of domestic bank credit and FDI inflows on renewable energy productivity: an analysis of developing Asian economies. *Asia-Pacific Financial Markets*, *33*(1), 95-118. [9]	2026
2	11	11	Soto, G.H. (2024). Long run renewable energy productivity, carbon capture patents and air quality in Taiwan. *Journal of Environmental Management*, *351*, 119925. [11]	2024
3	8	9	Yang, X., Zhou, H., & Gao, J. (2025). Enhancing renewable energy productivity and energy efficiency of energy projects: How does cost of capital influence?. *Energy Strategy Reviews*, *57*, 101608. [13]	2025
4	103	107	Zhao, J., Sinha, A., Inuwa, N., Wang, Y., Murshed, M., & Abbasi, K. R. (2022). Does structural transformation in economy impact inequality in renewable energy productivity? Implications for sustainable development. *Renewable Energy*, *189*, 853-864. [5]	2022
5	3	5	Aggarwal, S., & Mahalik, M. K. (2025). The nexus of urbanization and renewable energy productivity: implications for sustainable development in developing Asia nations. *International Journal of Energy Sector Management*, *19*(6), 1406-1426. [12]	2025

The most relevant one [9] delves into financing impact on green energy productivity and it was previously discussed above. This study is the only research which considers green energy productivity as a dependent variable considering a panel data approach, as in our study. However, this research used the regression analysis for estimating the influencing factors of renewable energy productivity (REP), while the reference [9] used the Generalized Method of Moments (GMMs) technique. The second research from Table 3 [11] explores the relationships of REP with air emissions, fossil fuel energy productivity, and GDP, finding no statistically significant and obvious relationship between REP and air emissions, at least not on the short-term. The third positioned paper from Table 3 [13] explores the microeconomic level related with energy projects by considering the cost of capital and other influencing factors on REP in China between 2009 and 2023, indicating a negative relationship between the cost of capital and REP. The last two papers from the top five most relevant research on green energy productivity were previously presented above.

Further, the word cluster analysis was performed on Scopus research on the analyzed topic and Figure 4 illustrates the word network map, which included all terms from the title and the abstracts of all Scopus publications about green energy productivity that occurred at least 5 times.

 doi:10.20944/preprints202605.0324.v1

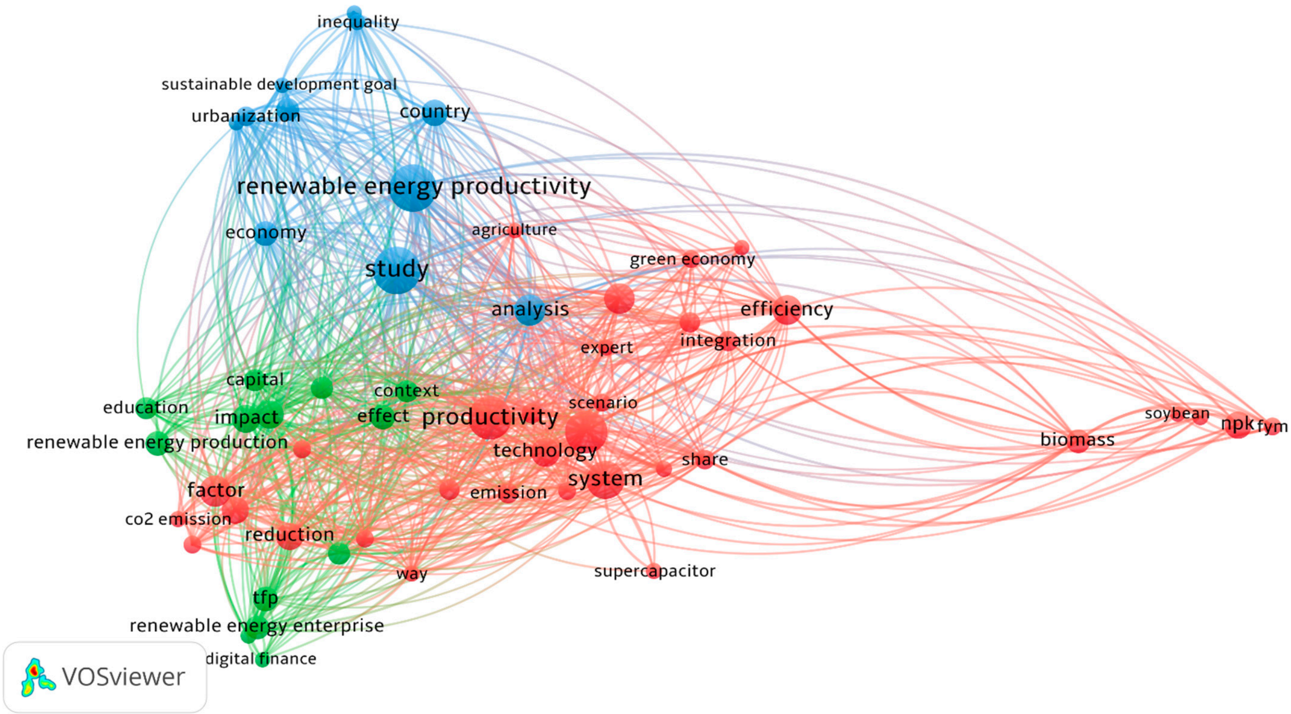


Figure 4. Main themes of green renewable energy research found in titles and abstracts from Scopus until April 2026. Made with VOSviewer.

Considering the criterion of five times the occurrence of a term, 57 words were found and illustrated in Figure 4, indicating the most used topics in this field, namely: renewable energy productivity and study – with an occurrence of 44 times each, productivity and renewable energy – with 37 and 36 occurrences, system – with 29 occurrences, factor and analysis – with 20 occurrences each, investment, efficiency, technology, impact, role, NPK, China, reduction, country, TFP (Total Factor Productivity), renewable energy production, economy, effect, biomass, renewable energy enterprise, sustainable development – with occurrences between 11 and 19, and education, research, context, capital, and transition – with 10 occurrences each.

VOSviewer generated three word-clusters for the 57 analyzed terms, focusing on: sustainable development pillars and structural transformation – the blue cluster, transition towards renewable energy companies and drivers – the green cluster, and transition towards green agriculture and technological advancement for green transition – the red cluster.

Finally, this word-cluster analysis is in line with previous content discussion of the most cited, the most relevant, and the newest papers on green energy productivity.

2.3. Gaps and Development of Hypotheses

As previously seen, the research about green energy productivity was at an early stage in April 2026, with an increased interest from researchers on WoS, Scopus, and Google Scholar. The present research aims to reveal the drivers and blockers of green energy productivity.

The hypotheses of this research are presented in next part of the article, following several directions:

H1. The economic variables affects in a positive way the green energy productivity as European countries have goals in terms of environmental protection. Moreover, climate neutral aim exists among the EU countries which provides evidence that more green technologies are used. Thus, GDP growth (annual %) (GDP_GROWTH), Domestic credit to private sector (% of GDP (XDCPS), and

 doi:10.20944/preprints202605.0324.v1

Research and development expenditure (% of GDP) (XRDE) should encourage the of green energy productivity

H2. The social development of a country (Proportion of seats held by women in national parliaments express in % (XSW), Ratio of female to male labor force participation rate (%) (XLF), Labor force with advanced education as % of total working-age population with advanced education (XLTE), Urban population (% of total population (XURP)) contributes to the increase of green energy productivity as women and tertiary education are more included for sustainable development and as cities and industry are propensity inclined to green development.

H3. The variables that are linked with traditional sources, such as primary energy consumption (PEC), energy price (EP) and Total greenhouse gas emissions including LULUCF (t CO2e/capita (GHG_WITH_LULUCF) should decrease the value of green energy productivity. Their increase should make countries implementing more green policies, providing tax facilities and other advantages for the one who use renewable energy and green technologies.

H4. The variables that are link with the adoption and the utilization of renewable sources (such as Diversity index of energy supply (DIVERSITY_INDEX), Share of energy from renewable sources (%) (XER), Total energy taxes in GDP (%) (XET),) should encourage the production of green energy and thus, should increase the green value added to GDP.

H5. As the EU countries emphasize the adoption of green policies though environmental taxes (Total environmental taxes in GDP (%) (XENVT), Total taxes on pollution/resources in GDP (%) (XTP), Total transport taxes in GDP (%) (XTT)) sustainable and green growth can be ensured and thus, the level of green energy productivity increases.

3. Materials and Methods

The present research aims to reveal the impact of different economic, social, and especially environmental factors on the green energy productivity, in order to better emphasize strategic options for achieving sustainability within the energy sector.

This study looks forward to present two types of analyses. The first one, emphasizes the link between different economic, social, and especially environmental macroeconomic variables and the green energy productivity, using a panel model approach on the 27 European Countries. The analysis takes into account data from 2007-2023, because of the lack of information for the analyzed variables for 2024. Second, the found public policy correlations were retested using combine variables in panel model. The second approach takes into account only environmental variables and economic growth in order to emphasize on what public policies should focus for increasing the value of green energy productivity.

The period on which the analyses were conducted was based both on data availability and on the fact the in 2007 Romania and Bulgaria became members of the European Union. After that, only Croatia joined the European Union in 2013, while the United Kingdom left it in 2020. As a fact the number of countries that were taken remained constant at 27. This ensures unity and comparability in data.

The estimation of the regression models has been done with EViews, based on data from Eurostat, World Bank, and own calculation variables, as summarizes in **Table 4.**

Table 4. Information on the variables included into the analysis.

Variable's code	Name of the variable and Unit of measurement	Source
ENER_PROD_REAL or GEP_REAL & ENER_PROD_PPS or GEP_PPS	Green energy productivity, Thousand tonnes of oil equivalent per comparable million euro & Thousand tonnes of oil equivalent per million PPS	Own calculation based on Eurostat: Gross available energy - renewables and biofuels [31] and Real GDP or PPS GDP [32]

 doi:10.20944/preprints202605.0324.v1

DIVERSITY_INDEX	Diversity index of energy supply (%)	Eurostat [33]
EP_adjusted	Energy price (US$), the variable was adjusted with Harmonized Price Consumption Index	US Energy Information Administration [34]
GDP_GROWTH	GDP growth (annual %)	World Bank Group [35]
GHG_WITH_LULUCF	Total greenhouse gas emissions including LULUCF (t CO2e/capita)	World Bank Group [35]
PEC	Primary energy consumption (million tons of oil equivalent)	Eurostat [36]
XDCPS	Domestic credit to private sector (% of GDP)	World Bank Group [35]
XENVT	Total environmental taxes in GDP (%)	Eurostat [37]
XER	Share of energy from renewable sources (%)	Eurostat [38]
XET	Total energy taxes in GDP (%)	Eurostat [37]
XLF	Ratio of female to male labor force participation rate (%)	World Bank Group [35]
XLTE	Labor force with advanced education (% of total working-age population with advanced education)	World Bank Group [35]
XRDE	Research and development expenditure (% of GDP)	World Bank Group [35]
XSW	Proportion of seats held by women in national parliaments (%)	World Bank Group [35]
XTP	Total taxes on pollution/resources in GDP (%)	Eurostat [37]
XTT	Total transport taxes in GDP (%)	Eurostat [37]
XURP	Urban population (% of total population)	World Bank Group [35]

Source: own processing from Eurostat, World Bank, and the US Energy Information Administration databases, 2026.

