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The Role of Environmental Regulations, Renewable Energy, and Energy Efficiency in Finding the Path to Green Economic Growth

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Abstract: European Union (EU) countries pay meticulous attention to environmental issues and achieve carbon-free development. In this direction, reducing greenhouse gas emissions and extending renewable energy are the primary goals. At the same time, the energy price and declining energy efficiency increase countries' environmental expenditures and hinder their capabilities for economic growth. Against this backdrop, this research aims to examine the influence of environmental regulations, renewable energy, and energy efficiency on green economic growth. The originality of the study is twofold: first, it evaluates the green economic growth of a country, which simultaneously reveals the options for economic growth and the capability to eliminate its negative effect on the environment by applying the Global Malmquist–Luenberger productivity index; second, it develops an econometric model based on panel data for EU countries for 2000–2020 to investigate the nonlinear impact of environmental regulations, the effect of extending renewable energies, and the growth of energy efficiency on a country's green economic growth. The study applies the following methodology: a system generalized method of moments (GMM) analysis. The empirical results confirm the U-shape, nonlinear impact of environmental regulations on a country's green economic growth along with a gradual increase in energy efficiency. In addition, the findings indicate that renewable energy is crucial for furthering a country's green economic growth. At the same time, environmental regulation has a significant role in extending renewable energy. The study results could be used as the basis for implementing green economic growth for EU countries and improving the policy of carbon-free development of these countries.

Keywords: sustainable development; green economic growth; inclusive growth; green energy

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1. Introduction

Considering the Glasgow Climate Pact, accepted by the experts at the UN Climate Change Conference in Glasgow (COP26), all countries should reorient their policy development from resource intensification to green economic growth [1,2]. Attaining green economic growth simultaneously ensures wellbeing, reduces inequalities and gaps, and eliminates environmental degradation [3,4]. Thus, transformation to carbon-free development is the core catalysator of attaining green economic growth [5]. Notably, green economic growth and sustainable development are closely related and mutually complementary [6]. Both require consolidation of government, business, and society powers. At the same time, green economic growth requires enhancing green policies and regulations [7–9], green entrepreneurship [10,11], attracting green investment [12–15], enlarging green innovation [16–19], enhancing green knowledge, and promoting green awareness [20–26].

Analysis of the theoretical framework on green economic growth allows us to conclude that the efficacy of environmental regulation could restrict or boost the transition into green economic growth [27–30]. The core undesirable results of green economic growth are increasing carbon dioxide emissions, which intensify environmental degradation and restrict green growth. Furthermore, considering [31,32], globalization and economic development lead to increasing energy intensity and final energy consumption. This could, consequently, hinder green economic growth, which could be overcome by extending renewable energy and implementing green technologies and innovations [33–36]. It should be noted that the vast range of scientists [37–39] prove that digitalization and its penetration in all sectors and levels promote green economic growth. This contributes to spreading clean and affordable energy and improving the quality of governance by providing e-governance and enhancing e-business. Prior studies [40,41] have confirmed the assumption that green economic growth cannot be attained without increasing the energy efficiency of a country, which depends on renewable energy extension and requires adequate environmental regulations.

It bears noting that most studies focus on analyzing green economic growth in Asian or OECD countries, and the limited research involves EU countries as an object for analysis within green economic growth and its core dimensions. The EU countries have different levels of development, practices in environmental regulations and values of investments in green innovations, which allows for comparison and identification of best practices. Thus, this study aims to estimate green economic growth and check the impact of environmental regulations, renewable energy, and energy efficiency on it.

This paper contributes to the theoretical framework for assessing green economic growth by identifying its core dimensions (energy efficiency, renewable energy, environmental regulations) for EU countries. This study is original due to developing an approach for assessing the global Malmquist–Luenberger productivity index for estimating green economic growth, which allows consideration of positive and negative production effects on nature. This is crucial for EU countries, which are obliged to fulfill a vast range of national and international environmental obligations and standards. Furthermore, the estimation of green economic growth covered the period of 2006–2020, a time of significant change and development for the European Union (EU). In addition, the period includes several key EU policies and initiatives, including the Europe 2020 strategy for smart, sustainable, and inclusive growth, the Paris Agreement on climate change. This study applies the system generalized method of moments (GMM) to investigate the impact of environmental regulations, renewable energy, and energy efficiency on green economic growth. GMM allows providing dynamic estimation that adjusts heteroskedasticity, serial correlation, and cross-dependence of data. In contrast to other studies that apply static models (random and fixed effects model, ordinary least squares techniques), this approach allows eliminating heterogeneity issues. In addition, using GMM in this study allows accurate results to be obtained, which differs from previous research that was based on static models. The results of this study could be a prerequisite for government policy development and the business community in green economic growth.

The paper has the following structure: (a) Section 2 analyses the theoretical landscape of estimating green economic growth and the effect of energy efficiency, renewable energy, and environmental regulations on green economic growth to justify the research hypotheses; (b) Section 3 describes the data, methods, and instruments for checking the research hypotheses; (c) Section 4 expound the empirical findings obtained by applying the selected methodology; (d) Section 5 develops the core results of the research, its comparison with prior studies, limitations, and further directions of research.

2. Literature Review

2.1. Environmental Regulations and Green Economic Growth

A prior study [42] analyzes the impact of the "resources curse" on the green growth of Chinese cities for 2003–2018 (which was estimated by the Global Malmquist Luenberger (Global ML) index). Based on the results of the difference-in-differences method (DID), the scholars concluded that China could boost green economic growth by providing effective environmental regulations measured by the sulfur dioxide removal rate in the city. In addition, they empirically justify that declining corruption (as the indicator of governance quality) leads to boosting green economic growth. Hou et al. [43] apply Super-SBM techniques to analyze the relationship between income inequality and green economic growth. Based on the empirical results, they confirm that effective environmental regulation can compensate for the negative impact of income inequality on green economic growth. Scholars emphasize that the Chinese government should modernize environmental regulation, which consequently could enhance green economic growth. Pan et al. [44] prove that effective environmental regulations could boost green growth in developing countries that undergo the transformation process. Applying the difference-in-differences method (DID) model, they empirically justify that improving environmental regulations increases green economic growth by 14.2%, and this effect is long term. Li et al. [45] arrive at a similar conclusion on the positive effect of environmental regulation on Chinese green economic growth and confirm the crucial role of green financing in attaining green economic growth. Applying TOPSIS and entropy methods Lin B. and Y. [6] prove the statistically significant impact of environmental regulation on green economic growth in Chinese cities. However, the power of the environmental regulation impact depends on the Chinese regions. The impact of environmental regulation on the green development of China is estimated by means of the Tobit model [46]. Based on the empirical findings, this research confirms that environmental regulation promotes green development in the long term. In addition, Liu et al. [47] empirically prove that environmental regulations restrict the positive impact of digitalization on green economic growth. It is highlighted that the government should provide coherent ecological, financial, and digital policy in the country to attain green economic growth. Luo S. and Zhang S. [48] confirm that green regulation has a statistically significant positive impact on green economic growth. Luo et al. [49] prove the U-shaped effect on the eco-efficiency of China. Scholars emphasize that in the short term, environmental regulation decreases green growth, and in the long term, environmental regulation is conducive to green growth due to enhancing renewable energy and attracting green investment. Similar conclusions on the U-shape relationship between environmental regulations and green economic growth are confirmed by prior studies [50–53]. In addition, scholars [52] outline that improving environmental regulations reduces the negative impact of FDI on the green economic development of China. Song et al. [54] outline that environmental regulation had a mediating effect on the link between digitalization and green economic growth in Chinese provinces in 2011–2019. Based on the results of the symmetric and asymmetric links among green economic growth, green technologies, innovations, and environmental regulations (applying the linear autoregressive distributed lag model (ARDL)), Su and Gao [55] confirm that environmental regulations positively affect green economic growth in the long term. The results of nonlinear autoregressive distributed lag models (NARDL) show that positive changes in environmental regulations have a statistically significant positive impact on green economic growth. At the same time, the negative shock in environmental regulations does not have a statistically significant impact on green economic growth. Considering the abovementioned results, this study aims to test the following hypothesis:

Hypothesis 1. *Environmental regulations have a statistically significant effect on green economic growth.*

