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Renewable Energy, Knowledge Spillover and Innovation: Capacity of Environmental Regulation

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Abstract: The European Union (EU) countries have declared the ambitious goal of providing carbon-free economic development. Considering this, the EU countries are going to pursue relevant policies for a step-by-step refusal of mining and coal energy, consequently reducing greenhouse gas emissions. The analysis of the theoretical background showed that renewable energy is the core dimension of reducing greenhouse gas emissions. In this case, the paper aims to justify the impact of core dimensions (knowledge spillover, innovation, and environmental regulation) that could boost renewable energy penetration into all sectors and levels. The following methods are applied to test the hypotheses: stationarity testing in panels; cross-section dependence testing; cointegration testing; and estimation in heterogeneous parameter models. The data are obtained from Eurostat, the OECD, and the World Data Bank. The object of research is the EU country in the period 2010–2020. The findings confirm the hypothesis on the statistically significant impact of innovation and knowledge spillover on renewable energy. In addition, environmental regulation has a mediating positive effect on interconnections among knowledge spillover, innovations, and renewable energy. In this case, countries should boost the development of appropriate environmental regulations, which should be effective and transparent for all stakeholders.

Keywords: sustainable development; green economy; renewable energy; green awareness

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Citation: Dzwigol, H.; Kwilinski, A.; Lyulyov, O.; Pimonenko, T. Renewable Energy, Knowledge Spillover and Innovation: Capacity of Environmental Regulation. *Energies* **2023**, *16*, 1117. https://doi.org/10.3390/en16031117

Academic Editor: Brent S. Steel

Received: 1 January 2023
Revised: 9 January 2023
Accepted: 17 January 2023
Published: 19 January 2023

1. Introduction

The European Union (EU) countries declared the ambitious goal to achieve carbon neutral development [1]. Thus, they are going to reduce greenhouse gas emissions by at least 55% by 2030, compared to 1990, and achieve no net emissions by 2050 [1]. It should be noted that the EU countries are going to pursue relevant policies for a step-by-step refusal of mining and coal energy. In this case, the EU will invest more than 25% of its financial resources from investment funds into projects aimed at eliminating climate issues [2,3], particularly extending renewable energy. Considering the prior studies [4–15], renewable energy is a core dimension to reduce greenhouse gas emissions. In addition, Agenda 2030 [16] promotes the extension of renewable energy toward SDG 7—clean and affordable energy. Based on the analytical reports on SDG achievement [16], all the EU countries can be divided into three groups: (1) countries that have achieved the target for the share of renewable energy in total energy consumption (Austria, Croatia, Denmark, Estonia, Finland, Germany, Italy, Latvia, Lithuania, Portugal, Romania, Slovenia, Spain, Sweden, Slovak Republic, Bulgaria, and Greece); (2) countries that have not achieved the target for renewable energy (Cyprus, Czech Republic, France, Hungary, Ireland, Luxembourg, and Poland); and (3) countries that are far from the indicated target (Belgium, Malta, and The Netherlands). Scholars have not achieved consensus on the core dimensions that stimulate renewable energy. Prior studies [17,18] confirm that investment is the most effective instrument for extending renewable energy. Another group of scientists [19] proved that knowledge could boost green awareness in society on the advantages of renewable energy. At the same time, renewable energy requires relevant innovations [20–25] and energy infrastructure [26–30]. Scholars [31–37] confirm that digitalization and the achievement of Industry 4.0 could boost renewable energy spillover. However, most researchers analyze renewable energy as the core determinant of a decarbonizing economy.

The analysis of the theoretical landscape on renewable energy development shows that researchers mostly analyze renewable energy as the independent variable and core determinant of the decarbonized economy. In this case, further research is required to analyze renewable energy as a dependent variable to empirically justify the core dimensions that could boost its penetration in all sectors and levels. Thus, this paper fills this research gap in justification of the core dimensions that impact on renewable energy. The paper aims to contribute to the theoretical framework on renewable energy by developing approaches to justify the impact of knowledge spillover, innovation, and environmental regulation on renewable energy penetration into all sectors and levels. Considering this, the paper has the following structure: (1) Literature review analyzes the theoretical background on links among renewable energy, knowledge spillover, and environmental regulation to justify the research hypotheses; (2) Materials and Methods describes dependent and independent variables and explains the methodology and econometrical techniques that are applied to test the research hypotheses; (3) Results explains the core findings of the research; (4) Discussion & Conclusion compares the obtained findings with the prior studies and defines limitations and further implications for research.