In order to reveal the influence of several social, economic and environmentally factors on the level of green energy productivity (GEP), the analysis was conducted using panel model techniques. That means that data for 27 European Countries data was collected from 2007 to 2023. Panel models look both at time specific characteristics and countries' specific characteristics and facilitate the increase of the number of data observation n included into the analysis. Initially, the data was estimated using the model presented in equation (1)

$$EP\_Real_{it} = \lambda_{it} + \sum \beta_{it} * Energy_{variables} + \sum \eta_{it} * Enviromental_{variables} + \sum \gamma_{it} * Social_{variables} + \sum \delta_{it} * Economic_{variables} + \varepsilon_{it} \quad (1)$$

where

$Energy_{variables}$ are elements that include: Diversity index of energy supply (DIVERSITY_INDEX), primary energy consumption (PEC), energy price (EP), Share of energy from renewable sources (%) (XER), Total energy taxes in GDP (%) (XET);

$Enviromental_{variables}$ are Total greenhouse gas emissions including LULUCF (t CO2e/capita (GHG_WITH_LULUCF), Total environmental taxes in GDP (%) (XENVT), Total taxes on pollution/resources in GDP (%) (XTP), Total transport taxes in GDP (%) (XTT);

$Social_{variables}$ are variables that are link with social features that a country has, such as Proportion of seats held by women in national parliaments express in % (XSW), Ratio of female to

 doi:10.20944/preprints202605.0324.v1

male labor force participation rate (%) (XLF), Labor force with advanced education as % of total working-age population with advanced education (XLTE), Urban population (% of total population (XURP);

$Economic_{variables}$ are variables that are link with economic characteristics of the country such as GDP growth (annual %) (GDP_GROWTH), Domestic credit to private sector (% of GDP (XDCPS), Research and development expenditure (% of GDP) (XRDE).

i – is a proxy for cross section information; t- is a proxy for time information;

ε_{it} is the combined errors of both cross estimation and time one and it includes other factors that might affect the green energy productivity.

The study provides novelty in terms of the factors which can affect the green energy productivity. At such, the study looks at the price of non-renewable energy, such as the oil price, as it can increase the necessity of producing green energy and, thus, forcing countries to focus more on green energy productivity rather than traditional one. The computation of this variable uses the methodology proposed by the reference [39]. Çoban and Topcu (2013). They suggest that the price of reporting Barrel Oil has to be adjusted with the consumer price index for each Member State.

The panel data model was done based on the recommendations provided by Wooldridge (2002). The analysis is made using several steps.

Step 1. Information about the descriptive statistics of the variable included into the analysis is presented.

Step 2. Each data series was tested for stationarity. The conducted stationary tests were related with testing stationary with trend and intercept, testing stationary only with intercept and testing stationary with none of these features. The third case (testing stationary without trend and intercept) does not have economic relevance and this could be the reason for which many of the analysed data were stationary in level. The stationary process was conducted with Dickey and Fuller's (1981) , ADF (Phillips and Perron, 1988) , Breitung, 2000). Levin et al. (2002), Im et al. (2003) tests and the data series was accepted to be stationary when no unit root exists both at individual and panel approach. The stationarity process is obtained by making the first difference. For some variables, such as URP (urban population of total population), XET (Total energy taxes in GDP), XENVT (Total environmental taxes as GDP) the first difference hasn't solved the stationarity problem, mainly because of the Breitung t-test. Related with this, reference [40] Moon and all (2006) emphasize in their research that the Beitrung test has a lower rate of rejecting the null hypothesis than the initial values. Starting from this assumption, we considered that this data series were also stationary in the first difference. The aim was to reveal if this additional environmental indicators can increase the value of green energy productivity, while urbanization can decrease it. Actually, we look at the economic relevance of this indicators together with their possible relationship with green energy productivity.

Step 3. Granger causality tests were conducted in order to reveal if the link between independent variables and green energy productivity is one-way direction causality of or if is bidirectional causality. For testing this short term relationship, a number of 3 lags were taken into account.

Step 4. The correlation matrix was created and the correlation relationships were analyzed. If the correlation coefficient was about 0.3 then the variables were included in different models. High correlation between variables creates biased results, which could be doubtful both from the statistical point of view and from the economic one.

Step 5. The panel data analysis was conducted starting with the pool models. Each model was tested, afterward, for different effect significance. Thus, the relevance of fixed effects, random effects or omitted random effects was tested and the results were pointed out in the results section. The fixed effect model emphasizes in its null hypothesis that there is no statistically difference between countries or time period. Its alternative hypothesis reveals that the effects are statistically significant belong countries or/and time period. After testing for country's particularities, the Random effect was measured. It was tested with the Hausman test. The Hausman null hypothesis considers that both the fixed effect model and the random effect model are consistent estimators, but only the random one approach is efficient. The alternative hypothesis of this test is that only the fixed approach is consistent. The problem with the random effect model is that this assumption considers that the variables are statistically independent from each other, which in economic world this is quite impossible. If the random effect model was chosen than Omitted Random effect-The LaGrange Multiplier was applied. Its null hypothesis that no significant panel- level heterogeneity exists, which means pool model is reliable, while its alternative hypothesis considers that significance random effect exists, which enquire the random model to be used. Each model was testes for heteroscedasticity and autocorrelation. If they exist, the model was adjusted with the robustness analysis, where generalized least square method was used and the correlation matrix was adjusted in order to avoid both heteroscedasticity and autocorrelation. When the number of periods is smaller than the number of cross country data, the results could be adjusted with Period SUR or period Weights within the generalized least square method. While period weights is recommended, the problems related with missing data, generated a smaller period on which the analysis was conducted. Thus, the correlation of heteroscedasticity and autocorrelation is done by using the Period SUR, as the other one provided unreliable economic data. The used methodology implies that there is a general correlation among different period of time for specific country clustering. While correction of heteroskedasticity and general autocorrelation of observations within a country was done, the lack of totally autocorrelation could not be avoided. Regarding, the correlation matrix, the robustness analysis used the White period method of estimation it. This method emphasizes that a cross-sectional correlation exists between the series errors and tries to readjust it by grouping the data at cross country level.

Step 6. After the main influence of economic, environmental, social and energy variables was found on energy productivity, additional analysis was conducted. The purpose was to reveal if energy and environmental variables do affect the green energy productivity, both in terms of real values and in terms of purchasing power parity. Thus, for each variable, additional correlation matrix was done between Green energy productivity measured in real values of Purchasing power parity, the economic growth, the energy or environmental variable and the mixed effect between economic growth and environmental or energy proxy. The model were tested using equation (2) or (3)

$$EP_{Real_{it}} \text{ or } EP_{PPS_{it}} = \lambda_{it} + \beta_{it} * Energy_{variable} + \eta_{it} * Energy_{variable} * growth_{gdp} + \gamma_{it} * growth_{GDP} + \varepsilon_{it} \quad (2)$$

$$EP_{Real_{it}} \text{ or } EP_{PPS_{it}} = \lambda_{it} + \beta_{it} * Enviromental_{variable} + \eta_{it} * Enviromental_{variable} * growth_{gdp} + \gamma_{it} * growth_{GDP} + \varepsilon_{it} \quad (3)$$

where

$Energy_{variables}$ are elements that include Share of energy from renewable sources (%) (XER), Total energy taxes in GDP (%) (XET);

$Enviromental_{variables}$ are Total greenhouse gas emissions including LULUCF (t CO2e/capita (GHG_WITH_LULUCF), Total environmental taxes in GDP (%) (XENVT), Total taxes on pollution/resources in GDP (%) (XTP), Total transport taxes in GDP (%) (XTT);

i – is a proxy for cross section information;

t- is a proxy for time information;

ε_{it} is the combined errors of both cross estimation and time one and includes other factors that might affect the green energy productivity.

The methodological approach could be improved by presenting the link between public policies and green energy productivity.

4. Results and Discussions

The aim of the research is to present ways is which green energy productivity can be improved at European country's level. The results aim to be useful for academic purpose, but more importantly, they can provide policy guidance at European Level for ensuring zero carbon emissions till 2050. In order to achieve the objective of this research in finding which of the encountered economic, social,

 doi:10.20944/preprints202605.0324.v1

environmental and energy variable do affect the green energy productivity, firstly the descriptive statistic of the variables was done. The information is found in **Table 5.**

Table 5. Descriptive statistics of variables included into the analysis.

Indicator	GEP_REAL	GEP_PPS	DIVERSITY_INDEX	EP_AJUSTED	GHS_WITH_LULUCF	GDP_GROWTH
Mean	143.88	148.66	0.20	79.27	132.64	1.85
Median	45.13	63.32	0.18	74.33	59.59	2.09
Maximum	10570.63	10193.02	0.55	138.85	957.10	24.62
Minimum	12.68	14.64	0.12	41.82	-1.95	-16.04
Std. Dev.	776.47	748.82	0.08	25.06	194.02	4.03
Skewness	12.17	12.17	2.07	0.23	2.50	-0.24
Kurtosis	153.21	153.12	8.11	1.83	9.50	7.10
Number of observations	486	486	432	459	459	486

	PEC	XDCPS	XENVT	XER	XET	XLF
Mean	50.59	84.99	2.66	20.10	2.01	79.59
Median	23.20	80.54	2.52	17.48	1.92	80.98
Maximum	320.80	254.67	5.60	66.39	4.81	91.02
Minimum	0.70	23.05	0.85	0.18	0.51	47.40
Std. Dev.	71.13	42.93	0.74	12.03	0.59	6.64
Skewness	2.22	1.27	0.63	0.98	0.89	-1.38
Kurtosis	7.24	5.04	3.20	3.99	4.76	6.32
Number of observations	459	448	459	459	459	459

	XLTE	XRDE	XSW	XTP	XTT	XURP
Mean	78.65	1.59	27.11	0.13	0.51	72.87
Median	79.07	1.34	25.83	0.07	0.43	71.28
Maximum	89.57	3.73	47.28	0.94	2.11	98.19
Minimum	66.68	0.38	8.70	0.00	0.02	51.98
Std. Dev.	3.88	0.89	10.24	0.18	0.36	12.80
Skewness	-0.02	0.63	0.14	2.53	1.01	0.21
Kurtosis	2.56	2.22	1.94	10.19	3.94	2.02
Number of observations	455	432	459	459	459	459

Source: Own computation using Eviews, 2026.