2.2. Renewable Energy and Green Economic Growth

Prior studies [56] do not confirm the impact of the "resources curse" on the green growth of China. At the same time, they maintain that renewable energy capabilities boost green economic growth. Luo S. and Zhang S. [48] prove that renewable energies require appropriate environmental regulations that are conducive to green economic growth in Belt and Road countries. Applying FMOLS and DOLS techniques, Ahmed et al. [57] also confirm that extending renewable energy positively contributes to green economic growth in South Asian economies in 2000–2018 and argue that renewable energy reduces the consumption of traditional energy resources and enhances green GDP generation, which contributes to green economic growth. Aimon et al. [58] show that growth of renewable energy by 1% decreases fuel oil consumption by 0.006%, which, consequently, restricts environmental degradation and contributes to green economic growth. At the same time, scholars prove that green economic growth has a negative effect on declining fuel oil consumption. Improving green economic growth by 1% results in a reduction in fuel oil consumption by 0.07%. Cao L. [59] analyzes the impact of renewable energy on the green growth of E7 developing countries in 2005–2018 by applying second-generation panel cointegration techniques, and his findings show the positive link between renewable energy and the green economic growth index with declining carbon dioxide emissions in the long and short run. Renewable energy is emphasized as the core catalysator of carbon dioxide emissions and green growth in the short term in China [60], while requiring sufficient green finance [61–64]. The ARDL model is applied to confirm the hypothesis that the green finance tax rate on energy and green tax revenues from energy taxes positively affect renewable energy, which is the core stimulator of green economic growth in Romania [61]. Similar conclusions are obtained by [65] for South Asian countries and by [66] for ten leaders in green growth (Iceland, Denmark, Netherlands, the United Kingdom, Norway, Finland, France, Germany, Sweden, and South Korea), which confirms the core macroeconomics theory [65,66]. Fang et al. [65] elaborate the ordinary least square model (OLS) to confirm that research and development and industry modernization stimulate green economic growth due to enhancing renewable energies and declining carbon dioxide emissions. The links among green growth, green energy, and green finance in China are analyzed for the period of 2011–2019 [67]. Based on the empirical results, it is concluded that green growth positively affects the spread of green energy, and this impact is heterogeneous and asymmetric. Green innovations play a mediating role in the link between green economic growth and green energy; however, the mediating impact of green finance is not significant. A positive impact of renewable energy on green growth is proven for non-OECD countries [68]. However, for OECD countries, this impact is not statistically significant. Furthermore, Taşkın et al. [69] reported controversial results, confirming the positive contribution of green energy to green economic growth despite the high cost of developing relevant infrastructure for renewable energy in OECD countries for the 1990–2015 period.

Considering the analysis of the theoretical framework on the link between renewable energy impact and green economic growth, this study tests the following hypothesis:

Hypothesis 2. *Renewable energy has a statistically significant effect on green economic growth.*

2.3. Energy Efficiency and Green Economic Growth

Based on the Korean experience, Lee K. [70] stresses that energy efficiency is one of the core and effective drivers that allows carbon dioxide emissions to be reduced to attain green economic growth. Data envelopment analysis (DEA) is used to justify the positive relationship between attaining sustainable development goals and the energy efficiency of 20 Asian and Pacific countries [71]. Applying meta-frontier SBM and DEA (data envelopment analysis), Luo S. and Zhang S. [48] study green economic growth through energy efficiency and confirm that the latter has a positive effect on green economic growth. Lee et al. [5] and Khan et al. [72] empirically justify that improving energy efficiency (due to enlarging renewable energy) is the predictor of green economic growth. In addition, Khan et al. [72] emphasize the impact of the governance effect on extending renewable energy and energy efficacy technologies. Kėdaitienė and Klyvienė [73] prove that improving energy intensity and changing the structure of final energy consumption contribute to the economic growth of EU countries, involving green growth. Lin and Benjamin [74] also confirm the coherent conclusions for Shanghai based on the results of quantile analysis. High energy intensity and energy poverty are shown to decrease green economic growth in West African states [75]. Withal, the spread of green energy allows changes in the structure of final energy consumption. Sun et al. [76] maintain that energy efficiency is the crucial determinant of green economic growth and, based on the analysis of the leaders on energy efficiency (France, Germany, the Netherlands, Switzerland, and the UK), demonstrate that technological innovation and knowledge spillover positively contribute to energy efficiency. Moreover, the advancement of research and development capabilities in the countries is needed. Chen et al. [77] assert that energy efficiency depends on energy intensity, structure, and value of final energy consumption, which is conducive to sustainable development goals (clean and affordable energy, decent work and economic growth, industry, innovation and infrastructure, quality education). In addition, they empirically justify that the structural transformation of the economy could provoke a decline in energy intensity and restructure the final energy consumption. Energy efficiency is able to improve by changing the energy consumption structure [78], simultaneously leading to a decline in greenhouse gas emissions. Consequently, it promotes attaining green economic growth and sustainable development [79,80]. Yan et al. [81] indicate that EU countries have different levels of energy efficiency that depend on technological and energy infrastructure, the efficacy of energy policy, and the spread of renewable energy. Considering the abovementioned analysis, the third hypothesis of this study is formulated as follows:

Hypothesis 3. *Energy efficiency has a statistically significant effect on green economic growth.*

3. Materials and Methods

3.1. Measuring Green Economic Growth

Green economic growth aims at an effective use of available resources in the country (labor, capital) for GDP growth and significant reduction of the production impact on the environment [82,83]. The efficiency of resource use in the country can be shown by Formula (1):

$$P^G = \langle (y, b, x \mid x \ can \ produce \ (y, b) \rangle \quad (1)$$

where x is available resources in the country; y is a desirable output of the production process; and b is an undesirable output.

This index allows comparing the growth indicators in the countries with the etalon production frontier, which represents the most efficient production. The index measures the change in productivity over time by calculating a gap between the actual production and the level of frontier productions [84]. The changes in such a gap over time reflect changes in the country's productivity and efficiency. Consequently, the functional dependence (1) can be represented as follows:

$$Ged_t^{t+1} = \frac{1 + \overset{\rightarrow G}{D_0}\left(x^t, y^t, b^t; y^t, b^t\right)}{1 + \overset{\rightarrow G}{D_0}\left(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, b^{t+1}\right)} \quad (2)$$

where Ged_t^{t+1} is a value of green economic growth of the countries; x is available resources in the country (Labor force and Gross capital formation); y is a desirable output of the production (the gross domestic product of each country); b is an undesirable output (greenhouse gas emission); $\overset{\rightarrow G}{D_0}\left(x^s, y^s, b^s; y^s, b^s\right) = max\left\{\beta : \left(y^s + \beta y^s, b - \beta b^s \in P^G(x^s)\right\}\right.$, $s = t, t+1$ are the global technology set.

Incorporation of ecological factors in model (2) reveals the negative impact of production on the environment. The value of Ged ranges from 0 to infinity, where a value of 1 indicates no change in productivity over time, a value greater than 1 indicates an increase in productivity over time, and a value less than 1 indicates a decrease in productivity over time. Using the global Malmquist–Luenberger productivity index [12,30,41] for evaluating green economic growth allows: (1) considering qualitive and quantitative characteristics of the input data, which is conducive to a detailed estimation of the impact of production on the environment, and (2) comparing the productivity growth among countries, which allows identifying the best practices on the way to green economic growth. The descriptive statistics of the parameters from model (2) for the EU countries for the period of 2006–2020 are summarized in Table 1.

Table 1. Descriptive statistics of the green economic growth parameters.

Countries	Labor Force World Data Bank [85]		Gross Capital Formation World Data Bank [85]		Gross Domestic Product World Data Bank [85]		Greenhouse Gas Emission Eurostat [86]	
	LogL		LogK		LogGDP		LogGHG	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Austria	15.303	0.040	25.280	0.105	10.783	0.068	2.235	0.064
Belgium	15.412	0.033	25.468	0.091	10.710	0.062	2.435	0.106
Bulgaria	15.028	0.018	23.213	0.157	8.925	0.201	1.933	0.086
Croatia	14.434	0.032	23.265	0.187	9.541	0.091	1.599	0.078
Cyprus	13.291	0.046	22.253	0.288	10.266	0.109	2.433	0.114
Czech Republic	15.484	0.016	24.764	0.127	9.914	0.118	2.525	0.065
Denmark	14.889	0.019	24.947	0.105	10.981	0.060	2.376	0.192
Estonia	13.447	0.014	22.604	0.218	9.809	0.177	2.541	0.145
Finland	14.811	0.010	24.809	0.098	10.773	0.070	2.115	0.205
France	17.220	0.015	27.121	0.079	10.611	0.066	1.946	0.087
Germany	17.568	0.023	27.317	0.100	10.690	0.076	2.403	0.086
Greece	15.402	0.022	24.274	0.533	10.022	0.201	2.269	0.168
Hungary	15.315	0.046	24.163	0.187	9.553	0.107	1.813	0.081
Ireland	14.651	0.028	25.023	0.525	11.014	0.185	2.731	0.095
Italy	17.043	0.025	26.687	0.149	10.458	0.085	2.016	0.155
Latvia	13.856	0.055	22.687	0.245	9.577	0.172	1.433	0.323
Lithuania	14.211	0.013	22.927	0.218	9.602	0.213	1.525	0.193
Luxembourg	12.487	0.135	23.121	0.135	11.626	0.075	3.114	0.165
Malta	12.223	0.167	21.484	0.271	10.098	0.177	1.888	0.226
Netherlands	16.015	0.030	25.890	0.101	10.838	0.071	2.519	0.084
Poland	16.701	0.020	25.311	0.128	9.485	0.146	2.272	0.026
Portugal	15.494	0.026	24.455	0.207	9.998	0.073	1.807	0.117
Romania	16.039	0.027	24.625	0.202	9.164	0.208	1.532	0.119
Slovak Republic	14.814	0.013	23.754	0.091	9.766	0.101	1.892	0.108
Slovenia	13.840	0.014	23.057	0.195	10.078	0.090	1.940	0.185
Spain	16.961	0.019	26.388	0.237	10.295	0.085	1.958	0.150
Sweden	15.447	0.046	25.540	0.110	10.896	0.083	0.664	0.365
Total	15.088	1.346	24.460	1.512	10.203	0.650	2.071	0.504

Note: Log. stands for logarithm; mean is an average value; s.d. means a standard deviation.

