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The Impact of Renewable Energy Consumption on Environmental Quality in Central European Countries: The Mediating Role of Digitalization and Financial Development

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Abstract: Green initiatives and digital transitions in Central European countries are catalyzing significant transformations within the region's socio-economic landscape, embedding contemporary technologies into daily life and commercial activities. Consequently, this fosters improved environmental quality through sustainable practices. This research unravels the complex interplay between renewable energy consumption, digitalization, and financial development in various national contexts, providing key insights into their respective and collective impacts on environmental quality. This study investigates the relationship among environmental quality, digitalization, renewable energy consumption, financial development, and economic growth in Central European countries, analyzing data from 1995 to 2019. An analysis of the panel data reveals a statistically significant positive relationship between economic growth and carbon emissions, and a negative relationship among digitalization, renewable energy consumption, and carbon emissions. In Central European nations, including the Czech Republic, Hungary, Latvia, and Slovakia, digitalization serves a mediating role in the relationship between renewable energy consumption and environmental quality. However, the role of financial development as a mediator between renewable energy consumption and environmental quality manifests varied impacts across different countries. These findings hold the potential to guide policy recommendations for the countries under consideration.

Keywords: digitalization; renewable energy; financial development; digital transition; Central Europe

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1. Introduction

In the 1990s, Central European countries underwent a significant economic transformation following the collapse of the Soviet Union and the end of communist regimes. These countries transitioned from centrally planned economies to market-oriented systems, implementing various reforms such as privatization, liberalization, and deregulation to stimulate economic growth, attract foreign investment, and integrate into the global economy. There was notable progress in financial development. These countries implemented reforms to establish modern financial systems, including the privatization of state-owned banks, the development of capital markets, and the enhancement of regulatory frameworks, which contributed to the growth of the banking sector, increased access to financial services, and facilitated investment and economic growth. Currently, Central European countries are experiencing a significant digitalization process. There is a growing adoption of digital technologies across various sectors, including e-commerce, digital government services, and digital infrastructure development, aiming to enhance efficiency, innovation, and connectivity. It should be added that nowadays the new media environment, which has a prevalence of digital technologies, significantly influences corporate green technology innovation, especially among heavily polluting industries, by motivating enterprises to adhere to stakeholder demands and enhance their green technological advancements, according to a study by Li et al. [1]. Moreover, Europe is entering a phase of both climate neutrality and digital supremacy. An important aspect in this regard is the increase in the consumption of energy from renewable sources. The objective is to position the European industry as a frontrunner in this era of transition.

The research goal of this study is to examine the relationship between environmental quality and digitalization, renewable energy consumption, financial development, and economic growth in Central European countries. Data spanning from 1995 to 2019 were utilized, focusing on eleven Central European countries, namely Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. The independent variable was CO_2 emissions per capita, while the independent variables encompassed the degree of digitalization, renewable energy consumption as a share of total final energy consumption, GDP per capita, and the Financial Development Index. To achieve this research goal, the methodology includes several steps. Firstly, cross-section dependence tests and slope homogeneity tests are conducted to investigate the potential cross-sectional dependence among the variables and assess the equality of the slopes. Secondly, the unit root and cointegration tests are employed to analyze the stationarity properties of the variables and investigate their long-term equilibrium relationship. Finally, the estimation of long-term effects and causality tests are conducted to assess the magnitude and significance of the established relationships and explore the direction of causality.

The intricate interplay among renewable energy consumption, digitalization, and financial development across diverse national contexts, as unfolded in the present research, elucidates crucial insights into their collective and individual impacts on environmental quality. In nations like the Czech Republic, Hungary, Latvia, and Slovakia, where renewable energy consumption and digitalization have demonstrated substantial potential in mitigating CO_2 emissions and enhancing environmental quality, respectively, the research underscores the pivotal role of embracing technological and digital advancements. Simultaneously, the variegated influence of financial development—being both a conduit for enhancing environmental quality in contexts like Lithuania and Latvia and a potential detractor in nations such as Bulgaria, Croatia, Estonia, and Slovenia—emphasizes the necessity to scrutinize and navigate the economic, policy, and regulatory frameworks judiciously. This research, while illuminating the multifaceted relationships among the explored variables, stands instrumental in guiding policy making and strategic development aimed at environmental sustainability. It has the potential to fortify strategic decision making, assist in structuring more efficacious policies, and inspire further research that might delve deeper into the nuanced mechanisms through which digitalization and financial development can be harnessed to optimize the environmental impacts of renewable energy consumption, thereby propelling nations towards their sustainability objectives.

This paper follows a structured outline. It begins with an introduction, providing an overview and stating the research objectives. The literature review section delves into the existing research on the connection between digitalization, renewable energy consumption, and environmental quality, as well as the relationship between financial development and environmental degradation, identifying gaps in the knowledge. The methodology section outlines the data collection process, the model employed, and the empirical procedures utilized in the analysis. The results and discussion section presents the findings, analyzes their implications, and compares them to prior research. Finally, the paper concludes with a summary of the main findings, potential policy recommendations, and suggestions for future research.

2. Literature Review

2.1. The Relationship between Digitalization, Renewable Energy Consumption, and Environmental Quality

Numerous studies underscore the direct impact of digitization on the environment, a topic that has garnered considerable interest across various regions and country groups. Several investigations have probed its relationship in diverse global contexts, exploring how digital transformation influences environmental factors. For example, Ke et al. [2] further explore the effect of digitalization on CO_2 emissions in developing countries. They find that while ICTs can contribute positively to reducing CO_2 emissions, globalization increases them. The interaction between ICTs and financial development also leads to an increase in emissions. These findings suggest that ICTs, while being a powerful tool in reducing emissions, can inadvertently contribute to increasing them when combined with other factors like globalization and financial development. Chen [3] investigates the influence of government size and the level of digitalization on CO_2 emissions in BRICS economies, including China. The findings indicate a negative effect of digitalization on CO_2 emissions, suggesting that investments in digital infrastructure can improve environmental quality. This provides an important perspective for policymakers on how to strike a balance between digital development and environmental sustainability. Lastly, Briglauer et al. [4] examine the net environmental impact of core ICT elements such as data centers, broadband networks, and consumer devices. Their results suggest that the CO_2 reducing effects outweigh the CO_2 increasing effects, providing evidence that both old and new broadband networks could generate positive environmental effects.

Researchers often shed light on both the positive and negative implications of digitalization on environmental quality. While aspects like improved resource optimization and enhanced energy efficiency are beneficial, digitalization can also precipitate challenges such as electronic waste generation and an increase in energy demand to power devices and data center increases. This can lead to an increase in greenhouse gas emissions and other forms of environmental pollution [5]. For example, Wang and Zhu investigate the impact of the digital economy on the energy demand in China and suggest that the rapid development of the digital economy leads to a sharp increase in energy demand, potentially hindering the transition to green and low-carbon development [6]. Similarly, the integration of digital technologies and automation in manufacturing processes, for example, leads to a greater energy consumption due to the operation of machinery and equipment [7]. However, it is important to note that the impact of digitalization on environmental quality is not solely determined by the technology itself. Policy and regulatory frameworks play a crucial role in shaping the environmental outcomes of digitalization. Environmental regulations can incentivize the development and adoption of environmentally friendly digital technologies and practices [8].

The second aspect of our research involves the relationship between digitalization, renewable energy consumption, and environmental quality, which has emerged as a pivotal area of research in recent years. Rapid digital transformation redefines various sectors, including business, education, and public services. Despite its undeniable benefits, the potential environmental impacts of this sweeping transition are a matter of significant concern. In the context of Central European countries, this issue takes on a unique dimension given their historical and socio-economic backdrop. By doing so, this review aspires to elucidate the complexities of this relationship.