Regarding the information found in **Table 5,** several characteristics are revealed. First of all, in the energy category, it can be observed huge differences between share of energy from renewable sources (%) (XER) between countries. While the maximum value of share of energy from renewable sources (%) is 66.39% in Sweden in 2023, the minimum value is found in Malta, in 2008, of 0.18%. It can be observed that there is a high diversity of using or not using the energy from renewable sources which suggest that countries don't have a common public policy regarding the need of renewable resources. While the average increases from 13.63% in 2007 to 27.22% in 2023, the data still presents important difference between countries. From the initial data, it can be observed that countries such as Sweden, Denmark, Finland, Latvia, Estonia have the share of energy from renewable sources

 doi:10.20944/preprints202605.0324.v1

higher than 40%, while countries such as Belgium, Czech Republic, Hungary, Ireland, Italy, Luxembourg, Malta, Netherlands, Poland and Slovakia still have main values under 20%, even if we consider 2023 data. Regarding the variable: total energy taxes in GDP (%) (XET). It can be observed that the minim value was 0.51% in 2014 in Ireland and the maxim value was registered in Poland in 2015, of 4.81%. Doing comparison between years, in 2007, the average of this indicator is found to be 1.59%, while in 2023, its average value reach 1.66%. This suggests that the data is quick uniform, so no important increases were done in terms of total energy taxes in GDP. The data reveals the difficulty to pass from conventional energy sources to renewable ones. Regarding the values of diversity index, there is a trend in decreasing it, which suggest the increase in the variety in countries' energy sources. At such, the average value for 2007 was 0.21, while the average value for 2022 is 0.18. On the other hand, the maximum value is found in Malta of 0.55 in 2014, and the minimum value is found in Czech Republic in 2021. The problem with this indicator is that it presents variety in countries' energy sources, but it does not make a difference if the country has more or less renewable sources than other countries. For the analysis, it can be observed that energy price varies between 41.82$ in Austria in 2010 to 138.84$ in Luxembourg in 2017. Average value is found around 79.27$. A particularity of this indicator is that the average seems to be reliable for all countries, their individual values being around the mean. No significant differences were observed for 2027-2023 at European Level. Primary energy consumption (PEC), expressed in million tonnes of oil equivalent has the highest value in France in 2013, of 320 million tonnes of oil equivalent, while the minimum values were found in Malta and Romania in 2018 of 0.7 million tonnes of oil equivalent. The 2018 year seems to be the one with the minimum values at European level, with 4.49 million tonnes of oil equivalent as average, while 2013 seems to be the one with the highest average, of 252.4 million tonnes of oil equivalent. The average at European level, for the period encountered, is 50.59 million tonnes of oil equivalent

Regarding environmental variables, we firstly present the characteristics for Total environmental taxes in GDP (%) (XENVT), Total taxes on pollution/resources in GDP (%) (XTP), Total transport taxes in GDP (%) (XTT). As a fact, Total environmental taxes in GDP (%) (XENVT) have an average value of 2.66%, with a minimum value being found in Poland in 2015, of 0.85% and with a maximum value being found in Ireland in 2014, of 5.6% in terms of yearly values, in 2027. The average at the Level of European Union was 2.44%, while in 2023 is 2.08% which proves that they are not a main variable though which sustainable development is encouraged. Around average values are countries such as Austria, Belgium, Croatia, Romania, Sweden, while above average values are: Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland and Italy. All the others are below average values, if we consider individual country's analysis.

Small share related to GDP have both Total taxes on pollution/resources in GDP (%) (XTP), Total transport taxes in GDP (%) (XTT). Total taxes on pollution/resources in GDP (%) (XTP) have an average value of 0.13%, while Total transport taxes in GDP (%) (have an average of 0.51%. The minimum values for total taxes on pollution/resources in GDP (%) (XTP) could be 0.01% and 0% in several countries and years, while the maximum value was found in Spain and Slovenia of 0.94% in 2008. Other high values were registered in Sweden in 2008 of 0.92% and in Czech Republic and Denmark in 2009, of 0.89%. On the other hand, when total transport taxes in GDP (%) (XTT) were analyzed, we observed that the minimum values were found in Netherlands and Poland, in 2010, of 0.02%, while the maximum, was in Portugal, in 2011, of 2.11%. The average value of this indicators is 0.51%.The data revealed that countries do not have important environmental and energy's policies on which sustainable development is conducted. Other important variables is Total greenhouse gas emissions including LULUCF (t CO2e/capita (GHG_WITH_LULUCF). Average value at European Union for 200 7-2023 is 132.64 (t CO2e/capita), with a maximum high of 957.1 (t CO2e/capita) in Finland in 2013, and with a minimum value of -1.95 (t CO2e/capita) in Luxembourg in 2023. Below average values, for the entire period, are countries Denmark, Estonia, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg and Spain.

Other types of data were also taken into consideration are social variables. From the point of view of social variables, we considered the proportion of seats held by women in national parliaments express in % (XSW). The average in 27.11%, with maximum value found in Greece, Romania, Slovakia and Slovenia in 2018around 47%, while the minimum values were detected in 2018, In Germany, Greece, Hungary, Ireland and Italy of 8.69% Regarding the variable Ratio of female to male labor force participation rate (%) (XLF), the average is 79.59%, with the minimum value found in France in 2018 of 47.40% and the maximum was in Luxembourg in 2012 with 91.01%. Another variable that was part of the analysis was Labor force with advanced education as % of total working-age population with advanced education (XLTE). We observed that the average value is 78.65%, with the lowest one found in Estonia of 66.68% and the highest one being in Spain of 89.56%. in this case, the average seems to be relevant for all countries, as the analysis conducted at country level, prove that there are small fluctuations related with the mean of 1 percentage point. On the other hand, when we look at Urban population (% of total population (XURP) we could observed significance differences among countries. Thus the maximum values was found in Czech Republic and Denmark in 2008 of 98.1% , while the minimum values were presented in Croatia and Cyprus of 51.9% and 52.2% in 2022.

The last category on independent variables is part of the economic field. The most significant is the GDP growth (annual %) (GDP_GROWTH). The results reveal that negative values were registered during economic crisis in 2007-2009, while important and significant values were detected afterwards. The highest one was in Ireland in 2015, of 24.61%, Followed by Malta of 9.62% also in 2015. One variable that was included also other research papers is Domestic credit to private sector (% of GDP (XDCPS), with minimum values found in Hungary of 23.05% in 2021 and the maximum value being registered in Poland, in 2009, of 254.6%. Average for this indicator is 84.9%, with highest value above 90% being found in Denmark, Estonia, Portugal, and Romania. The last variable is Research and development expenditure (% of GDP) (XRDE). Its average is 1.58%, with highest values in 3.73% in Croatia in 2012 and smallest value also in Croatia of 0.38% in 2021. This reveals that the expenditures related with research and development are less important at European level.

After the descriptive statistics was conducted, the correlation matrix was constructed. The results are presented in Figure 1.

Probability	D_ENER_P	D_ENER_P	D_DIVERS	D_EP_ADJUSTED	D_GHS_W	GDP_GRO	PEC	D_XDCPS	D_XENVT	D_XER	D_XET	D_XLF	D_XLTE	D_XRDE	D_XSW	D_XTP	D_XTT	D_XURP
D_ENER_PROD_REAL	1																	
D_ENER_PROD_PPS	0.9985***	1																
D_DIVERSITY_INDEX	-0.0005	-0.0161	1															
D_EP_ADJUSTED	0.0559	0.0525	0.0158	1														
D_GHS_WITH_LULUCF	-0.0141	-0.0141	0.0345	0.0279	1													
GDP_GROWTH	-0.069	-0.058	-0.1569**	-0.0107	-0.0406	1												
PEC	-0.017	-0.0159	-0.0066	0.0269	0.012	0.0261	1											
D_XDCPS	0.1703***	0.1606***	0.1322**	0.1166**	0.0262	-0.1541**	-0.0242	1										
D_XENVT	0.0584	0.0569	0.0566	-0.0426	-0.1131**	-0.0087	-0.0171	0.1936***	1									
D_XER	0.0024	0.0011	0.0377	-0.043	-0.0122	-0.2277**	0.0077	0.0167	-0.0189	1								
D_XET	0.0111	0.0128	-0.0186	-0.0333	0.0277	0.0199	0.006	-0.1719**	0.774***	-0.0313	1							
D_XLF	0.0271	0.0254	0.0575	-0.0358	-0.0865	-0.0053	-0.0002	0.0581	-0.064	0.01287	-0.0561	1						
D_XLTE	0.0877	0.0806	0.0733	0.0292	-0.2621**	-0.084	-0.0052	0.4043***	-0.14394	0.054157	-0.36821	0.138166	1					
D_XRDE	-0.0671	-0.068	0.1197**	-0.034	0.3449***	0.0499	-0.0152	0.1192***	-0.0171	-0.0262	-0.1376**	0.4300***	-0.1855**	1				
D_XSW	-0.0479	-0.0472	0.0556	-0.1022*	0.3423***	0.0517	-0.007	0.0759	0.1187***	-0.0283	0.0472	0.4625***	-0.1481**	0.7411***	1			
D_XTP	0.055	0.0522	0.07	-0.0404	-0.1253**	-0.0442	-0.004	0.1273**	0.5079***	0.0116	0.1396**	0.1828***	0.1242**	-0.0888	-0.0191	1		
D_XTT	0.0708	0.0668	0.101*	-0.0118	-0.2041**	-0.0287	-0.04	0.5817***	0.4915***	0.0071	-0.1280**	-0.1166**	0.2421***	0.2184***	0.1615***	0.3163***	1	
D_XURP	-0.016	-0.016	0.0879	-0.0447	0.0306	0.1660***	-0.0202	0.1733***	0.0502	-0.1091*	-0.1031*	-0.071	-0.0924	0.3322***	0.3346***	-0.1512**	0.3227***	1

Source own computation, using Eviews 9, 2026

Note ***,**,* provides significance at 1%, 5% and 10%. Red colour indicates high correlation coefficients (above 0.4); green colour indicates small correlation coefficients (below 0.3); blue colour indicates correlation coefficients between 0.3 and 0.4., where D_ENER_PROD_REAL=D_GEP_REAL and D_ENERGY_PROD_PPS=D_GEP_PPS

Figure 1. Correlation matrix.