3.2. The Model to Measure the Impact of Environmental Regulations, Renewable Energy, and Energy Efficiency on Green Economic Growth

3.2.1. Data Characteristics

This study measures the impact of environmental regulations, renewable energy, and energy efficiency on green economic growth by using Ged as the dependent variable and uses the following explanatory variables:

- The share of renewable energy in the total primary energy supply: this indicator reveals the share of energy consumption from renewable sources, which could contribute to the reduction of greenhouse gas emissions and the attainment of sustainable energy [87,88]. Countries with a higher share of renewable energy are likely to have a lower carbon footprint and feel a positive impact on green economic growth rates;
- Government expenditure on environmental protection: this indicator determines the values of government expenses on environmental protection as a percentage of the country's GDP. On the one hand, the growth of government expenses on environmental protection indicates the government's orientation to solve ecological issues and contribute to green economic growth. On the other hand, considering previous studies [89], the ratio between government expenditure on environmental protection and green economic growth has an inverted U-shape relationship. In the beginning, when government spending on environmental protection increases, there is a positive effect on green economic growth. However, after a certain level has been reached, further increases in public spending could provoke a negative impact

on green economic growth, which could be caused by factors such as diminishing marginal returns to investment, inefficient resource allocation, or unfair negative consequences such as crowding out private investment;

- Energy intensity reveals the energy that is required for the production of one unit of GDP. Using energy by countries to achieve similar economic results indicates the more efficient use of resources and less impact on the environment [90]. Thus, the decline in energy intensity could be caused by the implementation of technological and institutional innovations that contribute to sustainable economic growth;
- Final energy consumption measures the energy consumption in the countries, which could be a significant indicator in estimating a country's energy security and impact on nature [91]. Countries with low values of final energy consumption could have more energy efficacy with the lowest impact on the environment.

The study included the following control variables to measure the impact of environmental regulations, renewable energy, and energy efficiency on green economic growth:

1. Research and development (R & D): Investments in R & D contribute to developing technologies and innovations that reduce pollutant emissions, restrict environmental degradation, and increase labor productivity and the energy efficiency of processes. Similar to previous studies [92–95], R & D is measured by patents in environment-related technologies.
2. Government institutions: Institutional quality influences green economic growth within the following mechanisms: protection of property rights (well-developed legal and economic institutions ensure effective protection of property rights and stimulate innovative development and advancing technologies that reduce the negative impact on the environment). This could develop the appropriate climate for business development and investments in the sectors of green economic growth: the rule of law (the stability of legal and economic institutions is an important factor for providing the affordable conditions of green economic growth) [96]; corruption (affects the country's investment climate and contributes to the flow of foreign investments aimed at increasing energy-efficient production, consumption of renewable sources, etc.) [97,98]. This study uses the average value of the institutions' quality indicators in different countries (which are calculated by the World Bank [85]) to estimate government institutions. These indicators cover six dimensions of state governance: voice and accountability (estimating citizens' ability to participate in the political process and hold their governments accountable); political stability and absence of violence (describing the probability of political instability and violence in the country); government effectiveness (the quality of public services, the bureaucracy, and the competence of local authorities); regulatory quality (transparency, efficiency, and effectiveness of regulatory acts in promoting economic activity); rule of law (indicating compliance with laws and the independence and impartiality of the judiciary); and control of corruption (corruption of public officials and abuse of power for personal gain).
3. Trade openness: the high level of a country's integration into the world economy provides access to innovative technologies, environmentally friendly production, and green investments [99,100]. In addition, trade openness is conducive to intensifying competitiveness in the domestic market, which boosts companies' performance and decreases costs by applying clean and green technologies [101,102].

The object of this research is EU countries in the period of 2006–2020. All data is logarithm to eliminate skewness of a measurement variable. The descriptive statistics of the explanatory and control variables for evaluating the impact of environmental regulations, renewable energy, and energy efficiency on green economic growth are shown in Table 2.

Table 2. Explanation of the selected variables and descriptive statistics.

Symbols	Explanation	Source	Mean	CV	Min	Max	VIF
		Explanatory variables					
LogRE	The share of renewable energy in the total primary energy supply	Eurostat [86]	2.461	0.247	1.040	3.750	1.58
LogEnvReg	Government expenditure on environmental protection		0.118	2.562	−2.303	0.742	1.34
		Energy Efficiency					
LogEI	Energy intensity	Eurostat [86]	5.079	0.091	3.798	6.319	1.68
LogFEC	Final energy consumption		2.956	0.418	0.451	5.407	6.32
		Control variables					
LogWGI	Estimate of governance	World Data Bank [85]	−0.159	−4.184	−2.442	0.636	2.19
LogRD	Patents in environment-related technologies		3.821	0.527	−1.609	8.112	5.56
LogTO	Trade openness		4.705	0.093	3.816	5.940	2.58

Note: Mean stands for average value among the analyzed data; CV is a coefficient of variation; Min is a minimum value among the analyzed data; Max is a maximum value among the analyzed data; VIF is a variance inflation factor.

3.2.2. Regression Framework

Using the panel data allows controlling county and time effects, which could influence the dependent variable Ged. This study applies the system generalized method of moments (GMM) [103,104] to analyze the impact of environmental regulations, renewable energy, and energy efficiency on green economic growth in EU countries. It allows consideration of the endogenous variables and cross-sectional dependence:

$$Ged_{it} = \alpha_0 + \beta_1 Ged_{it-1} + \beta_2 LogEnergy_{it} + \beta_3 LogWGI_{it} + \beta_4 LogRD_{it} + \beta_5 LogTO_{it} + \varepsilon_{it} \quad (3)$$

where Ged_{it}, Ged_{it-1} are green economic growth in an i-country in t and $t-1$ time; $Energy_{it}$ is renewable energy and energy efficiency in i-country in t-time; WGI_{it} is a quality of institutions in i-country in t-time; RD_{it} is patents in environment-related technologies in i-country in t-time; TO_{it} is a trade openness in an i-country in t-time; α_0 is a constant; $\beta_1 \ldots \beta_5$ are searching parameters of the model; Log is a logarithm function; ε_{it} is the error term.

This study applies the following model to test the hypothesis on the nonlinear relationship between government expenditure on environmental protection and green economic growth [6,103]:

$$\begin{aligned} Ged_{it} = \gamma_0 + \mu_1 Ged_{it-1} + \mu_2 Log\text{EnvReg}_{it} + \mu_3 Log\text{EnvReg}_{it}{}^2 + \\ \mu_4 LogEnergy_{it} + \mu_5 LogWGI_{it} + \mu_6 LogRD_{it} + \mu_7 LogTO_{it} + \varepsilon_{it} \end{aligned} \quad (4)$$

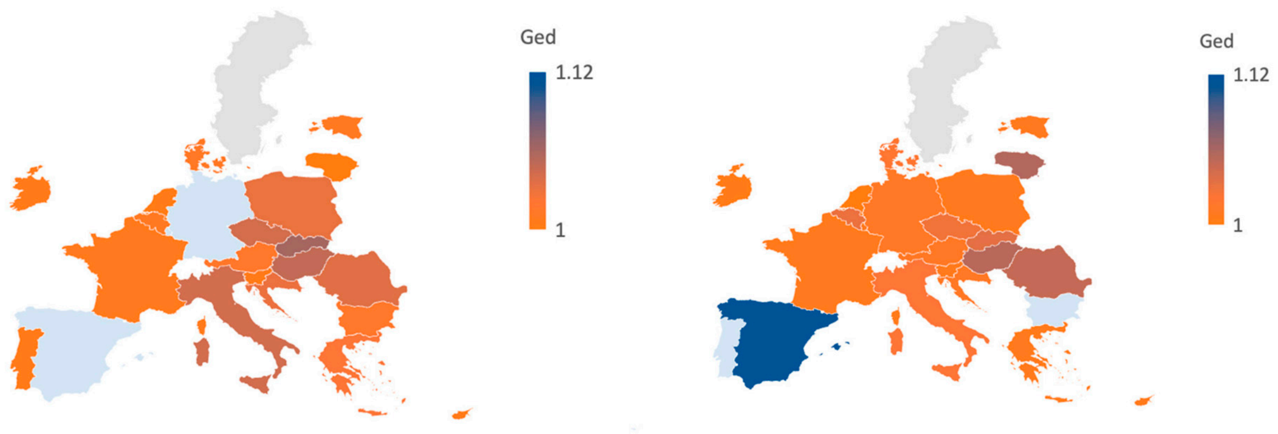
where EnvReg_{it} is government expenditure on environmental protection; γ_0 is a constant; $\mu_1 \ldots \mu_6$ are the searching parameters of the model; Log is a logarithm function; and ε_{it} is the error term.