Recently, several studies have been published on the impact of digitalization on renewable energy consumption and the environment in Europe. Haller et al. [9] found that the volume of greenhouse gas emissions in European countries is significantly impacted (decreasing) by digitalization (the number of individual internet users), economic growth, and renewable energy consumption. Ha et al. [10] investigate the relationship between digitalization and environmental performance in 25 European countries. The findings reveal that digital skills, business digitization, and digital public services significantly enhance environmental performance. Notably, the positive impact of digital skills and business digitization became more evident during the COVID-19 pandemic. Kuzior et al. [11] investigate the impact of digitalization on greenhouse gas emissions in the European Union countries. Surprisingly, the study concludes that digitalization's direct impact on greenhouse gas emissions is not significant or statistically noteworthy, and no observable effect was detected within a 1 to 4-year delay.

Thanh et al. [12] present the relationship in a slightly different context. They have conducted an empirical study to explore the connection between digital transformation and energy security in 27 European countries. Significantly, the research highlights that digitalization promotes sustainable economic development by increasing non-fossil and renewable energy consumption and reducing CO_2 emissions, particularly in the long term. Also, Martínez et al. [13] provide valuable insights into the link between digitalization and sustainable production in the 27 European Union countries from 2015 to 2019. The study reveals that all aspects of digitalization, alongside innovation and environmental policies, positively impact sustainability. This underscores the potential of digitalization and proactive policy making in enhancing sustainability, highlighting the need for societal commitment to sustainable practices.

We observe similar phenomena in other economically developed countries and groups. For example, Karlilar et al. [14] found that combining digitalization with green innovation, renewable energy, and financial development significantly enhanced environmental sustainability in OECD countries from 2000 to 2018. Furthermore, the synergistic interaction between these factors intensifies the positive ecological impact of digitalization, indicating that combining digitalization with environmental policies can lead to more effective environmental quality improvements than implementing them separately. The study by Mehmood et al. [15] examines data from G8 economies between 1990 and 2018. The findings show that green energy, technological innovation, and digitalization positively affect the environment. Zhou et al. [16] found that the increasing use of digital technology in Japan is driving up the demand for renewable energy, as evidenced by ICT's positive and significant coefficients. Similarly, higher levels of education are strongly associated with a greater need for renewable energy in both the short and long term.

A significant number of research publications center their focus on the countries located in the Asian continent that are transforming their economies. For instance, the study by Wang et al. [17] reveals that the digital economy positively influences renewable energy generation in Asian countries from 2003 to 2019, and this relationship is further strengthened by financial development, political stability, and the rule of law. Additionally, the impact of the digital economy on renewable energy generation is more pronounced in developed Asian countries compared to their developing counterparts, with East and South Asian countries showing particularly significant positive effects. The research conducted by Rehman et al. [18] reveals that while information digitalization in South Asian countries positively impacts renewable electricity generation at the decision level, it is not effectively implemented, leading to a negative influence due to mismanagement at administrative levels. Additionally, technology innovation boosts renewable electricity generation in these countries, thanks to the technology spillover effect, as they prioritize importing renewable technologies and attracting foreign investments for renewable energy projects.

2.2. The Relationship between Financial Development, Renewable Energy Consumption, and Environmental Quality

Understanding how financial development influences renewable energy consumption and carbon emissions is crucial for designing effective policies and strategies to mitigate climate change. This literature review aims to comprehensively analyze the existing research on the influence of financial development on carbon emissions.

Despite the environmental Kuznets curve's regularities, financial development often increases carbon emissions in developed and developing countries. For instance, Samour et al. [19] showcase that financial development is positively associated with carbon emissions, while renewable energy consumption enhances environmental quality in the top ten carbon-emitting countries. The authors used data from China, USA, India, Russia, Japan, Iran, Germany, South Korea, Saudi Arabia, and Indonesia spanning 1990–2018. Shoaib et al. [20] also found that financial development significantly increased carbon emissions in both developed and developing countries from 1999 to 2013. To enhance environmental quality, the study recommends investing more funds in renewable energy projects through an improved financial system, implementing strict monetary policies, and adopting measures to reduce trade-embodied emissions.

Positive effects of investments in renewable energy projects have been presented, among others, in studies by Kim and Park [21]. The authors analyzed a 30-country sample from 2000 to 2013. They found that countries with well-developed financial markets experience faster growth in the renewable energy sectors that rely heavily on debt and equity financing. Financial development contributes to reducing CO_2 emissions by facilitating the deployment of renewable energy through robust financial markets. Wen et al. [22] found that financial development and capital flows positively influence renewable energy consumption across all three categories of developing countries (high-income, low-income, and overall). There is bidirectional causality between financial development and renewable energy, as well as between capital flows and renewable energy in both high-income and overall developing countries. However, causality flows solely from financial development and capital flows to renewable energy in low-income countries. Ahmad et al. [23] investigated 11 countries (Croatia, Ecuador, El Salvador, Georgia, Honduras, Indonesia, Jordan, Morocco, Pakistan, Paraguay, and Sri Lanka) under the Environmental Kuznets Curve framework. The study unveiled that renewable energy transition and financial globalization significantly diminish the ecological footprint, whereas the abundance of natural resources amplifies it. The research also deduces that financial globalization acts as a moderating force, attenuating the ecological footprint through the renewable energy transition, reaffirming the EKC hypothesis for these nations.

Similar relationships are shown in studies in the group of economically developed countries. For instance, Al-Mulali et al. [24] examined the interplay between renewable energy consumption, economic growth, financial development, urbanization, and CO_2 in 23 European countries from 1990 to 2013. Economic growth, urbanization, and financial development increased CO_2 emissions in the long run, while renewable electricity from combustible renewables, waste, hydroelectricity, and nuclear power reduced CO_2 emissions. However, the effect of renewable electricity generated from solar and wind power on CO_2 emissions was insignificant. Optimistically, Khalid et al. (2022) [25] found that renewable energy consumption and globalization are improving environmental quality in the long term, while urbanization, economic growth, and nonrenewable energy consumption in G-7 countries are hampering it. But Lin et al.'s [26] overarching findings suggest that both financial development and governance exert a modest impact on these countries' GHG emissions and renewable energy production. However, causality exists from financial development to renewable energy generation and governance to GHG emissions. The authors investigated the influence of financial development and governance on renewable energy generation and greenhouse gas (GHG) emissions across 35 high-income countries between 1996 and 2020. It is important to add that in some countries, financial development can affect energy diversification positively, for example in Australia, as proven in the research of Shahbaz et al. [27].

Khan et al. [28] analyzed 34 high-income countries (Asia, Europe, and America) from 1995 to 2017. The authors showed that financial development is associated with decreased GHG emissions in Asia and America and that a link between financial development and renewable energy consumption is evident in Europe. Recommendations from the study include promoting renewable energy and eco-friendly technologies in Asia and America, establishing renewable energy agencies with mandatory targets, supporting eco-friendly projects with financial incentives, and emphasizing environmentally friendly tourism and education about the importance of a clean environment. Aydin et al. [29] conducted research that partially confirms the results for European countries. The authors analyzed the top ten renewable energy-consuming OECD countries from 1994 to 2019. They found that environmental taxes play a significant role in encouraging renewable energy consumption in the long run. While financial development, green innovation, and environmental taxes were found to boost renewable energy consumption, the influence of economic growth was not consistently significant, highlighting the intricate relationship between these factors and renewable energy use. Additionally, the green financial policy in OECD countries, as illuminated through a comparative analysis from 2001 to 2019 by Steffen [30], utilizes key instruments like carbon disclosure requirements, low-carbon investment policies for public funds, and green state investment banks to redirect financial flows toward investments in low-carbon technologies, thereby aiding in the mitigation of deleterious climate change by fostering a transition to more sustainable practices.