2. Literature Review

2.1. Renewable Energy and Innovation

The results of the theoretical framework of the renewable energy connection with innovation show that the scientific community has contrasting views on that matter. Scholars [31–37] highlight that innovation boosts the extension and spread of renewable energy. Using the OLS technique and QARDL approach, scholars [38–40] analyze renewable energy as a catalyst of CO_2 emissions decline. At the same time, they highlight that innovation is conducive to renewable energy. Kumetat D. [41] confirms the direct impact of innovation policy on renewable energy efficiency. Based on findings of a causal relationship, the study [42] proves that renewable energy could reduce CO_2 emissions by spreading innovations among all sectors. Furthermore, researchers highlight that energy policy should focus on developing renewable energy based on the achievement of Industry 4.0 [43] and capacity generated by new technologies [44]. Scholars [45,46] have applied EKC theory to check the impact of renewable energy on environmental degradation. Based on the findings, they confirm the moderating role of innovations in the "renewable energy–environmental pollution" chain. At the same time, scholars [47] prove the pivotal role of innovation and green investment in enhancing renewable energy. In addition, they confirm that innovation is a channel to achieve SDG 7–clean and affordable energy and SDG 13–climate action for G7 countries. Scholars [48] show that countries with high emissions in nature should boost technological innovation for renewable energy development; consequently, it allows changing countries' energy structure and decreasing the carbon footprint. Murshed and Alam [49] empirically justify (applying the ARDL model and the Hacker and Hatemi-J bootstrapped causality test) that innovations decrease nonrenewable energy consumption and stimulate the demand for renewable energy in Bangladesh. Based on the findings for 33 OECD countries for 1990–2015, a past study [50] confirms that innovation promotes geothermal, hydropower, and marine energy, but it is not conducive to the development of wind and solar energy. Furthermore, green investment [51–54] catalysts extend innovation for renewable energy development. However, Usman and Radulescu [55] empirically justify that technological innovations and nonrenewable energy restrict environmental sustainability. Thus, scholars emphasize the necessity of changing the energy structure by providing relevant policies and strategies in the energy sector.

2.2. Innovation and Knowledge

The summarized results of the theoretical background on innovation and knowledge find that they are closely related to each other. In addition, scholars [56,57] highlight the role of green knowledge management in innovation development. At the same time, diversification of knowledge is conducive to innovation development [58]. Scholars [58] apply the SBM model and prove that knowledge diversification positively correlates with innovation development in the Yangtze River Delta region. Previous studies [59–66] conclude that knowledge integration capability intensifies green innovation extension. Scholars [67–69] analyze the business sector as the core driver of sustainable development in China. Based on empirical findings, they prove that knowledge-dynamic capabilities induce green innovation in entrepreneurship. In addition, knowledge-dynamic capabilities play a mediating role between government subsidies and green innovation. Using the PLS-SEM approach, the researchers confirm that green knowledge sharing has a statistically positive effect on green innovation in the Pakistani industry [70]. It should be noted that green innovation catalyzes sustainable development achievement. At the same time, green knowledge is conducive to extending green innovation [71]. Yin and Yu [72] underline that the ongoing digitalization of all sectors causes the enhancement of digital knowledge, which affects digital green innovation efficiency. At the same time, they confirm the inverted U-shaped relationship between using digital knowledge and the efficiency of digital green innovation [72]. It should be noted that a vast range of scholars confirm the opposite relationship and empirically justify that innovation boosts knowledge extension in the country. Zhou and Li [73] find that knowledge increases the efficiency of the innovation development of Chinese companies. A similar conclusion is obtained by Pereira and Bamel [74] based on the findings of bibliometric analysis. However, researchers [75] find that innovation (which is measured by research and development) decreases the reliability of knowledge extension.