If the value of searching parameters $\mu_2 > 0$ and $\mu_3 = 0$, this will indicate a positive linear correlation between government expenditure on environmental protection and green economic growth, which indicates permanently increasing green economic growth with rising government expenditure on environmental protection. If $\mu_2 < 0$, and $\mu_3 > 0$, this will indicate U-shape dependence, which means that green economic growth initially increases as government expenditure on environmental protection increases, but then declines after reaching a peak. If $\mu_2 > 0$, and $\mu_3 < 0$, this will indicate an inverted U-shape relationship between government expenditure on environmental protection and green economic growth.

In the first step, this study applies Levin–Lin–Chu [105], Im–Pesaran–Shin [106], and Augmented Dickey–Fuller [107] with the second-generation tests Cointegrated Augmented Dickey Fuller (CADF) [108] and Cross-sectionally augmented Im-Pesaran-Shin (CIPS) [108] to calculate the search parameters of the model. While first-generation tests suggest independence across cross sections, the second-generation tests eliminate this assumption by making them useful in situations with dependence across cross sections. EU countries are integrated into common political, legal, and economic processes [109,110], which could provoke significant cross-dependence, which should be considered when analyzing panel data. To solve this issue, this study applies the CD test, which was developed by Pesaran (2004) [111] and uses the correlation coefficient of the time series of variables in the analysis. This method is robust to the nonstationary of variables, differences, or structural gaps between countries.

4. Results

The empirical results indicate that green economic growth in EU countries gradually increases throughout the analyzed period (Figure 1). The graphical interpretation of Ged for 2007 and 2020 years is shown in Figure 1.



(**a**) (**b**)

Figure 1. The values of Ged for EU countries in 2007 (**a**) and 2020 (**b**).

The average values of Ged for each country are higher than one and range from 1.000 to 1.020 (Table 3). The value of the coefficient of variation (CV) changes from 0.0018 to 0.0497, which indicates a relatively moderate variability of Ged values in different countries.

Table 3. Descriptive statistics of Ged.

Country	Mean	CV	Min	Max	Country	Mean	CV	Min	Max
Austria	1.003	0.019	0.959	1.034	Italy	1.002	0.005	0.988	1.008
Belgium	1.003	0.012	0.969	1.015	Lithuania	1.016	0.035	0.929	1.061
Bulgaria	1.008	0.012	0.983	1.031	Luxembourg	1.000	0.030	0.947	1.056
Croatia	1.006	0.021	0.957	1.041	Netherlands	1.002	0.026	0.921	1.027
Cyprus	1.007	0.042	0.876	1.051	Poland	1.001	0.002	0.997	1.004
Czech Republic	1.003	0.008	0.985	1.020	Portugal	1.008	0.029	0.950	1.063
Denmark	1.016	0.024	0.966	1.055	Romania	1.003	0.007	0.992	1.017
Estonia	1.011	0.023	0.963	1.058	Slovak Republic	1.012	0.020	0.961	1.048
France	1.002	0.007	0.987	1.010	Slovenia	1.014	0.048	0.929	1.135
Germany	1.002	0.004	0.993	1.007	Spain	1.002	0.004	0.991	1.009
Greece	1.008	0.013	0.983	1.030	Sweden	1.012	0.050	0.919	1.115

Table 3. *Cont.*

Country	Mean	CV	Min	Max	Country	Mean	CV	Min	Max
Hungary	1.004	0.013	0.979	1.022	Total	1.007	0.024	0.876	1.135
Ireland	1.020	0.026	0.974	1.061					

Note: Mean stands for an average value; CV is a coefficient of variation; Min is a minimum value; Max is a maximum value.

Austria, Belgium, Czechia, France, Germany, Italy, Poland, Romania, and Spain have Ged values close to the average among the EU countries, and the coefficient of variation is lower than 0.01, which confirms the high coherence of policy for attaining green economic growth during the period under research. Among the analyzed countries, Cyprus and Slovenia have the highest CV values, which indicates their unstable dynamics of green economic growth compared to other EU member states. Ireland, Luxembourg, and Slovenia have the highest Ged growth ranges with values higher than 1.02. However, Cyprus has the lowest value of Ged among the countries analyzed. Furthermore, the Ged distribution is positively skewed, with a skewness value of −0.058, and exhibits a moderate degree of skewness or kurtosis with a value of 9.521. The findings of the Pesaran test for RE, EnvReg, EI, FEC, WGI, RD, and TO are shown in Table 4, with all values having a probability of 0.000, which indicates the option for accepting an alternative hypothesis on the existence of panel data cross-dependence.

Table 4. Pesaran test of cross-sectional independence.

Parameters	RE	EnvReg	EI	FEC	WGI	RD	TO
Stat.	25.895	28.728	28.862	27.925	27.947	28.296	27.687
Prob.	0.000	0.000	0.000	0.000	0.000	0.000	0.000

This study uses Levin–Lin–Chu, Im–Pesaran–Shin, and augmented Dickey–Fuller tests to check the stationarity of the data. The findings confirm nonstationary of data at level (Table 5). However, at the first differences, all data have become stationary with a 1% significance level for all tests. The findings of the Pesaran CD test confirm the necessity to check data on stationarity by second-generation tests. The CADF test allows checking the unit root test while controlling cross-sectional dependence, and the CIPS test indicates the structural gaps in the dashboard panel settings [108]. At level, the test findings for the variables show different characteristics. The findings of CADF tests allow rejecting (1% significance level) the null hypothesis of nonstationary for RE, FEC, WGI, and TO. However, the CADF test results do not allow us to reject (1% significance level) the null hypothesis of nonstationary for RD and EI. Similar results are obtained by CIPS tests. However, the results of CADF and CIPS indicate that the null hypothesis of nonstationary is rejected at the 1% significance level for the first differences of the data. This confirms that all data are stationary in a differentiated series of the first order, meaning that the data do not show trends and have a constant variance over time.

Table 5. The findings of stationarity tests.

Variables	Levin–Lin–Chu		Im–Pesaran–Shin		ADF		CADF		CIPS	
	Lev.	1st dif.	Lev.	1st dif.	Lev.	1st dif.	Lev.	1st dif.	Lev.	1st dif.
RE	1.888	−4.449 *	1.624	−7.687 *	−2.029	31.193 *	−2.046	−2.670 *	−2.612	−4.727 *
EnvReg	−4.257 *	−7.820 *	−3.326 *	−8.125 *	7.543 *	35.714 *	−1.909	−2.703 *	−2.198	−3.915 *
EI	1.160	−11.846 *	5.054	−8.246 *	−3.442	30.761 *	−2.117 **	−2.316 *	−2.569 *	−3.884 *
FEC	−3.961 *	−4.491 *	−1.874 **	−6.860 *	3.961 *	26.016 *	−1.806	−2.913 *	−2.023	−3.363 *

Table 5. *Cont.*

Variables	Levin–Lin–Chu		Im–Pesaran–Shin		ADF		CADF		CIPS	
	Lev.	1st dif.	Lev.	1st dif.	Lev.	1st dif.	Lev.	1st dif.	Lev.	1st dif.
WGI	−1.776 **	−3.932 *	0.017	−8.096 *	−0.376	35.948 *	−1.620	−2.336 *	−2.131	−3.498 *
RD	−7.680 *	−9.778 *	−5.521 *	−8.883 *	15.644 *	46.709 *	−2.658 *	−3.512 *	−3.159 *	−4.496 *
TO	−2.885	−14.542	−0.368	−6.971	−0.458	18.061	−1.465	−3.251	−1.078	−3.238

Note: Lev is at level; 1st dif. is the first difference; ADF is the augmented Dickey–Fuller test; *, ** is statistical significance at 1% and 5%, respectively.

The findings of the generalized method of moments (GMM) for Model (3) are shown in Table 6. The coefficients of RE, EI, and FEC have p values less than 0.05, which confirms the statistically significant relationship with green economic growth. The increase in renewable energy and final energy consumption by one point promotes the improvement of green economic growth by 0.198 and 0.11, respectively.

Table 6. Results of the generalized method of moments (GMM) for Model (3).

Variables	RE		EI		FEC	
	coef.	p Value	coef.	p Value	coef.	p Value
Ged_{t-1}	0.378	0.000	0.394	0.000	0.392	0.000
RE	0.198	0.033	–	–	–	–
EI	–	–	−0.083	0.004	–	–
FEC	–	–	–	–	0.110	0.012
WGI	−0.026	0.388	−0.027	0.102	0.026	0.424
RD	0.009	0.454	0.005	0.085	0.005	0.010
TO	0.129	0.059	0.008	0.049	0.067	0.059
const	−1.134	0.043	0.404	0.003	−0.424	0.052
Wald chi2	160.40	0.000	233.26	0.000	96.26	0.000
AB AR (1)	1.74	0.082	−2.89	0.004	−2.56	0.011
AB AR (2)	1.63	0.104	1.54	0.124	−0.66	0.512
Hans.	5.20	0.816	9.41	0.494	5.51	0.787
Sarg.	5.62	0.777	15.03	0.131	6.11	0.729

Note: AB AR (1) is an Arellano–Bond test for AR (1) in the first differences; AB AR (2) is an Arellano–Bond test for AR (2) in the first differences; Hans. is a Hansen test of overidentifying; Sarg. is a Sargan test of overidentifying; coef. is the value of a coefficient.