The correlation matrix is important as high correlation between variables creates biased results, which could be doubtful both from the statistical point of view and from the economic one. Due to this feature, only variables that were less correlated were presented into the same model. The level of correlation on which analyses were conducted is below 0.3.

As the data analyzed are less correlated, **Table 6** aims to present the results of our estimation.

 doi:10.20944/preprints202605.0324.v1

Table 6. The impact of energy, environmental, social and economic variables on green energy productivity.

	Dependent variable D_GEP_REAL										
Variable	model 1	model 2	model 3	model 4	model 5	model 6	model 7	model 8	model 9	model 10	model 11
Constant	-4.3671 *	-9.6391 ***	-0.2519 (p=0.9447)	-3.3187 **	-1.8333 (p=0.6218)	-4.1186 (p=0.1188)	-7.3690 ***	-8.7402 ***	5.0653 *	-10.8141 ***	-6.8155 ***
D_DIVERSITY_ INDEX *100	0.2227 (p=0.3682)	-0.1657 (p=0.4145)	1.2516 **		-0.0973 (p=0.6970)		-0.1359 (p=0.4344)			0.0293 (p=0.7512)	
D_EP_ADJUSTED	0.0486 **	0.0980 **		0.0368 (p=0.1418)				0.0590 ***			0.0932 *
D_GHG_WITH_ LUCUCF	-0.0067 ***						-0.0004 (p=0.5229)			-0.0036 ***	
GDP_GROWTH	-1.4523 ***	-1.8174 **		-0.6433 (p=0.1979)	-1.6677 ***		-1.3739 ***				-1.7512 **
LOG(PEC)	-1.0808 (p=0.1731)		-2.8975 *		-1.9223 *				-3.0571 ***		
D_XDCPS				0.1402 ***		0.1504 **			0.1270 **		
D_XENVT		6.5208 **						4.2619 ***			
D_XER					-3.4571 ***	-1.2223 ***		-0.3410 (p=0.3222)			
D_XET				3.3980 **					1.2210 *		
D_XLF		0.3027 *								0.2730 ***	
D_XLTE					1.0383 **	-0.0690 (p=0.7188)	1.0569 ***				
D_XRDE						-3.1927 (p=0.3012)					
D_XSW								-0.2440 ***	-0.1184 (p=0.2653)		
D_XTP									-0.2373	19.6486 ***	

									(p=0.9541)		
D_XTT			11.2445**								11.6866***
D_XURP							-0.0224 (p=0.4491)				
Omitted random effect cross section	4.4705**	5.8101**	5.1054***	6.6324**	4.2653**	6.9888***	5.5004**	7.3571***	6.9374***	7.3464***	4.8529***
Omitted random effect time	0.0028 (p=0.9575)	0.0759 (p=0.7828)	0.7585 (p=0.3838)	0.2668 (p=0.6055)	0.0393 (p=0.8427)	1.2883 (p=0.2564)	5.0564 (p=0.8122)	0.1589 (p=0.6901)	0.9509 (p=0.3295)	0.4977 (p=0.4805)	0.1969 (p=0.6572)
Omitted random effect both cross sectional and time	4.4437**	5.8861**	5.8640**	0.8992***	4.3047**	8.2771***	5.5569**	7.5161***	7.8884***	7.8441***	5.0499**
Cross sectional fixed effects	1.7141*	1.8169***	1.7425*	1.7870**	1.6756**	1.7006**	1.1723**	1.8519***	1.7303**	1.8653***	1.7498**
Period fixed effects	1.1020 (p=0.3542)	1.0460 (p=0.4064)	0.8919 (p=0.5680)	1.0122 (p=0.4412)	1.0585 (p=0.3946)	0.6485 (p=0.8379)	1.1080 (p=0.3486)	0.9237 (p=0.5376)	0.7434 (p=0.7398)	0.9775 (p=0.4750)	0.9638 (p=0.4932)
Hausman test for random cross sectional effect	10.8026*	15.3248***	2.1726 (p=0.7040)	11.9668**	14.1159**	0.3396 (p=0.9871)	18.8123***	1.2650 (p=0.8673)	2.3741 (p=0.7953)	11.2410**	8.4722*
Hausman test for random period effect	2.6827 (p=0.7488)	2.4686 (p=0.7812)	6.3552 (p=0.1741)	4.5078 (p=0.3416)	5.2557 (p=0.3853)	0.5910 (p=0.9641)	5.9006 (p=0.3160)	1.8293 (p=0.8035)	3.0667 (p=0.6897)	7.0438 (p=0.1336)	2.3112 (p=0.6787)
R-squared	12.07%	21.54%	8.80%	8.29%	23.16%	8.98%	13.83%	9.23%	8.55%	13.09%	23.56%
F-statistic	10.3551***	21.9078***	8.0343***	9.1532***	22.24***	8.544***	12.559***	10.857***	7.1502***	15.0728***	28.977***
Durbin-Watson	1.58	1.81	1.67	1.88	1.82	1.86	1.89	1.53	1.92	1.62	2.08
Kurtosis	35.79	22.71	29.91	40.29	33.98	66.71	27.41	20.96	41.02	10.67	28.02
Skewness	-3.44	-0.92	-3.33	-3	-2.73	-6.69	-1.82	-1.57	-3.44	-1.01	-2.6
Breusch-Pagan LM cross dependence test	523.7813***	407.6338**	468.384	537.88***	598.95***	443.69***	543.12***	440.59***	569.31***	390.05*	535.19***

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2026 doi:10.20944/preprints202605.0324.v1

cross sectionel initial model	fixed	fixed	random	fixed	fixed	random	fixed	random	random	fixed	fixed
time initial model	none	none	none	random	random	random	random	random	random	random	random

Source: own computation, using Eviews 9, 2026. Note: ENER_PROD_REAL is Green energy productivity, DIVERSITY_INDEX is Diversity index of energy supply (%), EP_ajusted is energy price (US$), the variable was adjusted with Harmonized Price Consumption ,GDP_GROWTH is GDP growth (annual %), GHG_WITH_LULUCF is Total greenhouse gas emissions including LULUCF (t CO2e/capita), PEC is primary energy consumption (million tons of oil equivalent), XDCPS is Domestic credit to private sector (% of GDP), XENVT is Total environmental taxes in GDP (%), XER is Share of energy from renewable sources (%),XET is Total energy taxes in GDP (%), XLF is Ratio of female to male labor force participation rate (%), XLTE is Labor force with advanced education (% of total working-age population with advanced education), XRDE is Research and development expenditure (% of GDP), XSW is Proportion of seats held by women in national parliaments (%), XTP is Total taxes on pollution/resources in GDP (%), XTT is Total transport taxes in GDP (%), XURP is Urban population (% of total population), d_variable reveals the first difference for attending stationary.

In **Tabel 6.** The impact of energy, environmental, social and economic variables on green energy productivity is presented. Both positive and negative correlations were found between the increases of green energy productivity (GEP) measured in thousand tonnes of oil equivalent and independent variables. The results are summarized in **Table 7.**

Table 7. Summarized results on green energy productivity.

Type of variable	**Variable**	**Positive correlation**	**Negative correlation**
Energy variables	Diversity index of energy supply (DIVERSITY_INDEX)	YES	
	Primary energy consumption (PEC)		YES
	energy price (EP)	YES	
	Share of energy from renewable sources (%) (XER))		YES
	Total energy taxes in GDP (%) (XET)	YES	
Environmental variables	Total greenhouse gas emissions including LULUCF (t CO2e/capita (GHG_WITH_LULUCF)		YES
	Total environmental taxes in GDP (%) (XENVT)	YES	
	Total taxes on pollution/resources in GDP (%) (XTP),	YES	
	Total transport taxes in GDP (%) (XTT)	YES	
Social variables	Proportion of seats held by women in national parliaments express in % (XSW)		YES
	Ratio of female to male labor force participation rate (%) (XLF)	YES	
	Labor force with advanced education as % of total working-age population with advanced education (XLTE)	YES	
	Urban population (% of total population (XURP)		YES (not significant)
Economic variables	GDP growth (annual %) (GDP_GROWTH)		YES
	Domestic credit to private sector (% of GDP (XDCPS)	YES	
	Research and development expenditure (% of GDP) (XRDE)		YES (not significant)

Source: own computation based on the estimated results.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2026 doi:10.20944/preprints202605.0324.v1

From the encountered variables, Urban population (% of total population) (XURP) and Research and development expenditure (% of GDP) (XRDE) seems to be not statistically significant important. The correlation between the degree of urbanization and the green energy productivity (GEP) is negative. That means that an increase with 1 percentage point in the level of urbanization creates less green energy productivity. The results reveal a decrease in green energy productivity with 0.02 thousand tonnes of oil equivalent. Similar, the research conducted by reference [7] reveals that higher urbanization rates can affect economic output and, thus, this generates less green energy productivity. The results are also in line with other research papers, such as the one conducted by reference [41], where the authors point out that urbanization is a positively and significant factor of CO_2 production. Same trend was presented by reference [42], who reveal that urbanization creates more pollution. The research provided by [43] reveal negative link between urbanization and sustainable development. Thus, this variable should be further included into analysis, as another study [44] emphasizes that the effect of urbanization has a significant inverted U shape with energy intensity at OECD level. That means it could have a significant oppose shape when energy productivity is considered.

Another variable that was not statistically significant was the share of Research and development expenditure (% of GDP) (XRDE). The results suggest that an increase with one percentage point in the share of research and development expenditure in GDP points out a decrease with 3.19 thousand tonnes of oil equivalent in green energy productivity (GEP). The results reveal that the research and development expenditures are not focus on green energy or sustainable development. On the other hand, the research conducted by reference [45] suggest that public renewable energy R&D budgets could increase Energy transition index. Moreover, till R&D expenditure are not focus on technological advancement replacements in fundamental sectors such as transport, small improvement could be done in terms of energy transition, and thus, in value created by green energy productivity [46]. Based on this assumption, the budget of R&D expenditure that is link with environmental features should be considered, but the literature is characterized by lack of data on this subject.