2.3. Renewable Energy, Knowledge Spillover, and Environmental Regulation

Reasoning from the empirical findings, the study [76] showed that environmental taxes (as the measure of environmental policy) and renewable energy were conducive to sustainable development. Using institutional theory, the study [77] confirmed that strict and market-oriented regulations impacted knowledge spreading, which is pivotal for renewable energy development among Chinese companies. Scholars [78] found that innovation positively affects the energy efficiency of a country. At the same time, innovation development requires relevant knowledge. The scholars confirm that the most energy effective countries are Germany, France, The Netherlands, Switzerland, and the United Kingdom. In addition, these countries are leaders in innovation implementation considering Triadic Patent Families [78]. Informed by the empirical findings, they highlighted the necessity to develop innovative infrastructure, invest in research and development, and enhance knowledge dissemination [78]. Herman and Xiang [79], based on the Porter hypothesis, analyzed the connection between innovation and environmental policy. In addition, the researchers focused on foreign environmental policy. They assumed that environmental innovations with strong environmental policy result in advantages in the long term; however, in the short term, environmental innovations lead to declining economic and ecological benefits. Herman and Xiang [79] measure innovation by renewable energy technologies, and environmental policy stringency (which is calculated by experts from the OECD) was applied as an environmental policy proxy. The prior study [80] applied the GMM to justify the dimensions of energy innovation for China over the period of 2001–2015. Scholars found that the impact of energy prices on innovation is higher than that of renewable energy. They confirm that renewable energy development requires relevant environmental regulations in China. In addition, they show that knowledge stimulated renewable energy penetration. The coherent conclusions on the positive effect of environmental regulations on renewable energies were obtained by the study [81] for 35 OECD and BRICS countries. It bears noting that scholars [82] confirm that effective government incentives for renewable energy extension cause the growth of green patents. They showed that feed-in tariffs were the most effective instrument that had a continuously statistically significant impact on the extension of renewable energy. Tan and Uprasen [83] found that obligatory environmental regulation could encourage renewable energy consumption in BRICS countries. Scholars [84,85] empirically confirmed that China should intensify environmental regulation to boost renewable energy development. However, the latter requires relevant knowledge that simultaneously boosts green innovation.

3. Materials and Methods

Considering the analysis of the theoretical framework, this study tested the following hypotheses:

Hypothesis 1 (H1). *Innovation positively connects with knowledge spillover.*

Hypothesis 2 (H2). *Environmental regulation has a positive moderating effect on the interconnection between innovation and knowledge spillover.*

Hypothesis 3 (H3). *Innovation positively connects with renewable energy.*

Hypothesis 4 (H4). *Environmental regulation has a positive moderating effect on the interconnection between innovation and renewable energy.*

Hypothesis 5 (H5). *Knowledge spillover has a positive moderating effect on the interconnection between innovation and renewable energy, and environmental regulation strengthens this relationship.*

Hypothesis 6 (H6). *The interconnection between environmental regulation and knowledge spillover positively affects the interconnection between innovation and renewable energy.*

The selection of statistical data is grounded on the following preconditions:

(1) The common policy for all the EU member states on decarbonization of energy systems; implementation of both internal (which is declared in the EU Road map to carbon-free energy) and external (which is accepted in the framework of the Paris Agreement) obligations.
(2) The decarbonization of energy systems aims to harmonize the controversial policies and strategies of countries' development: ecological issues justify the necessity to gradually increase renewable energy and the declining consumption of nonrenewable resources, particularly to intensify CO_2 emissions; economic issues–countries should be ready to adapt to new circumstances in the world development and to integrate new priorities for sustainable economic development considering changeable economic and industrial environments. Thus, the innovation and knowledge that aim to tackle climate issues could open new windows for all the EU members.
(3) There is a lack of unequivocal results from the past studies on knowledge spillover, innovation, and the impact of environmental regulation on renewable energy.
(4) In addition, despite the numerous common features of the EU countries' development, they are a heterogeneous group in terms of renewable energy development and internal (economic) conditions, which ensures a high dispersion of the analyzed variables, which are important for econometric analysis. This study applies statistical data from the World Bank [86], Eurostat [87], and OECED [88] for the EU countries for 2000–2019. Considering the research objectives, the study uses the following variables:
    - Dependent variable: Based on prior studies [3,5,6,11,27,31] for renewable energy assessment, the study uses the share of renewable energy in the total primary energy supply (RE). The EU countries are continually monitoring the achievement of SDG 7—clean and affordable energy, which also justifies the selection of RE as the dependent variable.