The research results in the group of emerging economies are not so unambiguous. Habiba et al. [31] examined seven emerging countries from 1990 to 2020. They found that while financial development tends to increase carbon emissions, leading to environmental degradation, integrating renewable energy consumption with green technology significantly reduces carbon emissions in the long run. Furthermore, the research highlights that financial development, when aligned with renewable energy practices, becomes less harmful to the environment and can indeed foster environmental quality by adopting green technologies. The recent research by Ali et al. [32] examined the effects of financial development and energy resources on environmental sustainability in the world's seven fastest emerging economies (Brazil, China, India, Indonesia, Mexico, Russian Federation, and Türkiye) from 2000 to 2020. The findings indicate that while high financial development, rapid economic growth, and increased non-renewable energy consumption significantly impact environmental sustainability, renewable energy resources and globalization are associated with reduced CO_2 emissions. Zhou et al. [33] studied four emerging Asian countries between 2010 and 2021. They discovered that renewable energy output, green technological innovation, and financial development play crucial roles in reducing carbon emissions, thereby aiding these nations in their journey towards carbon neutrality. The research supports the environmental Kuznets curve hypothesis for these economies. It emphasizes the importance of investments in green recovery projects to achieve sustainable environmental goals and a carbon-neutral society.

Recently, green finance has emerged as a pivotal instrument in mitigating environmental degradation and propelling sustainable development by leveraging investments towards projects and initiatives that are environmentally friendly. The numerous studies cited demonstrate the myriad of ways through which green finance yields positive impacts, notably, the reduction of environmental degradation and promotion of environmental quality [34–36]. Particularly, green finance reduces the financial burden of green projects by diminishing their financing costs, which indirectly augments environmental quality through the reduction of abatement costs [34]. For example, the study by Afzal et al. [37] on green finance and sustainable development in Europe suggests that financial development is positively related to environmental quality, as measured through variables like energy use, CO_2 emissions, greenhouse emissions, and natural resource depletion across a sample of 40 European countries from 1990 to 2019. In addition to promoting high-quality economic development and curbing environmental pollution, green finance can sometimes dampen clean energy production [38].

3. Data, Model and Empirical Procedure

3.1. Data Collection and Model

The study employed annual data from the period of 1995 to 2019 for eleven Central European countries: Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. Table 1 provides an overview of the variables used in this study. Each variable is listed with its description and source. The dependent variable is CO_2 emissions per capita, and the independent variables include the level of digitalization (represented by the proportion of individuals using the internet), GDP per capita (constant 2010 USD), Financial Development Index, and renewable energy consumption (% of total final energy consumption).

Table 1. Data description.

Variable	Pictogram	Unit Measurement	Source
Carbon emissions	CO_2	CO_2 emissions (metric tons per capita)	World Bank Open Data
Digitalization	DG	Individuals using the Internet (% of population)	WDI
GDP per capita	Y	Constant 2010 USD	World Bank Open Data
Financial Development	FD	Financial Development Index	IMF Database
Renewable Energy	RE	Renewable energy consumption (% of total final energy consumption)	World Bank Open Data

The model developed in this study takes the form

$$CO_{2\ i,t} = \beta_0 + \beta_1 DG_{i,t} + \beta_2 Y_{i,t} + \beta_3 FD_{i,t} + \beta_4 RE_{i,t} + \varepsilon_{i,t} \quad (1)$$

where $i = 1, \ldots, N$ indicate cross-section units (country); $t = 1, \ldots, T$ is the time period; $\beta_0, \ldots\ldots, \beta_4$ represent parameters the coefficients that quantify the impact of the independent variables on the dependent variable in the model; and $\varepsilon_{i,t}$ represents the error term for country i at time t.

3.2. Empirical Procedure

In this section, we outline the empirical procedure employed to analyze the relationship between environmental quality and renewable energy consumption, digitalization, economic growth, and financial development. In the initial phase, the analysis involved cross-section dependence tests and conducting slope homogeneity. Subsequently, unit root and cointegration tests were employed in the second part of the analysis. Unit root tests were conducted to assess the stationarity properties of the variables, while cointegration tests aimed to investigate the long-term equilibrium relationship among the variables. Finally, the analysis included the estimation of long-term effects and causality tests.

To assess cross-section dependence (CSD), several tests were utilized in the analysis. These tests include Breusch-Pagan LM test: developed by Breusch and Pagan [39], this test examines the presence of heteroscedasticity and cross-sectional dependence in the data; Pesaran scaled LM (CD_{LM}) test: developed by Pesaran [40], this test is used to detect cross-sectional dependence by evaluating the residuals of the regression model; Pesaran CD test: also developed by Pesaran [41], this test examines cross-sectional dependence by analyzing the pairwise correlation coefficients between the residuals of the regression model; and Bias-Corrected Scaled LM (LMadj) test: developed by Pesaran, Ullah, and Yamagata [42], this test is an improved version of the Pesaran scaled LM test, which accounts for potential biases in the presence of cross-sectional dependence.

Equations (2)–(5) represent the mathematical formulations for the four tests mentioned earlier.

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \quad (2)$$

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T\hat{\rho}_{ij}^2 - 1 \right) \quad (3)$$

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=1+1}^{N} \hat{\rho}_{ij} \right) \quad (4)$$

$$LM_{adj} = \left(\frac{2}{N(N-1)} \right)^{1/2} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \frac{(T-K-1)\hat{\rho}_{ij} - \hat{\mu}_{Tij}}{v_{Tij}} \sim N(0,1) \quad (5)$$

To test slope homogeneity, the study employed Δ tests developed by Pesaran, Ullah, and Yamagata [42]. Additionally, if there were indications of serial correlation and heteroskedasticity in the regression errors, Δ tests developed by Blomquist and Westerlund [43] were utilized. The equations corresponding to these tests are as follows:

$$\Delta_{HAC} = \sqrt{N}\left(\frac{N^{-1}S_{HAC} - k}{\sqrt{2k}}\right) \tag{6}$$

$$S_{HAC} = \sum_{i=1}^{N} T\left(\hat{\beta}_i - \hat{\beta}\right)'\left(\hat{O}_{\dot{I}T} V_{\dot{I}T}^{-1} \hat{O}_{\dot{I}T}\right)\left(\hat{\beta}_i - \hat{\beta}\right) \tag{7}$$

$$\hat{\beta} = \left(\sum_{i=1}^{N} T\hat{O}_{\dot{I}T} V_{\dot{I}T}^{-1} \hat{O}_{\dot{I}T}\right)^{-1} \sum_{i=1}^{N} \hat{O}_{\dot{I}T} \hat{V}_{\dot{I}T}^{-1} X_i' M_T y_i \tag{8}$$

$$\hat{V}_{\dot{I}T} = \hat{\Gamma}_i(0) + \sum_{j=1}^{T-1} K\left(\frac{j}{M_{\dot{I}T}}\right)\left[\hat{\Gamma}_i(j) + \hat{\Gamma}_i(j)'\right] \tag{9}$$

In the study, the Cross Sectionally Augmented IPS (CIPS) and Cross-Sectionally Augmented ADF (CADF) panel unit root tests developed by Pesaran [41] were employed. These tests are used to assess the presence of unit roots in panel data. The equations corresponding to these tests are as follows:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + u_{it} \tag{10}$$

$$u_{it} = \gamma f_t + \varepsilon_{it} \tag{11}$$

In the absence of autocorrelation, the CADF regression is represented by Equation (12). However, in the presence of autocorrelation, Equation (13) is used, which includes the addition of the first-order differences of y_{it} and $\overline{y}_{it}$.