The decline in energy intensity by one point leads to a reduction in green economic growth by 0.083. In all models, there is a positive and statistically significant effect on green economic growth. Therefore, the trade openness of EU countries promotes new technologies and innovation, which reduces the negative impact on nature and increases the use of renewable energy [112,113]. In addition, trade openness stimulates the development of green markets and supports the demand for products that relate to renewable energy. Consequently, it encourages companies to produce environmentally friendly and energy-saving technologies, products, and services. The value of the RD coefficient is 0.005 and is statistically significant, leading to the conclusion that the growth of patent applications contributes to green economic growth. It bears noting that trade promotes the spread of new technologies and knowledge on renewable energy, which enhances the innovation and efficacy of this sector. However, the WGI does not have a statistically significant impact on green economic growth for all models. The results of Hansen and Sargan tests of overidentification of constraints for all types of models are not statistically significant, which indicates that the instrumental variables used in the model are valid.

The empirical results of the generalized method of moments (GMM) for Model 4 are shown in Table 7. The findings indicate that all variables of model (4) have positive and statistically significant effects on green economic growth, excluding WGI. The lag value of Ged_{t-1} positively affects green economic growth with 1% statistical significance. This means that improving green economic growth in the future could be caused by increasing green economic growth in the previous year. Moreover, these conclusions justify the empirical results of the *Ged* evaluation, which demonstrates the growth trend in the EU during 2006–2020.

Table 7. Results of the generalized method of moments (GMM) for Model (4).

Variables	RE		EI		FEC	
	coef.	*p* Value	coef.	*p* Value	coef.	*p* Value
Ged_{t-1}	0.383	0.000	0.376	0.000	0.374	0.000
RE	0.161	0.000	–	–	–	–
EI	–	–	0.016	0.197	–	–
FEC	–	–	–	–	0.027	0.000
WGI	−0.027	0.638	−0.023	0.517	−0.016	0.330
RD	0.010	0.000	0.012	0.002	0.004	0.094
TO	0.117	0.000	0.035	0.001	0.047	0.000
EnvReg	0.588	0.045	0.837	0.088	0.837	0.029
$EnvReg^2$	−1.049	0.039	−1.683	0.034	−1.623	0.011
const	−0.660	0.031	0.208	0.006	0.205	0.016
Wald chi2	79.010	0.000	73.360	0.000	94.870	0.000
AB AR (1)	−2.300	0.022	−1.970	0.049	−1.960	0.050
AB AR (2)	1.410	0.158	1.060	0.287	1.120	0.265
Hans.	3.300	0.914	2.200	0.948	1.180	0.978
Sarg.	4.410	0.819	2.280	0.943	2.030	0.917

Note: AB AR (1) stands for an Arellano–Bond test for AR (1) in the first differences; AB AR (2) stands for an Arellano–Bond test for AR (2) in the first differences; Hans. stands for a Hansen test of overidentifying; Sarg. stands for a Sargan test of overidentification; coef. is a value of the coefficient.

The coefficient values EnvReg and $EnvReg^2$ confirm the hypothesis of a U-shape relationship between government expenditure on environmental protection and green economic growth. The coefficient of $EnvReg^2$ is negative, which proves the thresholds of the positive impact of spending on green economic growth (the EnvReg coefficient has a positive and statistically significant value), after which the growth of government spending on environmental protection leads to a decline in green economic growth. The positive and statistically significant coefficients of RE, EI, and FEC prove their positive contribution to green economic growth. In addition, these findings are similar to the results summarized in Table 6. This additionally confirms the validity of the abovementioned empirical results. Furthermore, through the results of Wald chi2, Arellano–Bond for autocorrelation for the first and the second order in the first differences, Hansen and Sargan prove the reliability and validity of model search parameter calculations (4).

5. Discussion & Conclusions

This study contributes to the theoretical framework for identifying the core drivers and inhibitors of green economic growth. The empirical results allow us to conclude that Portugal, Slovenia, and Sweden are the leaders in green economic growth among EU countries for the period of 2006–2020. In addition, improving green economic growth in the previous year contributes to green economic growth in the following year. This is confirmed by the positive and statistically significant values of Ged within GMM. In addition, the findings confirm that the analyzed variables have a statistically significant effect on green economic growth, excluding WGI, for all analyzed models. Furthermore, the study confirms a U-shape relationship between environmental regulations and green economic growth, which is coherent with previous research [50–53]. However, the results of these studies are controversial [48,51,52]. Trade openness, research, and development enhance green economic growth, which is justified by the positive and statistically significant values of the relevant coefficients of the analyzed models. Such conclusions were also proven by previous research [5,59,65,66,68]. Expenditures on increasing renewable energy stimulate green economic growth. In this case, the government and local authorities should stimulate consumption from green energy and implement relevant policies on promoting green technologies in all sectors. It should be noted that the past studies [114–117] also confirm that green energy, responsible consumption, and production positively effect on green economic growth in developed and developing countries. At the same time, the government should intensify the improvement and implementation of legislation, which will consequently promote renewable energy consumption and boost green economic growth. In addition, it is necessary to develop new green financial instruments to enhance green economic growth. The carbon trading system is proven to have a positive and statistically significant impact on green economic growth [118]. In this case, EU countries should enhance the carbon trading system and develop appropriate mechanisms and incentives. In addition, based on the analysis of the theoretical framework underlying green economic growth, Tamasiga et al. [119] indicate the necessity to spread green FinTech, which allows the accumulation of financial resources for renewable energies and green innovations to attain green economic growth. In addition, Song et al. [54] consider enhancing digitalization to improve green economic growth in the long term. Consequently, the EU should intensify the implementation of a single digital market and enhance the penetration of digital technologies in all sectors and at all levels, which leads to increasing trust in the government, accountability, and transparency in making decisions. Therefore, it is necessary to modernize the energy policy [72], which results in higher energy efficiency due to improving energy intensity and increasing final energy consumption from renewable energy instead of traditional energy resources.

Despite the valuable findings, this study has a few limitations. First, further research should incorporate digitalization of different sectors and levels (government, finance market, energy, business, etc.) to the independent variables for analysis. In addition, it is necessary to study the impact of crypto trading (as alternative green financial resources) on green economic growth and environmental degradation. Secondly, this study used the values of government expenses on environmental protection as a percentage of the country's GDP as an indication of a country's commitment to environmental protection. Generally, a higher percentage of GDP spent on ecological protection suggests that a government places a greater emphasis on protecting the environment. However, factors such as the stringency of regulations, enforcement mechanisms, and the effectiveness of monitoring and reporting systems also play a crucial role in measuring the effectiveness of environmental regulations in different EU countries and should be added to future research. Moreover, future studies should consider more countries as the object of research to compare the empirical findings and define the state-of-the-art practices for boosting green economic growth. This paper studies the linear and nonlinear effects (for environmental regulations) of the selected variables on green economic growth. However, green economic growth is a multilevel and complex task that merges a vast range of factors and dimensions. Thus, it is necessary to find other determinants that could stimulate or restrict green economic growth.