- Independent variable: Patents in environment-related technologies (Innov) for measuring innovative activities in the country [11,30,34]; foreign direct investment, net inflows, % of GDP (Know) to evaluate knowledge spillover. A prior studies [89,90] indicates that knowledge spillover depends on innovation activities in the country, which requires the attraction of investment. In this case, using *Know* is an appropriate approach to measure knowledge spillover. Based on previous studies [3,5,11,15,20,27], total general government expenditure on environmental protection, % of GDP (Gov), is selected to evaluate environmental regulation in the country.

To consider the internal (economic) conditions of the EU countries' development, the following control variables are selected for research: GDP per capita, current US$ (GDP); Trade openness, % of GDP (TO). The real GDP, which depends on investments and transactions in all economic sectors, impacts nature and promotes the extension of renewable energy to boost economic decarbonization [3,5,11]. The intensive movement of goods and services is characteristic of an open economy. It promotes the attraction of foreign capital, knowledge, innovative technology transfer, etc. [3,5,11]. Thus, it assumes that an appropriate level of economic openness is conducive to extending renewable energy and supporting the sustainable development of the country. The descriptive statistics of the analyzed panel data are shown in Table 1.

Table 1. Descriptive statistics of the analyzed panel data.

Variable	Source	Mean	SD	Min	Max
RE	Eurostat [87]	21.262	19.867	0.00	85.338
Know	World Bank [86]	12.211	39.075	−57.532	449.083
Innov	OECED [88]	197.309	485.054	0.00	3335.6
Gov	Eurostat [87]	0.747	0.341	−0.3	1.9
GDP	World Bank [86]	29,386.95	21,525.2	1621.243	123,678.7
TO	World Bank [86]	118.934	62.618	45.419	380.104

Note: RE means renewable energy in total primary energy supply; Innov means patents in environment-related technologies; Know is foreign direct investment; Gov stands for environmental regulation; GDP is gross domestic product per capita; TO stans for trade openness; Mean is the average value among analyzed data; SD is a standard deviation; Min is the minimum value among analyzed data; Max is the maximum value among analyzed data.

The econometric analysis of the research hypotheses is provided by the following equations:

$$\text{Model 1 to test Hypothesis 1}: \ FDI_{\text{it}} = \alpha_0 + \beta_1\text{Innov}_{\text{it}} + \beta_2\text{GDP}_{\text{it}} + \beta_3\text{TO}_{\text{it}} + \varepsilon_{\text{it}} \quad (1)$$

$$\text{Model 2 to test Hypothesis 2}: \ FDI_{\text{it}} = \alpha_1 + \beta_4\text{Innov}_{\text{it}} + \beta_5\,\text{Gov}_{\text{it}} + \beta_6\text{GDP}_{\text{it}} + \beta_7\text{TO}_{\text{it}} + \varepsilon_{\text{it}} \quad (2)$$

$$\text{Model 3 to test Hypothesis 3}: \ RE_{\text{it}} = \alpha_2 + \beta_8\text{Innov}_{\text{it}} + \beta_9\text{GDP}_{\text{it}} + \beta_{10}\text{TO}_{\text{it}} + \varepsilon_{\text{it}} \quad (3)$$

$$\text{Model 4 to test Hypothesis 4}: \ RE_{\text{it}} = \alpha_3 + \beta_{11}\text{Innov}_{\text{it}} + \beta_{12}\,\text{Gov}_{\text{it}} + \beta_{13}\text{GDP}_{\text{it}} + \beta_{14}\text{TO}_{\text{it}} + \varepsilon_{\text{it}} \quad (4)$$