One of the most shocking results were presented between the link of economic growth and green energy productivity. The results are statistical significantly and suggest that an increase with one percentage point in the GDP growth creates less green energy productivity (GEP). The decrease is between 1.37 and 1.81 thousand tonnes of oil equivalent in green energy productivity. The results prove that even though green development is set as a target at European Union level, countries do not create their economic growth based on green energy, rather on traditional sources. Based on this, it can be emphasized that sustainable development is not yet achieved for European Union. The value added in these countries, is thus, created by traditional sources rather than renewable ones. The results are in line with the findings of reference [43], who suggests that an increase in the GDP per capita decreases sustainable development. Other research studies, such as the one conducted by reference [47], reveal that changes in the Pearl River Delta Metropolitan Region from China in terms of growth in energy productivity are negatively affected by GDP per capita. Based on this, it seems that both traditional energy productivity and the green energy productivity have a negative relationship with GDP and its components. Moreover, in a research conducted by the reference [5], it is emphasized that inequitable economic growth trajectory of OECD countries creates disparities in energy consumptions and implies disparities in terms of unequal distribution of renewable energy productivity across these countries.

Another negative correlation is found between the increases with one percentage point in the Proportion of seats held by women in national parliaments express in % (XSW). The relationship provides evidence that the green energy productivity (GEP) reduces with 0.24 thousand tonnes of oil equivalent. The results could be explained by the fact that the inclusion of women in parliaments is not related with their inclusion in cabinets and being part of the group of policy makers. According to the European Institute for Gender Equality [48], only eight national parliaments at European level (Austria, Croatia, Denmark, Finland, Ireland, the Netherlands, Portugal, and Slovakia) have rules

 doi:10.20944/preprints202605.0324.v1

related with the requirement of gender impact assessment of legislative proposals. Moreover, there are also states where the national assessments are not undertaken by the parliament. As a consequence of this, it is less likely that women can have significance positive effect on green energy productivity at the European level, thus the results are related with the actual European Situation.

Another correlation is between the Domestic credit to private sector (% of GDP (XDCPS) and green energy productivity (GEP). The results reveal a positive and statistically significant effect on green energy productivity. An increase with one percentage point in Domestic credit to private sector (% of GDP (XDCPS) creates an increase in green energy productivity (GEP) between 0.12 and 0.15 thousand tonnes of oil equivalent. The results are in line with the research conducted by reference [9] on 23 Asian economies who reveal that bank credit given to private sector increases the renewable energy productivity. The results are opposing the one found by reference [49], who showed that the financial development is insignificant related to renewable energy transition in the case of countries with higher development level.

The total greenhouse gas emissions including LULUCF (t CO2e/capita (GHG_WITH_LULUCF) were expected to have a negative correlation with energy productivity. The data reveal that an increase with one t CO2e/capita, created a decrease of 0.0067 thousand tonnes of oil equivalent in green energy productivity. The result reveals that economic growth is more focus on traditional measures rather than renewable ones.

Another negative correlation is related with the Share of energy from renewable sources (%) (XER)). A change with one percentage point in the Share of energy from renewable sources (%) (XER) decreases green energy productivity (GEP) between 1.22 and 3.45 thousand tonnes of oil equivalent. The reference [50] reveal that renewable sources are environmentally favorable, but the problem with them is related with their inherent instability. The energy shortages need to be balanced by other sources. Moreover, reference [51] emphasizes the problems with renewable energies: some of them such as solar or wind energy are inherently unstable because their production is linked with weather conditions. These should lead to the development of energy storage technologies, as the reference [52] reveal the negative correlation between energy from renewable sources and energy productivity pointing out the need for further innovations developments that decrease the costs of renewable sources. Based on this, unless advanced technologies related with energy's storage and sustainable development are going to be created, the green energy productivity cannot be improved. On the other side, the research conducted by the reference [53] pointed out the negative relationship between energy productivity and the use of renewable energy**.** Their results are confirmed by the Granger causality results found in the analysis (based on Dumitrescu and Hurlin test [54]) that reveal a bidirectional relationship between energy productivity and share of renewable sources, while the Granger causality provides only one direction relationship from Share of energy from renewable sources (%) XER to green energy productivity (GEP).

The last variable that has a negative impact in green energy productivity, in terms of the value of the coefficient, is primary energy consumption. The results reveal that an increase with 1% in primary energy consumption creates a decrease in green energy productivity (GEP) between 1.92 and 3.05 thousand tonnes of oil equivalent. The study of reference [50] splits primary energy consumption in its sources and clusters European Union's countries by them for 2021 year. At such, countries like Austria, Croatia, Germany, Greece, Hungary, Italy, Ireland, Lithuania, Malta, The Netherlands, Portugal, Romania, and Spain focus on oil energy (38%), natural gas energy (32%) and renewable energy (around 20%). Other countries, such as Belgium, Bulgaria, Czech Republic, France, Slovenia and Slovakia focus on oil sources (27%), nuclear sources (24%) and gas sources (19%), while renewable energy is around 13%. Luxembourg and Cyprus have 77% oil energy sources and 12% from renewable ones. Denmark, Finland, Latvia, and Sweden mainly focus on renewable energy sources (51%) and oil sources (28%). Among European countries, Poland focuses on fossil oils (41%), oil sources (31%) and renewable sources (19%), while Estonia uses around 60% from oil sources and 29% from renewable ones. Based on this, the effect of primary energy consumption on total value

 doi:10.20944/preprints202605.0324.v1

added created by green energy is negative, as most European member states still focus on traditional energy sources rather than renewable ones.

Regarding the positive results, one challenging situation is the link between the diversity index and green energy productivity. The results of aur analysis reveal that an increase or a decrease of diversity index creates an increase or a decrease in green energy productivity. That means that less diversification encourages more green energy productivity. The results are related with the study conducted by reference [55], who showed significant disparities in energy productivity between EU countries. They reveal that Western countries do have a high level of energy productivity, while in central and eastern countries the rate increased. Moreover, reference [56] point out that there is high diversity in the energy supply security on EU countries based on how they can rely on available energy infrastructure, energy resource endowments and the market integration levels. Thus, the Czech Republic seems to be the best in terms of energy security and diversification, followed by Belgium, while Sweden is one of the worst as it has high dependency on energy imports of natural oil. The problem with this indicator is that it presents variety in countries' energy sources, but it does not make a difference if the country has more or less renewable sources than other countries.

The correlation between the changes in energy price and the changes in green eenrgy productivity is also statistically significant. The results reveal that changes in energy price with 1 dollar in real values would increase green energy productivity (GEP) between 0.04 and 0.09 thousand tonnes of oil equivalent. The results of the study is in line with the research conducted by reference [57] who revealed that a 10% increase of the average energy prices of the previous five years results in a 2.7% increase in green innovations and 4.5% increase in the number of green innovations to total innovation. The reference [58] reveal the challenges that European countries have related with high energy prices. While states have adopted several fiscal and budgetary measures to protect both their households and industries from the consequences of high and volatile energy prices, the authors point out the need of EU countries to adopt clean technologies and to improve the industry's energy efficiency by using decarbonized energy technologies. Moreover, reference [59] reveals that expending green technologies affects in a positive way the GDP, the employment and the industries, producing inputs which could be bought by green products producers. Thus, production in one country could impact positively production in other countries generating high green value added.

Regarding environmental and energy variables, positive correlation was found between them. As a fact, an increase with one percentage point in the Total energy taxes in GDP (%) (XET) generates an increase between 1.22 and 3.39 thousand tonnes of oil equivalent of green energy productivity (GEP). Moreover, an increase with one percentage point in Total environmental taxes in GDP (%) (XENVT) generates an increase between 4.26 and 6.52 thousand tonnes of oil equivalent in green energy productivity (GEP. Significant and high effect on the increase of green energy productivity seems to have both Total taxes on pollution/resources in GDP (%) (XTP) and Total transport taxes in GDP (%) (XTT). While the increase with one percentage point in Total transport taxes in GDP (%) (XTT) creates an increase of green energy productivity between 11.24 and 11.68 thousand tonnes of oil equivalent, an increase with one percentage point in Total taxes on pollution/resources in GDP (%) (XTP) impacts positively the green energy productivity with 19.64 thousand tonnes of oil equivalent. The relationship is reliable if we take into account a decrease of all these variables. All these results are in line with other research papers. Reference [60] studied the impact of Energy tax revenues, Transport tax revenues, Pollution tax revenues and Resource tax revenues on GDP per capita on European Union from 2013 to 2022. Their results provide long run relationship on economic development, while on short run, effects vary by tax type and country. All variables do have positive effect on GDP per capita, even though the relationship between pollution tax revenues and GDP per capita was not statistically significant. The authors also point out the delayed benefits of energy taxation. Moreover, Transport tax revenues and Pollution tax revenues have significant effect in the long run on GDP per capita, as pollution taxes were found in having the largest effect, highlighting its importance for resource-dependent economies (similar with our research). Moreover, our results are similar with the study conducted by reference [61] on OECD countries, who point out that green

 doi:10.20944/preprints202605.0324.v1

energy adoption together with economic growth and technological innovation can encourage sustainable development, and thus the creation of value added by green energy sources.

Other positive results were found between changes in Ratio of female to male labor force participation rate (%) (XLF) and changes in green energy productivity (GEP). The results reveal that an increase or a decrease with one percentage point in Ratio of female to male labor force participation rate (%) (XLF) creates an increase or a decrease in green energy productivity between 0.27 and 0.3 tonnes of oil equivalent. The results are in line with the research conducted by reference [9], who proved direct correlation between labor force participation and green energy productivity. The result suggest that as female force increases they can also have decision position into a company and thus, that they can rely on green products. The results are in line with the research conducted by reference [62], who reveal that higher female labor force participation significantly boosts economic, social, and environmental development worldwide.

The last significant positive effect is between the changes in Labor force with advanced education as % of total working-age population with advanced education (XLTE) and the level of green energy productivity (GEP). The results reveal that an increase or a decrease with one percentage point in the Labor force with advanced education as % of total working-age population with advanced education (XLTE) creates an increase or a decrease in green energy productivity between 1.03 and 1.05 tonnes of oil equivalent. The results are in line with other research papers as education can drastically increase economic growth [63], and it contributes to green growth by improving technological advancement and public awareness [64]. Based on this, a study [65] conducted on G7 nations revealed the favorable effect of education on green growth.