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + d_0 \overline{y}_{t-1} + d_1 \Delta \overline{y}_t + \varepsilon_{it} \tag{12}$$

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + c_i \overline{y}_{t-1} + \sum\nolimits_{j=0}^{p} d_{i,j} \Delta \overline{y}_{t-j} + \sum\nolimits_{j=0}^{p} \beta_{i,j} \Delta y_{i,t-j} + \mu_{i,t} \tag{13}$$

To calculate the CIPS statistic as indicated in Equation (14), the t-statistics of the lagged variables are averaged.

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \tag{14}$$

In the case of Cross-Sectional Dependence (CSD), the study employs the Westerlund and Edgerton [44] Panel LM bootstrap cointegration test, which is based on the Lagrange test multiplier developed by McCoskey and Kao [45]. The test is derived from Equations (15) and (16).

$$\gamma_{it} = \alpha_i + x_{it}' \beta_{it} + Z_{it} \tag{15}$$

$$Z_{it} = \mu_{it} + V_{it}\ V_{it} = \sum\nolimits_{J=1}^{t} \eta_{ij} \tag{16}$$

The LM statistics, which are employed in the cointegration testing conducted by Westerlund and Edgerton [44] using bootstrap critical values under Cross-Sectional Dependence (CSD), are presented in Equation (17).

$$LM_N^{+} = \frac{1}{NT^2} \sum_{i=1}^{N} \sum_{t=1}^{t} \hat{\omega}_i^{-2}\, S_{it}^2 \tag{17}$$

The second-generation bootstrap AMG (Augmented Mean Group) estimator, developed by Eberhardt and Bond [46] and Teal and Eberhardt [47], is applicable in the presence of Cross-Sectional Dependence (CDS) and slope heterogeneity in panel data. The bootstrap AMG method follows a two-stage process, with the first stage represented by Equation (18).

$$\Delta X_{it} = \delta_i + \beta_i \Delta Y_{it} + \gamma_i A_t + \sum_{t=2}^{T} \delta_i \Delta D_t + \varepsilon_{it} \quad (18)$$

The model estimated in the second step is described by Equation (19).

$$\hat{\beta}_{AMG} = N^{-1} \sum_{i=1}^{N} \hat{\beta}_i \quad (19)$$

In the second stage, Equation (19) incorporates a time dummy variable included in the regression for each cross-sectional unit. These time dummies capture time-specific effects or trends in the data. The AMG (Augmented Mean Group) estimates are obtained by averaging the individual country estimates, which helps to account for country-specific heterogeneity while capturing the overall patterns and dynamics of the panel data.

It tests the relationship between X and Y. The Dumitrescu and Hurlin [48] bootstrap causality test, which can be used in heterogeneous panels in the case of N > T or T > N and cross-section dependence, is as follows:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \beta_{ik} y_{i,t-k} + \sum_{k=1}^{K} \gamma_{i,k} X_{i,t-k} + \varepsilon_{it} \quad (20)$$

In Equation (20), $X_{i,t}$ and $y_{i,t}$ represent the stationary variable observations in the t period for each i. It is assumed that the coefficients differ between each i but are invariant with time, the lag length is the same for each i, and the panel is balanced. In the CDS entity, bootstrapped critical values are used and can be formulated as follows.

$$\overline{W} = \frac{1}{N} \sum_{i=1}^{N} W_i \quad (21)$$

$$\overline{Z} = \sqrt{\frac{N}{2K}} \left(\overline{W} - K \right) \quad (22)$$

4. Results and Discussion

In this section of the research, empirical findings regarding the impact of digitalization, financial development, and renewable energy consumption on environmental quality in Central European countries are presented. Table 2 presents the descriptive statistics and correlation analysis of the variables utilized in the research.

Table 2. Summary statistics and correlation matrix.

	CO_2	DIG	Y	FD	RE
Mean	6.591	43.344	11,008.990	0.326	10.932
Std. dev.	2.850	29.289	6335.932	0.111	8.254
Min.	2.926	0.011	1361.392	0.090	0.451
Max.	14.904	90.228	27,595.600	0.570	34.515
Obs.	275	275	275	275	275
CO_2	1.0000				
DIG	0.0743	1.0000			
Y	0.2187	0.8531	1.0000		
FD	0.2207	0.3821	0.4908	1.0000	
RE	−0.2861	0.0251	−0.0726	0.0914	1.0000

The study outcomes underscore a discernible positive connection between environmental quality and economic growth, financial development, and digitalization. Fortunately, the data reveal a tenuous positive correlation between carbon dioxide emissions (CO_2) and digitalization (DIG), represented by a correlation coefficient of 0.0743. This suggests that despite there being a mild concurrent increase in both parameters, the relationship they share is relatively weak, indicating that the rise in digitalization does not significantly contribute to an upswing in CO_2 emissions. Optimistically, an inverse relationship was observed between renewable energy consumption and CO_2 emissions, fostering hope for a greener, sustainable future wherein an augmentation in renewable energy usage might potentially curb CO_2 emissions. The strongest relationship within the examined parameters exists between digitalization and economic growth, boasting a substantial positive correlation coefficient of 0.8531. This significant figure intimates that as digitalization proliferates, there tends to be a concurrent surge in economic growth, showcasing a robust synergy between the advancement in digital technology and economic prosperity. This relationship suggests that fostering digitalization could potentially be a catalyst for stimulating economic growth.

The results from the cross-sectional dependence tests, as indicated in Table 3, provide strong evidence of cross-sectional dependence among the variables. All four tests (Breush-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, and Pesaran CD) display highly significant results at the 1% level. These findings suggest that the variables are interrelated and influenced by common factors or spatial dependencies. It is imperative to account for the presence of cross-sectional dependence when analyzing or modeling these variables to ensure accurate and robust results.

Table 3. Cross-sectional dependence test results.

Variables	**CO_2**	**DIG**	**Y**	**FD**	**RE**
Breush-Pagan LM	396.412 ***	425.918 ***	781.515 ***	651.621 ***	544.917 ***
Pesaran scaled LM	40.521 ***	43.917 ***	87.632 ***	65.812 ***	76.835 ***
Bias-corrected scaled LM	37.219 ***	39.531 ***	52.053 ***	49.131 ***	52.743 ***
Pesaran CD	10.401 ***	12.429 ***	21.505 ***	19.734 ***	14.743 ***

Note: *** denotes significance at 1% level.

In the conducted research, the Blomquist and Westerlund slope homogeneity test, a pivotal statistical tool in discerning the nature of relationships between variables in a model, was employed, with the findings illustrated in Table 4. A crucial result from this test is the rejection of the null hypothesis (H_0), which posited the presence of slope homogeneity within the model. The negation of this hypothesis thereby signals a significant incidence of slope heterogeneity in the developed model. This heterogeneity implies that the relationships between the variables are not uniform, with different variables potentially having varying degrees of impact and interactions with each other. Consequently, it becomes imperative to integrate this insight into the subsequent analyses.

Table 4. Blomquist and Westerlund slope homogeneity test results.

$\tilde{\Delta}$	$\tilde{\Delta}$adj
7.984 ***	9.789 ***

Note: *** denotes significance at 1% level.