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References

1. COP26: Together for Our Planet. 2023. Available online: https://www.un.org/en/climatechange/cop26 (accessed on 1 January 2023).
2. Tan, J.; Su, X.; Wang, R. The impact of natural resource dependence and green finance on green economic growth in the context of COP26. *Resour. Policy* **2023**, *81*, 103351. [CrossRef]
3. Granoff, I.; Hogarth, J.R.; Miller, A. Nested barriers to low-carbon infrastructure investment. *Nat. Clim. Chang.* **2016**, *6*, 1065–1071. [CrossRef]
4. Kar, S.K.; Mishra, S.K.; Bansal, R. Drivers of green economy: An Indian perspective. In *Environmental Sustainability: Role of Green Technologies*; Springer: New Delhi, India, 2015; pp. 283–310. [CrossRef]
5. Lee, C.T.; Hashim, H.; Ho, C.S.; Fan, Y.V.; Klemeš, J.J. Sustaining the low-carbon emission development in Asia and beyond: Sustainable energy, water, transportation and low-carbon emission technology. *J. Clean. Prod.* **2017**, *146*, 1–13. [CrossRef]
6. Lin, B.; Zhou, Y. Measuring the green economic growth in China: Influencing factors and policy perspectives. *Energy* **2022**, *241*, 122518. [CrossRef]
7. Desalegn, G.; Tangl, A. Enhancing Green Finance for Inclusive Green Growth: A Systematic Approach. *Sustainability* **2022**, *14*, 7416. [CrossRef]
8. Fan, M.; Yang, P.; Li, Q. Impact of environmental regulation on green total factor productivity: A new perspective of green technological innovation. *Environ. Sci. Pollut. Res.* **2022**, *29*, 53785–53800. [CrossRef]
9. Shang, L.; Tan, D.; Feng, S.; Zhou, W. Environmental regulation, import trade, and green technology innovation. *Environ. Sci. Pollut. Res.* **2022**, *29*, 12864–12874. [CrossRef]
10. Wei, X.; Ren, H.; Ullah, S.; Bozkurt, C. Does environmental entrepreneurship play a role in sustainable green development? evidence from emerging Asian economies. *Econ. Res.-Ekon. Istraz.* **2023**, *36*, 73–85. [CrossRef]
11. Nawawi, M.; Samsudin, H.; Saputra, J.; Szczepańska-Woszczyna, K.; Kot, S. The Effect of Formal and Informal Regulations on Industrial Effluents and Firm Compliance Behavior in Malaysia. *Prod. Eng. Arch.* **2022**, *28*, 193–200. [CrossRef]
12. Kwilinski, A.; Lyulyov, O.; Pimonenko, T. Greenfield Investment as a Catalyst of Green Economic Growth. *Energies* **2023**, *16*, 2372. [CrossRef]
13. Dzwigol, H.; Aleinikova, O.; Umanska, Y.; Shmygol, N.; Pushak, Y. An Entrepreneurship Model for Assessing the Investment Attractiveness of Regions. *J. Entrep. Educ.* **2019**, *22*, 1–7.
14. Kostyrko, R.; Kosova, T.; Kostyrko, L.; Zaitseva, L.; Melnychenko, O. Ukrainian Market of Electrical Energy: Reforming, Financing, Innovative Investment, Efficiency Analysis, and Audit. *Energies* **2021**, *14*, 5080. [CrossRef]
15. Prokopenko, O.; Miśkiewicz, R. Perception of "green shipping" in the contemporary conditions. *Entrep. Sustain. Issues* **2020**, *8*, 269–284. [CrossRef]
16. Kotowicz, J.; Węcel, D.; Kwilinski, A.; Brzęczek, M. Efficiency of the power-to-gas-to-liquid-to-power system based on green methanol. *Appl. Energy* **2022**, *314*, 118933. [CrossRef]
17. Miśkiewicz, R.; Rzepka, A.; Borowiecki, R.; Olesińki, Z. Energy Efficiency in the Industry 4.0 Era: Attributes of Teal Organizations. *Energies* **2021**, *14*, 6776. [CrossRef]
18. Hezam, I.M.; Mishra, A.R.; Rani, P.; Saha, A.; Smarandache, F.; Pamucar, D. An integrated decision support framework using single-valued neutrosophic-MASWIP-COPRAS for sustainability assessment of bioenergy production technologies. *Expert Syst. Appl.* **2023**, *211*, 118674. [CrossRef]
19. Tih, S.; Wong, K.-K.; Lynn, G.S.; Reilly, R.R. Prototyping, Customer Involvement, and Speed of Information Dissemination in New Product Success. *J. Bus. Ind. Mark.* **2016**, *31*, 437–448. [CrossRef]
20. Dzwigol, H. Research Methodology in Management Science: Triangulation. *Virtual Econ.* **2022**, *5*, 78–93. [CrossRef]
21. Dzwigol, H. Methodological and Empirical Platform of Triangulation in Strategic Management. *Acad. Strateg. Manag. J.* **2020**, *19*, 1–8.
22. Us, Y.; Pimonenko, T.; Lyulyov, O.; Chen, Y.; Tambovceva, T. Promoting Green Brand of University in Social Media: Text Mining and Sentiment Analysis. *Virtual Econ.* **2022**, *5*, 24–42. [CrossRef]
23. Miśkiewicz, R. The importance of knowledge transfer on the energy market. *Polityka Energetyczna* **2018**, *21*, 49–62. [CrossRef]
24. Szczepańska-Woszczyna, K.; Gatnar, S. Key Competences of Research and Development Project Managers in High Technology Sector. *Forum Sci. Oeconomia* **2022**, *10*, 107–130. [CrossRef]
25. Trzeciak, M.; Kopec, T.P.; Kwilinski, A. Constructs of Project Programme Management Supporting Open Innovation at the Strategic Level of the Organization. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 58. [CrossRef]
26. Miśkiewicz, R. Knowledge and innovation 4.0 in today's electromobility. In *Sustainability, Technology and Innovation 4.0*; Makieła, Z., Stuss, M.M., Borowiecki, R., Eds.; Routledge: London, UK, 2021; pp. 256–275.
27. Sadiq, M.; Amayri, M.A.; Paramaiah, C.; Mai, N.H.; Ngo, T.Q.; Phan, T.T.H. How green finance and financial development promote green economic growth: Deployment of clean energy sources in South Asia. *Environ. Sci. Pollut. Res.* **2022**, *29*, 65521–65534.
28. Srivastava, A.K.; Dharwal, M.; Sharma, A. Green financial initiatives for sustainable economic growth: A literature review. *Mater. Today Proc.* **2022**, *49*, 3615–3618. [CrossRef]

29. Khan, S.A.R.; Yu, Z.; Umar, M. A road map for environmental sustainability and green economic development: An empirical study. *Environ. Sci. Pollut. Res.* **2022**, *29*, 16082–16090. [CrossRef] [PubMed]
30. Li, J.; Chen, L.; Chen, Y.; He, J. Digital economy, technological innovation, and green economic efficiency—Empirical evidence from 277 cities in China. *Manag. Decis. Econ.* **2022**, *43*, 616–629. [CrossRef]
31. Kharazishvili, Y.; Kwilinski, A.; Grishnova, O.; Dzwigol, H. Social safety of society for developing countries to meet sustainable development standards: Indicators, level, strategic benchmarks (with calculations based on the case study of Ukraine). *Sustainability* **2020**, *12*, 8953. [CrossRef]
32. Hussain, H.I.; Haseeb, M.; Kamarudin, F.; Dacko-Pikiewicz, Z.; Szczepańska-Woszczyna, K. The role of globalization, economic growth and natural resources on the ecological footprint in Thailand: Evidence from nonlinear causal estimations. *Processes* **2021**, *9*, 1103. [CrossRef]
33. Saługa, P.W.; Szczepańska-Woszczyna, K.; Miśkiewicz, R.; Chład, M. Cost of equity of coal-fired power generation projects in Poland: Its importance for the management of decision-making process. *Energies* **2020**, *13*, 4833. [CrossRef]
34. Saługa, P.W.; Zamasz, K.; Dacko-Pikiewicz, Z.; Szczepańska-Woszczyna, K.; Malec, M. Risk-adjusted discount rate and its components for onshore wind farms at the feasibility stage. *Energies* **2021**, *14*, 6840. [CrossRef]
35. Dźwigoł, H.; Wolniak, R. Controlling in the Management Process of a Chemical Industry Production Company. *Przem. Chem.* **2018**, *97*, 1114–1116. [CrossRef]
36. Cyfert, S.; Chwiłkowska-Kubala, A.; Szumowski, W.; Miśkiewicz, R. The process of developing dynamic capabilities: The conceptualization attempt and the results of empirical studies. *PLoS ONE* **2021**, *16*, e0249724. [CrossRef] [PubMed]
37. Ingber, L. Quantum path-integral qPATHINT algorithm. *Open Cybern. Syst. J.* **2017**, *11*, 119–133. [CrossRef]
38. Kianpour, M.; Kowalski, S.J.; Øverby, H. Systematically Understanding Cybersecurity Economics: A Survey. *Sustainability* **2021**, *13*, 13677. [CrossRef]
39. Miśkiewicz, R.; Matan, K.; Karnowski, J. The Role of Crypto Trading in the Economy, Renewable Energy Consumption and Ecological Degradation. *Energies* **2022**, *15*, 3805. [CrossRef]
40. Dźwigol, H.; Dźwigoł-Barosz, M.; Zhyvko, Z.; Miśkiewicz, R.; Pushak, H. Evaluation of the energy security as a component of national security of the country. *J. Secur. Sustain. Issues* **2019**, *8*, 307–317. [CrossRef]
41. Kwilinski, A.; Lyulyov, O.; Pimonenko, T. The Effects of Urbanization on Green Growth within Sustainable Development Goals. *Land* **2023**, *12*, 511. [CrossRef]
42. Cheng, Z.; Li, X.; Wang, M. Resource curse and green economic growth. *Resour. Policy* **2021**, *74*, 102325. [CrossRef]
43. Hou, S.; Song, L.; Dai, W. The impact of income gap on regional green economic growth—Evidence from 283 prefecture-level cities in China. *Kybernetes*, 2022; *ahead-of-print*. [CrossRef]
44. Pan, D.; Yu, Y.; Hong, W.; Chen, S. Does campaign-style environmental regulation induce green economic growth? evidence from China's central environmental protection inspection policy. *Energy Environ.* 2023; *ahead-of-print*. [CrossRef]
45. Li, Y.; Ding, T.; Zhu, W. Can green credit contribute to sustainable economic growth? An empirical study from China. *Sustainability* **2022**, *14*, 6661. [CrossRef]
46. Mao, J.; Wu, Q.; Zhu, M.; Lu, C. Effects of environmental regulation on green total factor productivity: An evidence from the yellow river basin, China. *Sustainability* **2022**, *14*, 2015. [CrossRef]
47. Liu, Y.; Ma, C.; Huang, Z. Can the digital economy improve green total factor productivity? An empirical study based on Chinese urban data. *Math. Biosci. Eng.* **2023**, *20*, 6866–6893. [CrossRef]
48. Luo, S.; Zhang, S. How R & D expenditure intermediate as a new determinants for low carbon energy transition in belt and road initiative economies. *Renew. Energy* **2022**, *197*, 101–109. [CrossRef]
49. Luo, Y.; Lu, Z.; Muhammad, S.; Yang, H. The heterogeneous effects of different technological innovations on eco-efficiency: Evidence from 30 China's provinces. *Ecol. Indic.* **2021**, *127*, 107802. [CrossRef]
50. Chen, Y.; Fan, X.; Zhou, Q. An Inverted-U Impact of Environmental Regulations on Carbon Emissions in China's Iron and Steel Industry: Mechanisms of Synergy and Innovation Effects. *Sustainability* **2020**, *12*, 1038. [CrossRef]
51. Su, S.; Zhang, F. Modeling the role of environmental regulations in regional green economy efficiency of China: Empirical evidence from super efficiency DEA-Tobit model. *J. Environ. Manag.* **2020**, *261*, 110227.
52. Qiu, S.; Wang, Z.; Geng, S. How do environmental regulation and foreign investment behavior affect green productivity growth in the industrial sector? an empirical test based on Chinese provincial panel data. *J. Environ. Manag.* **2021**, *287*, 112282. [CrossRef]
53. Tao, H.; Tao, M.; Wang, R. Do education human capital and environmental regulation drive the growth efficiency of the green economy in China? *Sustainability* **2022**, *14*, 16524. [CrossRef]
54. Song, X.; Tian, Z.; Ding, C.; Liu, C.; Wang, W.; Zhao, R.; Xing, Y. Digital economy, environmental regulation, and ecological well-being performance: A provincial panel data analysis from China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 11801. [CrossRef] [PubMed]
55. Su, Y.; Gao, X. Revealing the effectiveness of green technological progress and financial innovation on green economic growth: The role of environmental regulation. *Environ. Sci. Pollut. Res.* **2022**, *29*, 72991–73000. [CrossRef] [PubMed]
56. Wang, X.; Wang, Z.; Wang, R. Does green economy contribute toward COP26 ambitions? Exploring the influence of natural resource endowment and technological innovation on the growth efficiency of China's regional green economy. *Resour. Policy* **2023**, *80*, 103189. [CrossRef]