While the results on GDP growth variable on green energy productivity are challenging, it is important to present the cumulative effect of GDP growth and environmental or energy variables on green energy productivity. The results are both presented in **Tables 8** and **9**.

Table 8. The combine effect of environmental and energy variables with GDP growth on green energy productivity expressed in real values.

Dependent variable D_GEP_REAL								
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 4b**	**Model 5**	**model 5b**	**Model 6**
Constant	-15.7435 ***	-9.8340 ***	-11.7936 ***	-4.2028 ***	-5.0264 ***	-3.5972 (p=0.1081)	-4.9127 *	-12.6346 ***
GDP_GROWTH		-2.2147 ***	-3.4264 ***	-1.9915 ***	-2.1785 ***	-1.7254 ***	-2.4174 ***	-4.0881 ***
D_XER	0.6021 ***							
D_XET								
D_XTP						16.9815 *		
D_XTT				4.5833 **				
D_GHG_WITH_LULUCF								
GDP_GROWTH*D_XENVT		1.5328 ***						

GDP_GROWTH*D_XER	-0.6353***							
GDP_GROWTH *D_XET			-0.0059 (p=0.9250)					
GDP_**GROWTH** *D_XTP						6.8823**	8.6857***	
GDP_GROWTH *D_XTT				3.3030***	4.0863***			
GDP_GROWTH * D_GHG_WITH_LULUCF								-0.0085***
R-squared	34.74 %	38.50 %	50.92 %	23.44 %	22.72 %	16.17 %	25.92 %	54.32 %
F-statistic	114.21***	134.30***	222.55***	43.692***	63.071***	27.53***	75.07***	255.17***
Durbin-Watson	2.07	2.01	2.1	1.82	1.88	1.86	1.9	2.01
Kurtosis	7.2	9.62	7.13	21.97	19.4	20.24	13.98	9.78
Skewness	-0.48	-0.53	-0.32	-1.82	-1.65	-2.07	-1.47	-0.07
Breusch-Pagan LM cross dependence test	318.48 (p=0.8929)	292.67 (p=0.9897)	323.4308 (p=0.8517)	466.186***	437.92***	393.17*	336.87 (p=0.6968)	342.065 (p=0.6236)

Source: own computation, using Eviews 9, 2026. Note: D_GEP_REAL isgreen energy productivity in real values, GDP_GROWTH is GDP growth (annual %), GHG_WITH_LULUCF is Total greenhouse gas emissions including LULUCF (t CO2e/capita), XENVT is Total environmental taxes in GDP (%), XER is Share of energy from renewable sources (%), XET is Total energy taxes in GDP (%),XTP is Total taxes on pollution/resources in GDP (%), XTT is Total transport taxes in GDP (%), XURP is Urban population (% of total population),), d_variable reveals the first difference for attending stationary.

Table 9. The combine effect of environmental and energy variables with GDP growth on green energy productivity expressed in purchasing power parity.

Dependent variable D_GEP_PPS								
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 4b**	**Model 5**	**model 5b**	**Model 6**
Constant	-16.668***	-8.9712***	-11.504***	-5.2953***	-6.608***	-3.5409*	-4.3063*	-11.867***
GDP_GROWTH		-1.1717***	-2.3108***	-1.0533**	-1.267**	-0.9935**	-1.509**	-2.5222***
D_XER	-0.1470 (p=0.4357)							
D_XET								

 doi:10.20944/preprints202605.0324.v1

D_XTP						15.4508**		
D_XTT				2.5536 (p=0.1969)				
D_GHG_WITH_LULUCF								
GDP_GROWTH*D_XENVT		1.3533***						
GDP_GROWTH*D_XER	-0.5531***							
GDP_GROWTH *D_XET			-0.00167 (p=0.9679)					
GDP_GROWTH *D_XTP						6.8326***	8.1668***	
GDP_GROWTH *D_XTT				3.6079***	4.3525***			
GDP_GROWTH * D_GHG_WITH_LULUCF								-0.0073***
R-squared	37.16 %	31.39 %	36.52 %	17.55 %	18.47 %	13.80 %	21.35 %	35.95 %
F-statistic	126.88***	98.18***	123.44***	30.371***	48.605***	22.84***	58.249***	120.40***
Durbin-Watson	2.08	1.96	2.07	1.79	1.85	1.84	1.92	1.98
Kurtosis	6.44	8.87	6.85	18.5	15.54	17.59	12.28	9.36
Skewness	-0.33	-0.54	-0.39	-1.35	-1.17	-1.63	-1.31	-0.31
Breusch-Pagan LM cross dependence test	300.151 (p=0.9770)	309.828 (p=0.9443)	339.506 (p=0.6603)	503.92***	495.48**	413.53**	356.016 (p=0.4154)	349.46 (p=0.5131)

Source: own computation, using Eviews 9, 2026. Note: D_GEP_PPS is green energy productivity in purchasing power values, GDP_GROWTH is GDP growth (annual %), GHG_WITH_LULUCF is Total greenhouse gas emissions including LULUCF (t CO2e/capita), XENVT is Total environmental taxes in GDP (%), XER is Share of energy from renewable sources (%), XET is Total energy taxes in GDP (%),XTP is Total taxes on pollution/resources in GDP (%), XTT is Total transport taxes in GDP (%), XURP is Urban population (% of total population),), d_variable reveals the first difference for attending stationary.

From **Table 8 and Table** 9, we can suggest several conclusions: economic growth still affects negatively the green energy productivity, but countries that look at green policies and that focus their development on them, do have an increase in the green energy productivity. The data presented reveal same statistical significance in terms of independent variables either the analysis was conducted on green energy productivity express in real values or green energy productivity expressed in purchasing power parity.

The results reveal that a change with one percentage point in Total environmental taxes in GDP (%) (XENVT) cumulated with sustainable economic growth leads to an increase in green energy

 doi:10.20944/preprints202605.0324.v1

productivity with 1.53 thousand tonnes of oil equivalent if is expressed in real values, and with 1.35 of Thousand tonnes of oil equivalent if it is expressed in purchasing power parity.

Other positive results are related with the change with one percentage point in Total taxes on pollution/resources in GDP (%) (XTP) and Total transport taxes in GDP (%) (XTT), together with sustainable growth. The results on cumulative effect of Total taxes on pollution/resources in GDP (%) (XTP) and economic growth (GDP_GROWTH) provide evidence that the green energy productivity increases between 6.88 and 8.68 thousand tonnes of oil equivalent when we talk about real values and with 6.83 and 8.16 thousand tonnes of oil equivalent when purchasing power parity variable is analyzed. Regarding the effect of Total transport taxes in GDP (%) (XTT) combined with economic growth it seems that green energy productivity increases between 3.3 and 4.08 thousand tonnes of oil equivalent when we consider real values and with 3.6 and 4.35 thousand tonnes of oil equivalent when purchasing power parity of green energy productivity is emphasized. All these results are in line with the study conducted by reference [61] on OECD countries who point out that green energy adoption together with economic growth and technological innovation can encourage sustainable development, and thus the creation of value added by green energy sources.

While the change with one percentage point in the share of Total energy taxes in GDP (XET) creates more real green energy productivity between 1.22 and 3.39 thousand tonnes of oil equivalent, the combine effect with the economic growth is not statistically significant. Moreover. The effect seems to be negative suggesting that countries cannot have sustainable growth cumulated with energy policies. As a fact, the environmental policies cumulated with sustainable growth can lead to improvement in green energy productivity. The results are in line with reference [66], who pointed out that pollution control investment significantly improve green total factor productivity. Moreover, the environmental regulation can improve the total green factor productivity, but it has to be combined with technological innovations [67].

Moreover, if countries focus on economic growth based on traditional methods that imply increase in the level of Total greenhouse gas emissions including LULUCF (Mt CO2e), the effect on green energy productivity is negative both in real values and in purchasing power parity. It decreases with 0.0085 thousand tonnes of oil equivalent, respectively with 0.0073 thousand tonnes of oil equivalent. This result sustains the conclusion found by reference [68] on BRICS countries, revealing that policymakers should combine the productivity of resources used, with long run economic growth and environmental sustainability in order to achieve green energy value added and environmentally sustainable economic growth. The result also emphasizes the importance of Energy tax revenues, Transport tax revenues, Pollution tax revenues on future development being in line with the research conducted by reference [60].

The most confusing results are related with the cumulated effect of Share of energy from renewable sources (%), (XER) with economic growth. While results in terms of the change with one percentage point in the share of energy from renewable sources (%) (XER) are mixed (both positive and negative) on green energy productivity, the combine effect reveals that green energy productivity decreases both in real values and purchasing power parity. The results emphasize that the EU countries do not focus their economic growth on new and green technologies, thus, the green value added of these countries are insignificant. The results are similar with the research presented by references [52,53], pointing out the negative correlation between energy from renewable sources and energy productivity pointing out the need for further innovations developments, such as advanced technologies related with energy's storage and sustainable development that decrease the costs of renewable sources and creates more green value added.

5. Conclusions

The present research aimed to find the factors that can affect the value of green energy productivity at European level. The analysis was conducted on 27 states of the European Union, and the data is taken from 2007 to 2023. The analysis consisted of two parts: the first one revealed the findings of bibliometric analysis in terms of green energy productivity pointing out the need to

 doi:10.20944/preprints202605.0324.v1

address this subject, while the second one conducted estimation of financial data and provides to reveal impact of economic, social, environmental and energy variables.

The results of the analysis reveal how the hypothesis of research were reliable or not.

First of all, looking at H1, the economic variables, outside the Domestic credit to private sector (% of GDP (XDCPS), decrease the green energy productivity, making it partially false. The results reveal that either economic growth (measured through GDP growth) or R&D expenditure in GDP (even if is not statistically significant) are linked with using traditional sources and they do not emphasize the need of sustainable development. The results reveal disparities among the EU countries in terms of use and utility of renewable sources. Also, the findings suggest that the EU countries should focus more on green advance technologies that can generate green growth and green energy productivity. On the other side, the increase with one percentage point in the Domestic credit to private sector (% of GDP (XDCPS) suggests that private sector takes loans in order to invest in green development of their entities and try to adapt to EU regulation. On the other side, their effect should be combined to industrial policies and sustainable development.in order to encourage high values of green energy productivity.

In terms of social variable, only Ratio of female to male labor force participation rate (%) (XLF), Labor force with advanced education as % of total working-age population with advanced education (XLTE) affect positively the green energy productivity. The results provide signal that education can increase green growth by improving technological advancement and public awareness. Moreover, as female force increases they can also have decision position into companies and thus, that they can rely on green products.