Table 5 presents the results of the CADF (Cross-sectional Augmented Dickey–Fuller) and CIPS (Cross-sectional Im, Pesaran, and Shin) unit root tests. The test results indicate that all variables are non-stationary, as evidenced by the highly significant CADF test statistics. After taking the first difference, all variables become stationary, as indicated by the highly significant CADF and CIPS tests statistics for the first difference. These results suggest that differencing the variables can eliminate non-stationarity and help establish stationary time series, which are important for further analysis and modeling.

Table 5. CADF and CIPS unit root test results.

Variables	CADF (Constant)		CIPS (Constant)	
	Level	First Difference	Level	First Difference
CO_2	−0.433 ***	−2.250 ***	−3.341 ***	−8.713 ***
DIG	−0.457 ***	−2.491 ***	−3.591 *	−9.153 ***
Y	−0.792 ***	−3.957 ***	−5.143 **	−12.632 ***
FD	−0.650 ***	−3.282 ***	−4.522 *	−10.950 ***
RE	−0.583 ***	−2.597 ***	−5.727 **	−11.415 ***

Note: *, ** and *** denote significance at 10%, 5% and 1% level, respectively.

Table 6 presents the results of the Westerlund–Edgerton LM Bootstrap [44] cointegration test. Given the presence of cross-section dependency between the series, it is important to consider the Bootstrap-p value. In the context of the model developed in this study, since the Bootstrap-p value is greater than 0.05, the null hypothesis (H_0) of the Westerlund–Edgerton LM Bootstrap test is accepted. These findings indicate that the variables exhibit a co-movement in the long run, suggesting the presence of a cointegration relationship among them.

Table 6. Westerlund–Edgerton LM bootstrap cointegration test results.

	LM Statistic	Asymptotic p-Value	Bootstrap p-Value
LMN^T	7.893	0.000	0.805

Note: The number of bootstrap iterations is 1000. The test result is obtained with the constant and trend models.

Table 7 provides an analysis of the cointegration direction and coefficient estimation of the model using the AMG estimator. The analysis of the panel data reveals a statistically significant negative relationship between digitalization, renewable energy consumption, and carbon emissions, at a significant level of $p < 0.01$. This finding elucidates that advancements in digitalization and an uptick in renewable energy consumption reciprocally foster a positive influence on environmental quality in Central European countries. This can potentially signify a promising transition towards a more sustainable paradigm, wherein technological progression and renewable energy harnessing work synergistically to curb carbon emissions. Our findings align with similar conclusions found in studies on European countries. Haller et al. [9] found that the volume of greenhouse gas emissions is significantly impacted by digitalization and renewable energy consumption. The papers by Ha et al. [10], Thanh et al. [12], and Martínez et al. [13] collectively support the notion that digitalization has positive effects on various aspects of sustainability within the European Union countries.

Table 7. The long-term AMG estimation results (panel).

$CO_{2,i,t} = \beta_0 + \beta_1 DIG_{i,t} + \beta_2 Y_{i,t} + \beta_3 FD_{i,t} + \beta_4 RE_{i,t} + \vartheta_{i,t}$			
Dependent Variable: CO_2		**AMG**	
	Coefficient	**Standard Error**	p
DIG	−0.01152	0.00263	0.000
Y	0.00002	0.00001	0.000
FD	0.08656	1.1034	0.872
RE	−0.03300	0.00321	0.000
Wald chi^2		33.54	
Prob. > chi^2		0.000	

Furthermore, the study establishes a positive relationship between economic growth and carbon emissions in the Central European region. Specifically, an increase in GDP per capita is associated with higher carbon emissions per capita. These findings are consistent with previous research, such as Baloch et al. [49] and Majeed and Mazhar [50], while contrasting with the findings of Khan et al. [28]. Similarly, the panel results indicate that financial development does not significantly impact environmental quality ($p > 0.05$). Overall, the findings of this study support the notion that digitalization and renewable energy consumption contribute positively to environmental quality, while economic growth is associated with increased carbon emissions. Moreover, the study suggests that financial development does not play a significant role in shaping the environmental quality, in line with the research conducted by Shahbaz et al. [51]. This is surprising, given that previous results discussed by Al-Mulali et al. [24] indicated a significant relationship between financial development and CO_2 emissions in European countries.

Table 8 presents the results of the long-term AMG estimation, including the estimated coefficients, standard errors, and probabilities associated with the variables (*p*-value). In the context of Central European countries such as the Czech Republic, Hungary, Latvia, and Slovakia, digitalization plays a mediating role in the relationship between renewable energy consumption and environmental quality, as indicated by the observed statistical relationships. On the one hand, a negative and significant relationship is identified between renewable energy consumption and CO_2 emissions, signaling that an increase in renewable energy usage correlates with a decline in CO_2 emissions. Concurrently, digitalization is associated positively with environmental quality, attributed to its capability to augment resource efficiency and foster sustainable innovation by enabling meticulous resource management, optimization, and the cultivation of eco-friendly products, services, and business models. Therefore, in this context, digitalization acts as a mediator that not only directly improves environmental quality but also potentially enhances the impact of renewable energy consumption on environmental outcomes by facilitating more efficient and innovative uses of renewable energy, although a further detailed study would be necessary to fully elucidate this mediating role.

In this context, our finding bears similarity to the results discovered by other scholars, as mentioned above. Haller et al. [9] discerned a significant impact of digitalization and renewable energy consumption on reducing the volume of greenhouse gas emissions in European countries. Likewise, Ha et al. [10] unearthed a relationship between digitalization and enhanced environmental performance in 25 European countries, with digital skills, business digitization, and digital public services particularly boosting environmental performance. However, it is worthy to note the nuanced complexity in this subject, as seen in Kuzior et al.'s [11] study, which concluded that digitalization's direct impact on the environment (greenhouse gas emissions) in the European Union countries was neither statistically significant nor noticeable, even with a 1 to 4-year delay, thus emphasizing the multifaceted and diverse implications of digitalization on environmental outcomes across varied contexts and study parameters. Our findings address this issue in countries such as Bulgaria, Croatia, Estonia, Lithuania, Poland, Romania, and Slovenia, where neither renewable energy consumption nor digitalization was found to have a significant impact on environmental quality, highlighting the variable impacts and relationships across different regional contexts.

In Central European countries, the role of financial development as a mediator in the relationship between renewable energy consumption and environmental quality reveals varied impacts across different nations. In the context of Lithuania and Latvia, an increase in financial development exhibits a positive influence on environmental quality, signaling a potential mediating effect where financial development not only directly impacts environmental quality but may also amplify the positive effects of renewable energy consumption on the environment by facilitating investments in renewable energy projects, promoting energy efficiency, and supporting sustainable initiatives. These mechanisms are congruent with the findings of Afzal et al. [37], who, in their study on green finance and sustainable development across

Europe, posited a positive relationship between financial development and environmental quality. Khan et al. [28] also substantiate the relationship between financial development and renewable energy consumption within the European context, further affirming the aforementioned associations. This suggests that within Europe, financial development may potentially play a pivotal role in steering or influencing renewable energy consumption patterns, reinforcing the confluence between financial systems and sustainable energy initiatives. Furthermore, in this nexus, financial institutions emerge as pivotal actors, with the capacity to further fortify environmental quality by enforcing and promulgating environmental standards and policies. Through strategic investments, sagacious lending practices, and active shareholder activism, these institutions can serve to both directly and indirectly enhance the environmental benefits stemming from increased renewable energy consumption.

Table 8. The long-term AMG estimation results (countries).