$$\text{Model 5 to test Hypothesis 5}: \ RE_{\text{it}} = \alpha_4 + \beta_{15}\text{Innov}_{\text{it}} + \beta_{16}\text{Know}_{\text{it}} + \beta_{17}\text{Gov}_{\text{it}} + \beta_{18}\text{GDP}_{\text{it}} + \beta_{19}\text{TO}_{\text{it}} + \varepsilon_{\text{it}} \quad (5)$$

$$\text{Model 6 to test Hypothesis 6}: \ RE_{\text{it}} = \alpha_5 + \beta_{20}\text{Innov}_{\text{it}} + \beta_{21}\,\text{Know}_{\text{it}} + \beta_{22}\,\text{Gov}_{\text{it}} + \beta_{23}(\text{Know}\times\text{Gov})_{\text{it}} + \beta_{24}\text{GDP}_{\text{it}} + \beta_{25}\text{TO}_{\text{it}} + \varepsilon_{\text{it}} \quad (6)$$

where $\alpha_0 \ldots \alpha_5$ are constants of the equations, $\beta_1 \ldots \beta_{25}$ are searching parameters, $Know \times Gov$ stand for 'interconnection between Know and Gov', and ε_{it} is an error term.

All model variables are logarithmically transformed to smooth the data. In addition, the use of logarithmic data allows consistent and effective data to be obtained, compared to simple linear transformations. Since the variables are logarithmic, the measured coefficients are interpreted in terms of the corresponding point elasticities. The study applies the panel regression method to evaluate Equations (1)–(6). This method is reliable for providing a cross-sectionally dependent panel series. Compared to the time series of separate countries, the core advantage of panel data is obtaining a better estimation of dynamic indicators, considering the intercross-sectional and/or intracross-sectional characteristics of research objects. In addition, the analysis of the panel data assumes the least collinearity between variables and higher degrees of freedom [89]. The empirical analysis of knowledge spillover, innovation, and the environmental regulation effect on renewable energy is provided in the following stages:

1. Stationarity testing in panels;
2. Cross-section dependence testing;
3. Cointegration testing;
4. Estimation in Heterogeneous Parameter Models.

In the first stage, the time series is checked on stationarity by the Levin-Lin-Chu [91]; Im–Pesaran–Shin [92]; Pesaran's CADF [93]; and Im, Pesaran, and Shin CIPS [94] tests. These approaches allow the elimination of cross-sectional effects. In the second stage, the study analyzes the cross-section dependence. The panel data, which are grouped by political and economic unions, have cross-dependence (the economic results of certain countries' effects on the same economic indicators in other countries) [95]. Neglecting issues of cross-dependence could lead to inconsistent and biased findings. This study applies three types of tests for cross-dependence analysis: Breusch-Pagan LM [96,97], Pesaran scaled LM [93,98], and the Pesaran test for cross-sectional dependence (CD) [93,98]:

$$LM = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij}\hat{\rho}_{ij}^2 \rightarrow \chi^2 \frac{N(N-1)}{2} \tag{7}$$

$$CD = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij}\hat{\rho}_{ij}^2 \rightarrow N(0,\ 1) \tag{8}$$

where N is the sample size; T is the period; and ρ_{ij} stands for the estimate of the cross-sectional correlation of the errors of the i and j country.

The chosen tests allow testing the null hypothesis against the alternative hypothesis. At the next stage, the study checks the long-run cointegration among the models' parameters by applying Westerlund ECM panel cointegration tests [99]:

$$\Delta y_i = \delta_i^{'} d_t + \alpha_i y_{i,\ t-1} + \lambda_i^{'} x_{i,\ t-1} + \sum_{j=1}^{pi} \alpha_{ij} y_{i,\ t-1} + \sum_{j=1}^{pi} \gamma_{ij} x_{i,\ t-1} + \varepsilon_{it} \tag{9}$$

where i means the cross-sections; t means the observations; d_t stands for the deterministic components; α_i is the speed of convergence to the equilibrium; and pi means the lag lengths.