The Proportion of seats held by women in national parliaments express in % (XSW) and the Urban population (% of total population (XURP) makes H2 to be somehow doubtful. Their negative effect (although urban population's coefficient was not statistically significant) suggests that the growth of cities is still ensured by traditional resources- the increase of the urban population's needs cannot be satisfied with green products, while women in parliaments do not have right of decision on green growth.

The variables related with traditional sources (primary energy consumption (PEC), energy price (EP) and Total greenhouse gas emissions including LULUCF (t CO2e/capita (GHG_WITH_LULUCF)) did decrease the value of green energy productivity, making H3 true, which suggest that the economies should focus more on green technologies.

Beside the share of Total energy taxes in GDP (%) (XET), all other variables (Diversity index of energy supply (DIVERSITY_INDEX), Share of energy from renewable sources (%) (XER) have a negative impact on green energy productivity. Based on this, we can conclude that unless advanced technologies related with energy's storage and sustainable development are going to be created, the green energy productivity cannot be improved.

The implementation of green policies (Total environmental taxes in GDP (%) (XENVT), Total taxes on pollution/resources in GDP (%) (XTP), Total transport taxes in GDP (%) (XTT)- together with the implementation of Total energy taxes in GDP (%) (XET) makes H5 more reliable suggesting that sustainable and green growth can be ensured at EU economic level. The main problem with them is their small percentage related to GDP and their increase by one percentage point.

Based on this, the robustness analysis suggests that green energy adoption together with economic growth and technological innovation can encourage sustainable development at EU level.

The research contributes to the value added of the literature in both ways: by presenting a bibliometric analysis of literature review on green energy productivity and by pointed out the need to combine the productivity of resources used, with long run economic growth and environmental sustainability in order to achieve green energy value added and environmentally sustainable economic growth.

Author Contributions: Conceptualization, A.Z. and L.B.; methodology, A.Z. and L.B.; software, L.B.; validation, A.Z., L.B. and G.O.C.; formal analysis, A.Z. and L.B.; investigation, A.Z., L.B., M.B.P, I.O.C. and G.O.C.; data

 doi:10.20944/preprints202605.0324.v1

curation, L.B.; writing—original draft preparation, A.Z., L.B. and G.O.C.; writing—review and editing, A.Z., L.B., M.B.P, I.O.C. and G.O.C.; visualization, A.Z. and L.B.; supervision, A.Z.; project administration, A.Z.; funding acquisition, M.B.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Acknowledgments: During the preparation of this study, the authors used VOSviewer software, version 1.6.18, for the purposes of word-cluster analysis, and EViews 9 for the purposes of econometric analyses. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

GEP	Green energy productivity
REP	Renewable energy productivity
SDG	Sustainable development goal
GDP	Gross domestic product
EU	European Union

References

1. Aydin, M., Degirmenci, T., Ahmed, Z., & Apergis, N. (2025). Do the energy taxes, green technological innovation, and energy productivity enable the green energy transition in EU countries? Evidence from novel panel data estimators. *Renewable Energy*, 249, 123236. https://doi.org/10.1016/j.renene.2025.123236
2. Çetin, M., Sümerli Sarıgül, S. & Danish The green growth-CO2 emissions link in G7 countries: the role of energy productivity. *Int. J. Environ. Sci. Technol*. 22, 6095–6108 (2025). https://doi.org/10.1007/s13762-024-06097-3
3. Erdem, A., Okoth, E., Demirtas, N., Sogut, Y., & Erdogan, S. (2026). Do fiscal policies, energy productivity, and renewable energy generation contribute to environmental sustainability in EU countries? Evidence from new panel data estimators. *Renewable Energy*, 125453. https://doi.org/10.1016/j.renene.2026.125453
4. [UN] United Nations. 2015. "Transforming our world: the 2030 Agenda for sustainable development." Resolution adopted by the General Assembly on 25 September 2015, *A/RES/70/1*. Accessed April 10th, 2026. https://docs.un.org/en/A/RES/70/1
5. Zhao, J., Sinha, A., Inuwa, N., Wang, Y., Murshed, M., & Abbasi, K. R. (2022). Does structural transformation in economy impact inequality in renewable energy productivity? Implications for sustainable development. *Renewable Energy*, 189, 853-864. https://doi.org/10.1016/j.renene.2022.03.050
6. Yıldırım, M.Ş., Baycan, I.O. (2023). Analyzing the effects of energy productivity: the case of European Union countries. *Environ Sci Pollut Res* 30, 117519–117530. https://doi.org/10.1007/s11356-023-30516-6
7. Atalla, T., & Bean, P. (2017). Determinants of energy productivity in 39 countries: An empirical investigation. *Energy Economics*, 62, 217-229. https://doi.org/10.1016/j.eneco.2016.12.003
8. Yılmaz, G., & Daşdemir, E. (2020). Renewable Energy Use and Energy Productivity: A Panel Data Analysis. *Journal of Sustainable Economics and Management Studies*, 1(1), 73-82. https://izlik.org/JA45DU64CE
9. Aggarwal, S., & Mahalik, M. K. (2026a). The influence of domestic bank credit and FDI inflows on renewable energy productivity: an analysis of developing Asian economies. *Asia-Pacific Financial Markets*, 33(1), 95-118. https://doi.org/10.1007/s10690-024-09502-6
10. Yaman, H. (2026). Measuring renewable energy productivity in EU countries with the Hicks-Moorsteen index. *Journal of Polytechnic - Politeknik Dergisi*, 29(4):290406:1-7. https://doi.org/10.2339/politeknik.1438535
11. Soto, G.H. (2024). Long run renewable energy productivity, carbon capture patents and air quality in Taiwan. *Journal of Environmental Management*, 351, 119925. https://doi.org/10.1016/j.jenvman.2023.119925

12. Aggarwal, S., & Mahalik, M. K. (2025). The nexus of urbanization and renewable energy productivity: implications for sustainable development in developing Asia nations. *International Journal of Energy Sector Management*, 19(6), 1406-1426. https://doi.org/10.1108/IJESM-08-2024-0037
13. Yang, X., Zhou, H., & Gao, J. (2025). Enhancing renewable energy productivity and energy efficiency of energy projects: How does cost of capital influence?. *Energy Strategy Reviews*, 57, 101608. https://doi.org/10.1016/j.esr.2024.101608
14. Shahbaz, M., Eti, S., Yüksel, S., Dinçer, H., & Çırak, A. N. (2026). A multi-criteria decision-making framework for enhancing renewable energy productivity. *Renewable Energy*, 124990. https://doi.org/10.1016/j.renene.2025.124990
15. Clarivate (2026). Web of Science Core Collection. Accessed through the institutional platform: e-nformation.ro. Accessed in March 2026 at https://0410qmas3-y-https-www-webofscience-com.z.e-nformation.ro/wos/woscc/summary/027ee839-81be-445a-af69-6670c086ad40-01b02b4903/relevance/1
16. Elsevier, BV (2026). Scopus. Accessed through the institutional platform: e-nformation.ro. Accessed in March 2026 at https://04109mas2-y-https-www-scopus-com.z.e-nformation.ro/results/results.uri?st1=%22green+energy+productivity%22+OR+%22renewable+energy+productivity%22+OR+%22productivity+of+re-newable+energy%22+OR+%22productivity+of+green+energy%22&st2=&s=TITLE-ABS-KEY%28%22green+energy+productivity%22+OR+%22renewable+energy+productivity%22+OR+%22productivity+of+renewable+energy%22+OR+%22productivity+of+green+energy%22%29&limit=10&origin=searchbasic&sort=plf-f&src=s&sot=b&sdt=b&sessionSearchId=88bf1168f7f58e86bbb2d71e1bb5ac32
17. Pranckutė, R. (2021). Web of Science (WoS) and Scopus: The titans of bibliographic information in today's academic world. *Publications*, 9(1), 12. https://doi.org/10.3390/publications9010012
18. Wouters, P.; Thelwall, M.; Kousha, K.; Waltman, L.; de Rijcke, S.; Rushforth, A.; Franssen, T. The Metric Tide: Literature Review (Supplementary Report I to the Independent Review of the Role of Metrics in Research Assessment and Management); HEFCE: Bristol, UK, 2015. DOI:10.13140/RG.2.1.5066.3520
19. Google, Inc. (2026). Google Scholar. Accessed in March 2026 at https://scholar.google.com/scholar?start=20&q=allintitle:+%22green+energy+productivity%22+OR+%22renewable+energy+productivity%22+OR+%22productivity+of+renewable+energy%22+OR+%22productivity+of+green+energy%22&hl=en&as_sdt=0,5&as_vis=1
20. Van Eck, N.J., & Waltman, L. (2022). VOSviewer (Version 1.6.18) [Computer Software]. Leiden, The Netherlands: Leiden University, Centre for Science and Technology Studies (CWTS). Available from https://www.vosviewer.com/download
21. Van Eck, N.J., & Waltman, L. (2011). Text mining and visualization using VOSviewer. ISSI Newsletter, 7(3), 50-54. https://doi.org/10.48550/arXiv.1109.2058
22. Van Eck, N.J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523-538. https://doi.org/10.1007/s11192-009-0146-3
23. Orlov, A., Sillmann, J., & Vigo, I. (2020). Better seasonal forecasts for the renewable energy industry. *Nature Energy*, 5(2), 108-110. https://doi.org/10.1038/s41560-020-0561-5
24. Cevik, E. I., Yıldırım, D. Ç., & Dibooglu, S. (2021). Renewable and non-renewable energy consumption and economic growth in the US: A Markov-Switching VAR analysis. *Energy & Environment*, 32(3), 519-541. https://doi.org/10.1177/0958305X20944035
25. Cui, Q., He, L., Han, G., Chen, H., & Cao, J. (2020). Review on climate and water resource implications of reducing renewable power curtailment in China: A nexus perspective. *Applied Energy*, 267, 115114. https://doi.org/10.1016/j.apenergy.2020.115114
26. Park, G. L., Schäfer, A. I., & Richards, B. S. (2013). Renewable energy-powered membrane technology: Supercapacitors for buffering resource fluctuations in a wind-powered membrane system for brackish water desalination. *Renewable Energy*, 50, 126-135. https://doi.org/10.1016/j.renene.2012.05.026
27. Mandal, K. G., Hati, K. M., & Misra, A. K. (2009). Biomass yield and energy analysis of soybean production in relation to fertilizer-NPK and organic manure. *Biomass and Bioenergy*, 33(12), 1670-1679. https://doi.org/10.1016/j.biombioe.2009.08.010