$CO_{2,i,t} = \beta_0 + \beta_1 DIG_{i,t} + \beta_2 Y_{i,t} + \beta_3 FD_{i,t} + \beta_4 RE_{i,t} + \vartheta_{i,t}$				
		Coefficient	**Standard Err.**	***p*-Value**
Bulgaria	DIG	−0.0111	0.0100	0.2306
	Y	0.0002 **	0.0001	0.0122
	FD	1.4009	0.7668	0.0592
	RE	−0.0214	0.0241	0.1602
Croatia	DIG	−0.0067	0.0072	0.3054
	Y	−2.4448	0.0001	0.8396
	FD	6.6095 **	2.6341	0.0104
	RE	−0.0059	0.0047	0.4815
Czech Rep.	DIG	−0.0230 *	0.0109	0.0296
	Y	0.0001	0.0000	0.1253
	FD	−3.5235	3.4766	0.2706
	RE	−0.0167 **	0.0265	0.0192
Estonia	DIG	−0.0241	0.0260	0.3062
	Y	0.0001	0.0001	0.2219
	FD	21.9170 **	9.0962	0.0139
	RE	−0.0015	0.0053	0.5459
Hungary	DIG	−0.0110	0.0060	0.0583
	Y	0.0001	0.0000	0.0722
	FD	−0.8330	0.9335	0.3236
	RE	−0.0363 ***	0.0291	0.0000
Latvia	DIG	−0.0179 ***	0.0045	0.0000
	Y	0.0000	0.0000	0.0853
	FD	−5.0565 ***	0.8722	0.0000
	RE	−0.0194 ***	0.0031	0.0021
Lithuania	DIG	−0.0003	0.0074	0.8448
	Y	0.0001 ***	0.0000	0.0026
	FD	−2.9635 ***	1.0202	0.0035
	RE	−0.0012	0.0261	0.6961
Poland	DIG	−0.0069	0.0096	0.4089
	Y	0.0001	0.0001	0.2688
	FD	1.6458	2.3274	0.4167
	RE	−0.0084	0.0585	0.3065
Romania	DIG	−0.0050	0.0076	0.4446
	Y	0.0000	0.0000	0.4637
	FD	1.0437	1.3559	0.3837
	RE	−0.0031	0.0151	0.5013
Slovakia	DIG	−0.0112 ***	0.0036	0.0017
	Y	0.0000	0.0000	0.1140
	FD	−1.6226	2.1373	0.3898
	RE	−0.0252 ***	0.0421	0.0091
Slovenia	DIG	−0.0039	0.0041	0.2941
	Y	0.0000	0.0000	0.0461
	FD	3.1671 ***	0.6414	0.0000
	RE	−0.0016	0.0016	0.4322

Note: *, ** and *** denote significance at 10%, 5% and 1% level, respectively.

However, in countries like Bulgaria, Croatia, Estonia, and Slovenia, an expansion in financial development is associated with an uptick in carbon emissions, indicating a contrasting mediation effect. The aforementioned complexity underscores the necessity of a nuanced understanding of the intermediary role of financial development, particularly considering that, as revealed by the analysis, economic growth also plays a complex role in affecting environmental quality. Specifically, in Bulgaria, Hungary, Latvia, Lithuania, and Slovenia, an increase in economic growth correlates with a deterioration in environmental quality, emphasizing the importance of dissecting and understanding the various direct and indirect paths through which financial development and economic growth influence, and are influenced by, the utilization of renewable energy and the broader sustainable development context within each nation.

The intricate relationships among renewable energy consumption, carbon emissions, economic growth, digitalization, and financial development are corroborated by the results of the Dumitrescu–Hurlin panel bootstrap causality test, as depicted in Table 9. The findings disclose a bidirectional causality relationship between renewable energy consumption and carbon emissions, implying that alterations in one can influence the other and vice versa. Furthermore, a similar reciprocal causality is observed among economic growth, digitalization, financial development, and carbon emissions, revealing an interwoven and mutually impactful association among these variables, thereby underscoring the complexity of the relationships in the examined contexts. The detected bidirectional causality implies a nuanced and complex scenario for economic policy making. Therefore, meticulous attention to policy frameworks is paramount to ensure that interventions in one area do not inadvertently foster negative outcomes in another. Moreover, the mutual influence between economic growth, digitalization, and financial development in relation to carbon emissions suggests that policies in these areas must be formulated with a holistic, integrated approach.

Table 9. Dumitrescu–Hurlin panel bootstrap causality test results.

Hypothesis	W-Stat.	Zbar-Stat.	Bootstrapped *p*-Value
$DIG \neq CO_2$	13.6167	13.616	0.000
$CO_2 \neq DIG$	10.020	3.894	0.000
$Y \neq CO_2$	21.6217	14.9566	0.000
$CO_2 \neq Y$	12.3867	7.7472	0.000
$FD \neq CO_2$	12.8442	6.5528	0.000
$CO_2 \neq FD$	4.1112	7.2963	0.000
$RE \neq CO_2$	11.524	9.631	0.000
$CO_2 \neq RE$	6.272	4.989	0.000

5. Conclusions and Policy Recommendations

Understanding the interplay between digitalization, renewable energy consumption, financial development, and economic growth is essential for formulating effective strategies to promote sustainable development in Central European countries. Therefore, the aim of this study is to investigate these interactions, with a particular focus on their implications for environmental quality. The analysis utilizes annual data from 11 Central European countries (Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia) covering 1995 to 2019.

The study unfolds pivotal insights into the relationship between renewable energy consumption, digitalization, and environmental quality within a selection of Central and Eastern European countries. A discernible, negative correlation between renewable energy consumption and CO_2 emissions was empirically established in the Czech Republic, Hungary, Latvia, and Slovakia, while concurrently, a positive association between digitalization and environmental quality was also identified within the same nations. Digitalization emerges as a mediating factor, which not only intrinsically ameliorates environmental quality but potentially amplifies the positive repercussions of renewable energy consumption on environmental outcomes by enabling more efficacious and innovative applications of renewable energy. The need for further comprehensive studies is highlighted to thoroughly decipher the nuanced dynamics of this mediating role. Intriguingly, a stark contrast is noted in the context of Bulgaria, Croatia, Estonia, Lithuania, Poland, Romania, and Slovenia, where neither renewable energy consumption nor digitalization was found to exert a significant impact on environmental quality. This disparity in outcomes is potentially ascribed to a myriad of influences, such as divergent economic structures, environmental policies, technological infrastructures, and socio-cultural dimensions, underlining the intrinsic complexity and multifaceted nature of these relationships.

Diving deeper into the dynamics of financial development as a mediator between renewable energy consumption and environmental quality uncovers a spectrum of impacts thereby illustrating a complex and varied tapestry of outcomes across distinct nations. Particularly in Lithuania and Latvia, the augmentation of financial development seems to cast a beneficial glow upon environmental quality. It becomes apparent that financial development does not just directly influence environmental quality but could potentially serve to magnify the positive reverberations of renewable energy consumption on the environment by facilitating investments in renewable energy projects, which underpin a cleaner, more sustainable trajectory. This poses as a fascinating juxtaposition to the scenarios unraveling in countries like Bulgaria, Croatia, Estonia, and Slovenia, where a swelling in financial development is paradoxically tethered to a rise in carbon emissions, showcasing a contrasting and somewhat discordant mediating effect. This dichotomy underscores the imperative for a keen understanding of the diverse socio-economic and policy contexts that contour the pathways through which renewable energy consumption, digitalization, and financial development intersect and weave impacts upon environmental quality across different nations.