57. Ahmed, F.; Kousar, S.; Pervaiz, A.; Trinidad-Segovia, J.E.; del Pilar Casado-Belmonte, M.; Ahmed, W. Role of green innovation, trade and energy to promote green economic growth: A case of south Asian nations. *Environ. Sci. Pollut. Res.* **2022**, *29*, 6871–6885. [CrossRef]
58. Aimon, H.; Kurniadi, A.P.; Amar, S. Analysis of fuel oil consumption, green economic growth and environmental degradation in 6 Asia Pacific countries. *Int. J. Sustain. Dev. Plan.* **2021**, *16*, 925–933. [CrossRef]
59. Cao, L. How green finance reduces CO_2 emissions for green economic recovery: Empirical evidence from E7 economies. *Environ. Sci. Pollut. Res.* **2023**, *30*, 3307–3320. [CrossRef]
60. Deshuai, M.; Hui, L.; Ullah, S. Pro-environmental behavior–Renewable energy transitions nexus: Exploring the role of higher education and information and communications technology diffusion. *Front. Psychol.* **2022**, 13. [CrossRef]
61. Doran, M.D.; Poenaru, M.M.; Zaharia, A.L.; Vătavu, S.; Lobonț, O.R. Fiscal Policy, Growth, Financial Development and Renewable Energy in Romania: An Autoregressive Distributed Lag Model with Evidence for Growth Hypothesis. *Energies* **2023**, *16*, 70. [CrossRef]
62. Miskiewicz, R. Efficiency of electricity production technology from postprocess gas heat: Ecological, economic and social benefits. *Energies* **2020**, *13*, 6106. [CrossRef]
63. Coban, H.H.; Lewicki, W.; Miśkiewicz, R.; Drożdż, W. The Economic Dimension of Using the Integration of Highway Sound Screens with Solar Panels in the Process of Generating Green Energy. *Energies* **2023**, *16*, 178. [CrossRef]
64. Melnychenko, O. Energy Losses Due to Imperfect Payment Infrastructure and Payment Instruments. *Energies* **2021**, *14*, 8213. [CrossRef]
65. Fang, W.; Liu, Z.; Surya Putra, A.R. Role of research and development in green economic growth through renewable energy development: Empirical evidence from south Asia. *Renew. Energy* **2022**, *194*, 1142–1152. [CrossRef]
66. Wei, S.; Jiandong, W.; Saleem, H. The impact of renewable energy transition, green growth, green trade and green innovation on environmental quality: Evidence from top 10 green future countries. *Front. Environ. Sci.* **2023**, *10*, 1–18. [CrossRef]
67. Li, J.; Dong, K.; Taghizadeh-Hesary, F.; Wang, K. 3G in China: How green economic growth and green finance promote green energy? *Renew. Energy* **2022**, *200*, 1327–1337. [CrossRef]
68. Li, Z.; Shen, T.; Yin, Y.; Chen, H.H. Innovation Input, Climate Change, and Energy-Environment-Growth Nexus: Evidence from OECD and Non-OECD Countries. *Energies* **2022**, *15*, 8927. [CrossRef]
69. Taşkın, D.; Vardar, G.; Okan, B. Does renewable energy promote green economic growth in OECD countries? *Sustain. Account. Manag. Policy J.* **2020**, *11*, 771–798. [CrossRef]
70. Lee, K. Drivers and barriers to energy efficiency management for sustainable development. *Sustain. Dev.* **2015**, *23*, 16–25. [CrossRef]
71. Zakari, A.; Khan, I.; Tan, D.; Alvarado, R.; Dagar, V. Energy efficiency and sustainable development goals (SDGs). *Energy* **2022**, *239*, 122365. [CrossRef]
72. Khan, S.A.R.; Yu, Z.; Ridwan, I.L.; Irshad, A.U.R.; Ponce, P.; Tanveer, M. Energy efficiency, carbon neutrality and technological innovation: A strategic move toward green economy. *Econ. Res.-Ekon. Istraz.* 2022; *ahead-of-print*. [CrossRef]
73. Kėdaitienė, A.; Klyvienė, V. The relationships between economic growth, energy efficiency and CO_2 emissions: Results for the euro area. *Ekonomika* **2020**, *99*, 6–25. [CrossRef]
74. Lin, B.; Benjamin, N.I. Determinants of industrial carbon dioxide emissions growth in shanghai: A quantile analysis. *J. Clean. Prod.* **2019**, *217*, 776–786. [CrossRef]
75. Mohsin, M.; Taghizadeh-Hesary, F.; Iqbal, N.; Saydaliev, H.B. The role of technological progress and renewable energy deployment in green economic growth. *Renew. Energy* **2022**, *190*, 777–787. [CrossRef]
76. Sun, H.; Edziah, B.K.; Kporsu, A.K.; Sarkodie, S.A.; Taghizadeh-Hesary, F. Energy efficiency: The role of technological innovation and knowledge spillover. *Technol. Forecast. Soc. Chang.* **2021**, *167*, 120659. [CrossRef]
77. Chen, M.; Sinha, A.; Hu, K.; Shah, M.I. Impact of technological innovation on energy efficiency in industry 4.0 era: Moderation of shadow economy in sustainable development. *Technol. Forecast. Soc. Chang.* **2021**, *164*, 120521. [CrossRef]
78. Li, Y.; Liu, A.-C.; Wang, S.-M.; Zhan, Y.; Chen, J.; Hsiao, H.-F. A Study of Total-Factor Energy Efficiency for Regional Sustainable Development in China: An Application of Bootstrapped DEA and Clustering Approach. *Energies* **2022**, *15*, 3093. [CrossRef]
79. Neofytou, H.; Sarafidis, Y.; Gkonis, N.; Mirasgedis, S.; Askounis, D. Energy efficiency contribution to sustainable development: A multicriteria approach in Greece. *Energy Sources Part B Econ. Plan. Policy* **2020**, *15*, 572–604. [CrossRef]
80. Shpak, N.; Melnyk, O.; Horbal, N.; Ruda, M.; Sroka, W. Assessing the implementation of the circular economy in the EU countries. *Forum Sci. Oeconomia* **2021**, *9*, 25–39. [CrossRef]
81. Yan, D.; Liu, H.; Yao, P. Assessing energy efficiency for economic and sustainable development in the region of European union countries. *Front. Environ. Sci.* **2021**, *9*, 779163. [CrossRef]
82. Dzwigol, H.; Dzwigol-Barosz, M. Sustainable Development of the Company on the basis of Expert Assessment of the Investment Strategy. *Acad. Strateg. Manag. J.* **2020**, *19*, 1–7.
83. Kuzior, A. Technological Unemployment in the Perspective of Industry 4.0. *Virtual Econ.* **2022**, *5*, 7–23. [CrossRef]
84. Ojaleye, D.; Narayanan, B. Identification of Key Sectors in Nigeria—Evidence of Backward and Forward Linkages from Input–Output Analysis. *SocioEconomic Chall.* **2022**, *6*, 41–62. [CrossRef]
85. World Data Bank. Worldwide Governance Indicators. 2022. Available online: https://data.worldbank.org (accessed on 10 February 2023).