28. Aggarwal, S., & Mahalik, M. K. (2026b). The role of urbanization in fossil fuel demand of developing Asian economies: understanding the moderating effect of renewable energy productivity. *International Journal of Ambient Energy*, 47(1), 2623005. https://doi.org/10.1080/01430750.2026.2623005
29. Lin, B., & Zhang, A. (2025). Digital finance and total factor productivity of renewable energy enterprises: role of capital reallocation and supply chain optimization. *Applied Economics*, 1-16. https://doi.org/10.1080/00036846.2025.2577971
30. Yan, X., & Raza, M. Y. (2025). Decoupling the traded coal and its factors under the sustainable energy changeover in South Korea. *International Journal of Coal Preparation and Utilization*, 1–21. https://doi.org/10.1080/19392699.2025.2498514
31. Eurostat, Simplified energy balances, Gross available energy - renewables and biofuels, https://ec.europa.eu/eurostat/databrowser/view/nrg_bal_s__custom_21284519/default/table, 15 of January 2026. https://doi.org/10.2908/NRG_BAL_S
32. Eurostat, Gross domestic product (GDP) and main components (output, expenditure and income) - annual data, https://ec.europa.eu/eurostat/databrowser/view/nama_10_gdp/default/table?lang=en, 15 of January 2026. https://doi.org/10.2908/NAMA_10_GDP
33. Eurostat, Diversity index of energy supply, https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_di/default/table?lang=en, 15 of January 2026. https://doi.org/10.2908/NRG_IND_DI
34. US Energy Information Administration. Petroleum & Other Liquids. Spot Prices. Brent - Europe. https://www.eia.gov/dnav/pet/pet_pri_spt_s1_a.htm. 17 of January 2026.
35. World Bank Group. DataBank. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators. 16 of January 2026.
36. Eurostat, Primary energy consumption, https://ec.europa.eu/eurostat/databrowser/view/sdg_07_10/default/table?lang=en, 15 of January 2026. https://doi.org/10.2908/SDG_07_10
37. Eurostat, Environmental tax revenues, https://ec.europa.eu/eurostat/databrowser/view/env_ac_tax/default/table?lang=en, 15 of January 2026. https://doi.org/10.2908/ENV_AC_TAX
38. Eurostat, Share of energy from renewable sources, https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ren/default/table?lang=en, 15 of January 2026. https://doi.org/10.2908/NRG_IND_REN
39. Çoban, S., & Topcu, M. (2013). The nexus between financial development and energy consumption in the EU: A dynamic panel data analysis. *Energy Economics*, 39, 81-88. https://doi.org/10.1016/j.eneco.2013.04.001
40. Moon, H. R., Perron, B., & Phillips, P. C. B. (2006). On the Breitung test for panel unit roots and local asymptotic power. *Econometric Theory*, 22(6), 1179-1190. http://mapageweb.umontreal.ca/perrob/breitung.pdf
41. Mushtaq, M., Ahmed, S., Abbas, A., & Fahlevi, M. (2024). Impact of urbanization on environmental eminence: Moderating role of renewable energy. *International Journal of Energy Economics and Policy*, 14(2), 244-257.
42. Tranoulidis, A., & Farmaki, P. (2026). Long-Run Relationships Between Economic Growth, Urbanization, Renewable Energy, and CO2 Emissions in Greece. *Energies*, 19(4), 907. https://doi.org/10.3390/en19040907
43. Zeng, Q., Li, C., & Magazzino, C. (2024). Impact of green energy production for sustainable economic growth and green economic recovery. *Heliyon*, 10(17). https://doi.org/10.1016/j.heliyon.2024.e36643
44. Zhu, J., Huang, Z., Li, Z., & Albitar, K. (2021). The impact of urbanization on energy intensity—an empirical study on OECD countries. *Green Finance*, 3(4), 508-526. doi: 10.3934/GF.2021024.
45. Bergougui, B., Ghosh, S., Doğan, B., Samour, A., & Nepal, R. (2026). When does High-Tech research investment enable green energy Transition?. *Energy Conversion and Management*: 30, 101598. https://doi.org/10.1016/j.ecmx.2026.101598
46. Egli, F. (2020). Renewable energy investment risk: An investigation of changes over time and the underlying drivers. *Energy Policy*, 140, 111428. https://doi.org/10.1016/j.enpol.2020.111428

47. Liu, W., Zhan, J., Zhao, F., Wang, P., Li, Z., & Teng, Y. (2018). Changing trends and influencing factors of energy productivity growth: A case study in the Pearl River Delta Metropolitan Region. *Technological Forecasting and Social Change*, 137, 1-9. https://doi.org/10.1016/j.techfore.2018.09.027
48. European Institute for Gender Equality (2024). Gender Mainstreaming. Gender equality in the European Parliament and in national parliaments in the European Union ahead of the 2024 election year. Luxembourg: Publications Office of the European Union. ISBN 978-92-9486-246-4 doi:10.2839/558434.
49. Ma, X., & Mao, Q. (2025). Can Financial Development Promote Renewable Energy Transition? An Empirical Research Based on Global Panel Data. *Sustainability*, 17(20), 9270. https://doi.org/10.3390/su17209270
50. Kosowski, P., Kosowska, K., & Janiga, D. (2023). Primary Energy Consumption Patterns in Selected European Countries from 1990 to 2021: A Cluster Analysis Approach. *Energies*, 16(19), 6941. https://doi.org/10.3390/en16196941
51. Ang, T. Z., Salem, M., Kamarol, M., Das, H. S., Nazari, M. A., & Prabaharan, N. (2022). A comprehensive study of renewable energy sources: Classifications, challenges and suggestions. *Energy Strategy Reviews*, 43, 100939. https://doi.org/10.1016/j.esr.2022.100939
52. Kolosok, S. I., Myroshnychenko, Y. O., Mishenina, H. A., & Yarova, I. Y. (2021). Renewable energy innovation in Europe: Energy efficiency analysis. *E3S Web of Conferences*. https://www.e3s-conferences.org/articles/e3sconf/pdf/2021/10/e3sconf_icies2020_00021.pdf
53. Soto, G. H., Nghiem, X. H., & Martinez-Cobas, X. (2025). Analyzing the role of main energy transition policies upon renewable energy penetration in the EU: an assessment of energy productivity and low carbon economies. *Environmental and Sustainability Indicators*, 25, 100573. https://doi.org/10.1016/j.indic.2024.100573
54. Dumitrescu, E. I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic modelling*, 29(4), 1450-1460. https://doi.org/10.1016/j.econmod.2012.02.014
55. Grodzicki, T., & Jankiewicz, M. (2024). Energy productivity as a part of the green growth agenda in European Union countries. *Ethics in Science and Environmental Politics*, 24, 89-96. https://doi.org/10.3354/esep00215
56. Streimikiene, D., Siksnelyte-Butkiene, I., & Lekavicius, V. (2023). Energy Diversification and Security in the EU: Comparative Assessment in Different EU Regions. *Economies*, 11(3), 83. https://doi.org/10.3390/economies11030083
57. Ley, M., Stucki, T., & Woerter, M. (2016). The Impact of Energy Prices on Green Innovation. *The Energy Journal*, 37(1), 41-76. https://doi.org/10.5547/01956574.37.1.mley
58. Council of the European Union (2025). REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Report on energy prices and costs in Europe. Brussels, 26 February 2025 (OR. en) 6575/25. *COM(2025) 72 final*. https://data.consilium.europa.eu/doc/document/ST-6575-2025-INIT/en/pdf
59. Guadagno, F., Reiter, O., & Stehrer, R. (2024). The Impact of Green Technologies on GDP and Employment in the EU (No. 80). *Policy Notes and Reports*. https://wiiw.ac.at/the-impact-of-green-technologies-on-gdp-and-employment-in-the-eu-dlp-6918.pdf
60. Kalaš, B., Mirović, V., Bolesnikov, D., Akadiri, S. S., & Radulescu, M. (2025). Environmental Taxes and Sustainable Development in the EU: A Decade of Data-Driven Insights. Systems, 13(7), 503. https://doi.org/10.3390/systems13070503
61. Zhao, T., & Shah, S. A. A. (2024). Green Energy, Economic Growth, and Innovation for Sustainable Development in OECD Countries. *Sustainability*, 16(22), 10113. https://doi.org/10.3390/su162210113
62. Nawarathna, C. L. K. (2025). Female Labor Force Participation and Sustainable Development: A Global Study. *International Journal of Research and Innovation in Social Science*. 2417-2438. https://rsisinternational.org/journals/ijriss/articles/female-labor-force-participation-and-sustainable-development-a-global-study/ https://dx.doi.org/10.47772/IJRISS.2025.905000188

 doi:10.20944/preprints202605.0324.v1

63. Agasisti, T., & Bertoletti, A. (2022). Higher education and economic growth: A longitudinal study of European regions 2000–2017. *Socio-Economic Planning Sciences*, 81, 100940. https://doi.org/10.1016/j.seps.2020.100940
64. Liu, D., Wang, G., Sun, C., Majeed, M. T., & Andlib, Z. (2023). An analysis of the effects of human capital on green growth: effects and transmission channels. *Environmental Science and Pollution Research*, 30(4), 10149-10156. https://doi.org/10.1007/s11356-022-22587-8
65. Durani, F., Abbas, A., Xie, C., Keoy, K. H., Syed, Q. R., & Anwar, A. (2025). Exploring the key role of education in achieving green growth: evidence from group of seven countries. *Humanities and Social Sciences Communications*, 12(1), 1854. https://doi.org/10.1057/s41599-025-06127-6
66. Ren, Y. Research on the green total factor productivity and its influencing factors based on system GMM model. J Ambient Intell Human Comput 11, 3497–3508 (2020). https://doi.org/10.1007/s12652-019-01472-2
67. Chen, C., Lan, Q., Gao, M., & Sun, Y. (2018). Green Total Factor Productivity Growth and Its Determinants in China's Industrial Economy. *Sustainability*, 10(4), 1052. https://doi.org/10.3390/su10041052
68. Zhou, X., Patel, G., Mahalik, M. K., & Gozgor, G. (2024). Effects of green energy and productivity on environmental sustainability in BRICS economies: The role of natural resources rents. *Resources Policy*, 92, 105026. https://doi.org/10.1016/j.resourpol.2024.105026