Furthermore, the findings highlight that the relationship between economic growth and environmental quality varies among countries. Specifically, in Bulgaria, Hungary, Latvia, Lithuania, and Slovenia, economic growth has a negative impact on environmental quality. However, for Lithuania and Latvia, an increase in economic growth is associated with improved environmental quality. Additionally, the impact of financial development on environmental quality also differs across countries. In Bulgaria, Croatia, Estonia, and Slovenia, an increase in financial development is linked to higher carbon emissions. In contrast, for Lithuania and Latvia, an increase in financial development positively influences environmental quality. These divergent results underscore the country-specific nature of the relationship between economic growth, financial development, and environmental quality.

The obtained results provide a basis for formulating the following policy recommendation. Central European countries, especially Bulgaria, Croatia, Estonia, Lithuania, Poland, Romania, and Slovenia, should prioritize fostering a sustainable digitalization strategy. A comprehensive strategy should encompass encouraging the adoption of digital technologies that support environmental preservation, such as energy-efficient infrastructure and digital solutions for waste management and resource optimization. Additionally, strengthening financial support for green investments is crucial in accelerating the transition to a low-carbon economy. Bulgaria, Croatia, Estonia, and Slovenia should establish dedicated funds, provide tax incentives, and offer grants to incentivize investments in renewable energy projects, energy-efficient technologies, and sustainable infrastructure. By facilitating access to financial resources and creating an enabling investment environment, governments can drive the adoption of environmentally friendly practices and technologies. Also, collaboration and capacity building are key focus areas for Central European countries. Establishing regional partnerships, organizing joint research projects, and creating platforms for knowledge sharing can expand the adoption of sustainable practices across the region. By learning from the experiences and expertise of the Czech Republic, Hungary, Latvia, and Slovakia, other countries can collectively work towards sustainable development.

Further research can be pursued in several areas to enhance our understanding of the interplay between digitalization, renewable energy consumption, financial development, and environmental quality in Central European countries. Firstly, exploring the mediating factors that influence the varying effects of digitalization on environmental quality across countries would provide valuable insights. Furthermore, analyzing sector-specific impacts would allow for a deeper exploration of the challenges and opportunities for sustainable digital transformation and financial investment, particularly in sectors such as renewable energy, transportation, and manufacturing. Lastly, conducting comparative studies to analyze regional differences within Central European countries would shed light on the influence of local contexts, policies, and economic disparities on the relationship between digitalization, renewable energy consumption, financial development, and environmental quality.

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References

1. Li, Z.; Huang, Z.; Su, Y. New media environment, environmental regulation and corporate green technology innovation: Evidence from China. *Energy Econ.* **2023**, *119*, 106545. [CrossRef]
2. Ke, J.; Jahanger, A.; Yang, B.; Usman, M.; Ren, F. Digitalization, Financial Development, Trade, and Carbon Emissions; Implication of Pollution Haven Hypothesis During Globalization Mode. *Front. Environ. Sci.* **2022**, *10*, 873880. [CrossRef]
3. Chen, L. How CO_2 Emissions Respond to Changes in Government Size and Level of Digitalization? Evidence from the BRICS Countries. *Environ. Sci. Pollut. Res.* **2022**, *29*, 457–467. [CrossRef]
4. Briglauer, W.; Köppl-Turyna, M.; Schwarzbauer, W.; Bittó, V. Evaluating the Effects of ICT Core Elements on CO_2 Emissions: Recent Evidence from OECD Countries. *Telecommun. Policy* **2023**, *47*, 102581. [CrossRef]
5. Li, Z.; Li, N.; Wen, H. Digital Economy and Environmental Quality: Evidence from 217 Cities in China. *Sustainability* **2021**, *13*, 8058. [CrossRef]
6. Wang, L.; Zhu, T. Will the Digital Economy Increase Energy Consumption?—An Analysis Based on the ICT Application Research. *Chin. J. Urban Environ. Stud.* **2022**, *10*, 2250001. [CrossRef]
7. Popescu, M.-F.; Constantin, M.; Chiripuci, B.C. Transition to a Sustainable Energy Production and Consumption Model—Mapping the Patterns of Success. *J. Bus. Econ. Manag.* **2022**, *23*, 1–22. [CrossRef]
8. Rubashkina, Y.; Galeotti, M.; Verdolini, E. Environmental Regulation and Competitiveness: Empirical Evidence on the Porter Hypothesis from European Manufacturing Sectors. *SSRN Electron. J.* **2014**, *83*, 288–300. [CrossRef]
9. Haller, A.-P.; Ștefănică, M.; Butnaru, G.I.; Butnaru, R.C. Climate Neutrality through Economic Growth, Digitalisation, Eco-Innovation and Renewable Energy in European Countries. *Kybernetes* **2023**. [CrossRef]
10. Ha, L.T.; Huong, T.T.L.; Thanh, T.T. Is Digitalization a Driver to Enhance Environmental Performance? An Empirical Investigation of European Countries. *Sustain. Prod. Consum.* **2022**, *32*, 230–247. [CrossRef]
11. Kuzior, A.; Vyshnevskyi, O.; Trushkina, N. Assessment of the Impact of Digitalization on Greenhouse Gas Emissions on the Example of EU Member States. *Prod. Eng. Arch.* **2022**, *28*, 407–419. [CrossRef]
12. Thanh, T.T.; Ha, L.T.; Dung, H.P.; Huong, T.T.L. Impacts of Digitalization on Energy Security: Evidence from European Countries. *Environ. Dev. Sustain.* **2022**, *25*, 11599–11644. [CrossRef]
13. Martínez, J.M.G.; Puertas, R.; Martín, J.M.M.; Ribeiro-Soriano, D. Digitalization, Innovation and Environmental Policies Aimed at Achieving Sustainable Production. *Sustain. Prod. Consum.* **2022**, *32*, 92–100. [CrossRef]
14. Karlilar, S.; Balcilar, M.; Emir, F. Environmental Sustainability in the OECD: The Power of Digitalization, Green Innovation, Renewable Energy and Financial Development. *Telecommun. Policy* **2023**, *47*, 102568. [CrossRef]
15. Mehmood, U.; Tariq, S.; Aslam, M.U.; Agyekum, E.B.; Uhunamure, S.E.; Shale, K.; Kamal, M.; Khan, M.F. Evaluating the Impact of Digitalization, Renewable Energy Use, and Technological Innovation on Load Capacity Factor in G8 Nations. *Sci. Rep.* **2023**, *13*, 9131. [CrossRef]