86. Eurostat. 2022. Available online: https://ec.europa.eu/eurostat/web/main/data/database (accessed on 10 February 2023).
87. Gavkalova, N.; Lola, Y.; Prokopovych, S.; Akimov, O.; Smalskys, V.; Akimova, L. Innovative Development of Renewable Energy During the Crisis Period and Its Impact on the Environment. *Virtual Econ.* **2022**, *5*, 65–77. [CrossRef] [PubMed]
88. Coban, H.H.; Lewicki, W.; Sendek-Matysiak, E.; Łosiewicz, Z.; Drożdż, W.; Miśkiewicz, R. Electric Vehicles and Vehicle–Grid Interaction in the Turkish Electricity System. *Energies* **2022**, *15*, 8218. [CrossRef]
89. Kharazishvili, Y.; Kwilinski, A.; Sukhodolia, O.; Dzwigol, H.; Bobro, D.; Kotowicz, J. The systemic approach for estimating and strategizing energy security: The case of Ukraine. *Energies* **2021**, *14*, 2126. [CrossRef]
90. Samusevych, Y.; Vysochyna, A.; Vasylieva, T.; Lyeonov, S.; Pokhylko, S. Environmental, energy and economic security: Assessment and interaction. *E3S Web Conf.* **2021**, *234*, 00012. [CrossRef]
91. Mesagan, E.P.; Chidi, O.N. Energy consumption, capital investment and environmental degradation: The African experience. *Forum Sci. Oeconomia* **2020**, *8*, 5–16. [CrossRef]
92. Miśkiewicz, R. The Impact of Innovation and Information Technology on Greenhouse Gas Emissions: A Case of the Visegrád Countries. *J. Risk Financ. Manag.* **2021**, *14*, 59. [CrossRef]
93. Fila, M.; Levicky, M.; Mura, L.; Maros, M.; Korenkova, M. Innovations for business management: Motivation and barriers. *Mark. Manag. Innov.* **2020**, *4*, 266–278. [CrossRef]
94. Oe, H.; Yamaoka, Y.; Duda, K. How to Sustain Businesses in the Post-COVID-19 Era: A Focus on Innovation, Sustainability and Leadership. *Bus. Ethics Leadersh.* **2022**, *6*, 1–9. [CrossRef]
95. Vaníčková, R.; Szczepańska-Woszczyna, K. Innovation of business and marketing plan of growth strategy and competitive advantage in exhibition industry. *Pol. J. Manag. Stud.* **2020**, *21*, 425–445. [CrossRef]
96. Lyeonov, S.; Vasilyeva, T.; Bilan, Y.; Bagmet, K. Convergence of the institutional quality of the social sector: The path to inclusive growth. *Int. J. Trade Glob. Mark.* **2021**, *14*, 272–291. [CrossRef]
97. Szczepańska-Woszczyna, K.; Gedvilaitė, D.; Nazarko, J.; Stasiukynas, A.; Rubina, A. Assessment of Economic Convergence among Countries in the European Union. *Technol. Econ. Dev. Econ.* **2022**, *28*, 1572–1588. [CrossRef]
98. Miskiewicz, R. Clean and Affordable Energy within Sustainable Development Goals: The Role of Governance Digitalization. *Energies* **2022**, *15*, 9571. [CrossRef]
99. Keliuotytė-Staniulėnienė, G.; Daunaravičiūtė, K. The Global Green Bond Market in the Face of the COVID-19 Pandemic. *Financ. Mark. Inst. Risks* **2021**, *5*, 50–60. [CrossRef]
100. El Amri, A.; Oulfarsi, S.; Boutti, R.; Sahib Eddine, A.; Hmioui, A. Carbon Financial Markets Underlying Climate Change Mitigation, Pricing and Challenges: Technical Analysis. *Financ. Mark. Inst. Risks* **2021**, *5*, 5–17. [CrossRef]
101. Kabaklarli, E.; Duran, M.S.; Üçler, Y.T. High-technology exports and economic growth: Panel data analysis for selected OECD countries. *Forum Sci. Oeconomia* **2018**, *6*, 47–60. [CrossRef]
102. Didenko, I.; Volik, K.; Vasylieva, T.; Lyeonov, S.; Antoniuk, N. Environmental migration and country security: Theoretical analysis and empirical research. *E3S Web Conf.* **2021**, *234*, 00010. [CrossRef]
103. Zhang, D.; Mohsin, M.; Rasheed, A.K.; Chang, Y.; Taghizadeh-Hesary, F. Public spending and green economic growth in BRI region: Mediating role of green finance. *Energy Policy* **2021**, *153*, 112256. [CrossRef]
104. Chen, J.; Rojniruttikul, N.; Kun, L.Y.; Ullah, S. Management of green economic infrastructure and environmental sustainability in one belt and road enitiative economies. *Environ. Sci. Pollut. Res.* **2022**, *29*, 36326–36336. [CrossRef]
105. Levin, A.; Lin, C.F.; Chu, C.S.J. Unit root tests in panel data: Asymptotic and finite-sample properties. *J. Econom.* **2002**, *108*, 1–24. [CrossRef]
106. Im, K.S.; Pesaran, M.H.; Shin, Y. Testing for unit roots in heterogeneous panels. *J. Econom.* **2003**, *115*, 53–74. [CrossRef]
107. Cheung, Y.W.; Lai, K.S. Lag order and critical values of the augmented Dickey–Fuller test. *J. Bus. Econ. Stat.* **1995**, *13*, 277–280.
108. Pesaran, M.H. A simple panel unit root test in the presence of cross-section dependence. *J. Appl. Econom.* **2007**, *22*, 265–312. [CrossRef]
109. Drożdż, W.; Kinelski, G.; Czarnecka, M.; Wójcik-Jurkiewicz, M.; Maroušková, A.; Zych, G. Determinants of Decarbonization—How to Realize Sustainable and Low Carbon Cities? *Energies* **2021**, *14*, 2640. [CrossRef]
110. Kwilinski, A.; Lyulyov, O.; Pimonenko, T. Inclusive Economic Growth: Relationship between Energy and Governance Efficiency. *Energies* **2023**, *16*, 2511. [CrossRef]
111. Pesaran, M.H. General Diagnostic Tests for Cross Section Dependence in Panels. *Empir. Econ.* **2021**, *60*, 13–50. [CrossRef]
112. Djalilov, K. A Contingent Resource-Based Perspective on Corporate Social Responsibility and Competitive Advantage: A Focus on Transition Countries. *Bus. Ethics Leadersh.* **2022**, *6*, 92–108. [CrossRef]
113. Niftiyev, I.; Yagublu, N.; Akbarli, N. Exploring the Innovativeness of the South Caucasus Economies: Main Trends and Factors. *SocioEconomic Chall.* **2021**, *5*, 122–148. [CrossRef]
114. Shahbaz, M.; Nwani, C.; Bekun, F.V.; Gyamfi, B.A.; Agozie, D.Q. Discerning the role of renewable energy and energy efficiency in finding the path to cleaner consumption and production patterns: New insights from developing economies. *Energy* **2022**, *260*, 124951. [CrossRef]
115. Kiehbadroudinezhad, M.; Merabet, A.; Hosseinzadeh-Bandbafha, H. A life cycle assessment perspective on biodiesel production from fish wastes for green microgrids in a circular bioeconomy. *Bioresour. Technol. Rep.* **2023**, *21*, 101303. [CrossRef]
116. Wang, E.Z.; Lee, C.C. The impact of clean energy consumption on economic growth in China: Is environmental regulation a curse or a blessing? *Int. Rev. Econ. Financ.* **2022**, *77*, 39–58. [CrossRef]

117. Kiehbadroudinezhad, M.; Merabet, A.; Hosseinzadeh-Bandbafha, H. The role of the solar-based stand-alone microgrid to enhance environmental sustainability: A case study. *Energy Sources Part A Recovery Util. Environ. Eff.* **2022**, *44*, 6523–6536. [CrossRef]
118. Nie, X.; Chen, Z.; Yang, L.; Wang, Q.; He, J.; Qin, H.; Wang, H. Impact of carbon trading system on green economic growth in China. *Land* **2022**, *11*, 1199. [CrossRef]
119. Tamasiga, P.; Onyeaka, H.; Ouassou, E.h. Unlocking the Green Economy in African Countries: An Integrated Framework of FinTech as an Enabler of the Transition to Sustainability. *Energies* **2022**, *15*, 8658. [CrossRef]