16. Zhou, Y.; Liu, Z.; Wang, M.; Dong, R.K.; Yue, X.-G. Evaluating the Impacts of Education and Digitalization on Renewable Energy Demand Behaviour: New Evidence from Japan. *Econ. Res.-Èkon. Istraživanja* **2023**, *36*, 2164033. [CrossRef]
17. Wang, B.; Wang, J.; Dong, K.; Dong, X. Is the Digital Economy Conducive to the Development of Renewable Energy in Asia? *Energy Policy* **2023**, *173*, 113381. [CrossRef]
18. Rehman, F.U.; Islam, M.M.; Ullah, M.; Khan, S.; Rehman, M.Z. Information Digitalization and Renewable Electricity Generation: Evidence from South Asian Countries. *SSRN Electron. J.* **2022**, *9*, 4721–4733. [CrossRef]
19. Samour, A.; Joof, F.; Ali, M.; Tursoy, T. Do Financial Development and Renewable Energy Shocks Matter for Environmental Quality: Evidence from Top 10 Emitting Emissions Countries. *Environ. Sci. Pollut. Res.* **2023**, *30*, 78879–78890. [CrossRef]
20. Shoaib, H.M.; Rafique, M.Z.; Nadeem, A.M.; Huang, S. Impact of Financial Development on CO_2 Emissions: A Comparative Analysis of Developing Countries (D8) and Developed Countries (G8). *Environ. Sci. Pollut. Res.* **2020**, *27*, 12461–12475. [CrossRef] [PubMed]
21. Kim, J.; Park, K. Financial Development and Deployment of Renewable Energy Technologies. *SSRN Electron. J.* **2015**, *59*, 238–250. [CrossRef]
22. Wen, J.; Hong, L.; Khalid, S.; Mahmood, H.; Zakaria, M. Nexus between Renewable Energy Consumption, Foreign Capital Flows, and Financial Development: New Evidence Using CUP-FM and CUP-BC Advanced Methods. *Struct. Chang. Econ. Dyn.* **2023**, *67*, 82–88. [CrossRef]
23. Ahmad, M.; Dai, J.; Mehmood, U.; Houran, M.A. Renewable Energy Transition, Resource Richness, Economic Growth, and Environmental Quality: Assessing the Role of Financial Globalization. *Renew. Energy* **2023**, *216*, 119000. [CrossRef]
24. Al-Mulali, U.; Ozturk, I.; Lean, H.H. The influence of economic growth, urbanization, trade opennes, financial development, and renewable energy on pollution in Europe. *Nat. Hazards* **2015**, *79*, 621–644. [CrossRef]
25. Khalid, L.; Hanif, I.; Rasul, F. How Are Urbanization, Energy Consumption and Globalization Influencing the Environmental Quality of the G-7? *Green Financ.* **2022**, *4*, 231–252. [CrossRef]
26. Lin, B.; Okoye, J.O. Towards Renewable Energy Generation and Low Greenhouse Gas Emission in High-Income Countries: Performance of Financial Development and Governance. *Renew. Energy* **2023**, *215*, 118931. [CrossRef]
27. Shahbaz, M.; Siddiqui, A.; Ahmad, S.; Jiao, Z. Financial Development as a New Determinant of Energy Diversification: The Role of Natural Capital and Structural Changes in Australia. *Energy Econ.* **2023**, *126*, 106926. [CrossRef]
28. Khan, M.T.I.; Yaseen, M.R.; Ali, Q. Nexus between Financial Development, Tourism, Renewable Energy, and Greenhouse Gas Emission in High-Income Countries: A Continent-Wise Analysis. *Energy Econ.* **2019**, *83*, 293–310. [CrossRef]
29. Aydin, M.; Bozatli, O. The Effects of Green Innovation, Environmental Taxes, and Financial Development on Renewable Energy Consumption in OECD Countries. *Energy* **2023**, *280*, 128105. [CrossRef]
30. Steffen, B. A Comparative Analysis of Green Financial Policy Output in OECD Countries. *Environ. Res. Lett.* **2021**, *16*, 074031. [CrossRef]
31. Habiba, U.; Xinbang, C.; Ali, S. Investigating the Impact of Financial Development on Carbon Emissions: Does the Use of Renewable Energy and Green Technology Really Contribute to Achieving Low-Carbon Economies? *Gondwana Res.* **2023**, *121*, 472–485. [CrossRef]
32. Ali, K.; Jianguo, D.; Kirikkaleli, D. How Do Energy Resources and Financial Development Cause Environmental Sustainability? *Energy Rep.* **2023**, *9*, 4036–4048. [CrossRef]
33. Zhou, P.; Abbas, J.; Najam, H.; Alvarez-Otero, S. Nexus of Renewable Energy Output, Green Technological Innovation, and Financial Development for Carbon Neutrality of Asian Emerging Economies. *Sustain. Energy Technol. Assess.* **2023**, *58*, 103371. [CrossRef]
34. Chin, M.-Y.; Ong, S.-L.; Ooi, D.B.-Y.; Puah, C.-H. The Impact of Green Finance on Environmental Degradation in BRI Region. *Environ. Dev. Sustain.* **2022**, 1–16. [CrossRef]
35. Wang, H.; Jiang, L.; Duan, H.; Wang, Y.; Jiang, Y.; Lin, X. The Impact of Green Finance Development on China's Energy Structure Optimization. *Discret. Dyn. Nat. Soc.* **2021**, *2021*, 2633021. [CrossRef]
36. Zakari, A.; Khan, I. The Introduction of Green Finance: A Curse or a Benefit to Environmental Sustainability? *Energy Res. Lett.* **2022**, *3*. [CrossRef]
37. Afzal, A.; Rasoulinezhad, E.; Malik, Z. Green Finance and Sustainable Development in Europe. *Econ. Res.-Èkon. Istraživanja* **2022**, *35*, 5150–5163. [CrossRef]
38. Li, C.; Chen, Z.; Wu, Y.; Zuo, X.; Jin, H.; Xu, Y.; Zeng, B.; Zhao, G.; Wan, Y. Impact of Green Finance on China's High-Quality Economic Development, Environmental Pollution, and Energy Consumption. *Front. Environ. Sci.* **2022**, *10*, 1032586. [CrossRef]
39. Breusch, T.S.; Pagan, A.R. The Lagrange Multiplier Test and Its Applications to Model Specification in Econometrics. *Rev. Econ. Stud.* **1980**, *47*, 239. [CrossRef]
40. Pesaran, M.H. General Diagnostic Tests for Cross Section Dependence in Panels. *SSRN Electron. J.* **2004**, 1–40. [CrossRef]
41. Pesaran, M.H. A Simple Panel Unit Root Test in the Presence of Cross-section Dependence. *J. Appl. Econ.* **2007**, *22*, 265–312. [CrossRef]
42. Pesaran, M.H.; Ullah, A.; Yamagata, T. A Bias-adjusted LM Test of Error Cross-section Independence. *Econ. J.* **2008**, *11*, 105–127. [CrossRef]
43. Blomquist, J.; Westerlund, J. Testing Slope Homogeneity in Large Panels with Serial Correlation. *Econ. Lett.* **2013**, *121*, 374–378. [CrossRef]

44. Westerlund, J.; Edgerton, D.L. A Panel Bootstrap Cointegration Test. *Econ. Lett.* **2007**, *97*, 185–190. [CrossRef]
45. McCoskey, S.; Kao, C. A Residual-Based Test of the Null of Cointegration in Panel Data. *Economet. Rev.* **1998**, *17*, 57–84. [CrossRef]
46. Eberhardt, M.; Bond, S. *Cross-Section Dependence in Nonstationary Panel Models: A Novel Estimator*; MPRA Paper No. 17692; University Library of Munich: Munich, Germany, 2009.
47. Teal, F.; Eberhardt, M. *Productivity Analysis in Global Manufacturing Production*; Econ. Ser. Work. Pap. No. 515; Department of Economics, University of Oxford: Oxford, UK, 2010.
48. Dumitrescu, E.-I.; Hurlin, C. Testing for Granger Non-Causality in Heterogeneous Panels. *Econ. Model.* **2012**, *29*, 1450–1460. [CrossRef]
49. Baloch, M.A.; Zhang, J.; Iqbal, K.; Iqbal, Z. The Effect of Financial Development on Ecological Footprint in BRI Countries: Evidence from Panel Data Estimation. *Environ. Sci. Pollut. Res.* **2019**, *26*, 6199–6208. [CrossRef]
50. Majeed, M.T.; Mazhar, M. Financial development and ecological footprint: A global panel data analysis. *Pak. J. Commer. Soc. Sci.* **2019**, *13*, 487–514.
51. Shahbaz, M.; Dogan, M.; Akkus, H.T.; Gursoy, S. The Effect of Financial Development and Economic Growth on Ecological Footprint: Evidence from Top 10 Emitter Countries. *Environ. Sci. Pollut. Res.* **2023**, *30*, 73518–73533. [CrossRef] [PubMed]