The Westerlund ECM panel cointegration test [99] includes two tests for analyzing the cointegration hypotheses for all panel data, *Gt* and *Ga* (grouped statistics), and two tests for assessment of alternatives, in which at least one cross-sectional unit is cointegrated *Pt* and *Pa* (panel statistics). The selection of the econometric model is dictated by the specificity of the initial data obtained (time and availability). Feasible Generalized Least Squares (FGLS) [100,101] is applied to assess the regression's parameters. The FGLS estimator provides consistent and unbiased estimates of the model parameters that are robust to heteroskedasticity in the residual term. The coefficient of determination (R^2) allows for diagnosing the utility of the evaluated models. The statistical significance of the models' parameters is determined by Student's test at p value values of 1%, 5%, and 10%. The study applies a fully modified, ordinary, least squares regression to estimate the individual effects of knowledge spillover, innovation, and environmental regulation on renewable energy within each individual EU member. The findings of each stage of research and their interpretation are explained in the next part of the paper, focusing only on the results that are significant in terms of achieving the goal set and the proposed research hypotheses.

4. Results

Considering the proposed methodology, at the first stage, all data are checked for stationarity by the Levin-Lin-Chu [91], Im–Pesaran–Shin [92], Pesaran's CADF [93], and cross-sectionally augmented Im, Pesaran, and Shin (CIPS) tests [94]. The results of stationarity testing in panels are shown in Table 2.

Table 2. The empirical results of stationarity testing in panels.

Variables	Levin-Lin-Chu		Im–Pesaran–Shin		Pesaran's CADF		CIPS	
	Stat.	***p* Value**	**Stat.**	***p* Value**	**Stat.**	***p* Value**	**Stat.**	***p* Value**
at level								
RE	−4.1636	0.0000	2.3535	0.9907	−2.386	0.000	−3.839	0.000
Innov	−4.8523	0.0000	−2.3592	0.0092	−6.632	0.000	−9.634	0.000
Know	−4.6015	0.0000	−5.3546	0.0000	−2.398	0.000	−7.732	0.000
Gov	−2.7087	0.0034	−2.7257	0.0032	−1.814	0.367	−0.575	0.283
GDP	−12.0500	0.0000	−8.7496	0.0000	−1.627	0.742	2.290	0.989
TO	−3.8944	0.0000	−6.7036	0.0000	−1.937	0.161	0.865	0.806
Know × Gov	−2.6145	0.0045	−2.6965	0.0035	−1.787	0.422	−3.048	0.001
at the first difference								
RE	−9.0535	0.0000	−9.8833	0.0000	−3.146	0.000	−14.315	0.000
Innov	−10.2166	0.0000	−12.4047	0.0000	−10.595	0.000	−17.049	0.000
Know	−12.0696	0.0000	−14.4988	0.0000	−3.862	0.000	−17.763	0.000
Gov	−11.7797	0.0000	−13.0037	0.0000	−3.335	0.000	−14.967	0.000
GDP	−8.3862	0.0000	−0.4677	0.3200	−2.734	0.000	−6.577	0.000
TO	−9.2155	0.0000	−9.9742	0.0000	−2.352	0.001	−5.344	0.000
Know × Gov	−11.9567	0.0000	−13.0863	0.0000	−3.461	0.000	−14.919	0.000

Note: RE stands for renewable energy in total primary energy supply; Innov means patents in environment-related technologies; Know means knowledge spillover; Gov stands for environmental regulation; GDP is gross domestic product per capita; TO is trade openness; Know × Gov means interconnection between Know and Gov.

The results of Levin-Lin-Chu, Im–Pesaran–Shin, Pesaran's CADF and CIPS justify the conclusion that not all data are stationary at the level (*RE*, *Gov*, *GDP*, *TO*, *Know* × *Gov*). However, at the first difference, all variables have become stationary, with statistical significance at the 1% level. At the next stage, to avoid inconsistency and biased estimation, the study provides cross-section dependency tests, particularly the Pesaran CD, Breusch-Pagan LM, and Pesaran scaled LM tests. The findings of the Pesaran CD test are shown in Table 3.

Table 3. The results of Pesaran test for cross-sectional dependence.

Variable	CD Test	*p* Value	Corr	Abs(Corr)
RE	72.20	0.00	0.862	0.862
Innov	43.59	0.000	0.520	0.562
Know	12.60	0000	0.150	0.305
Gov	4.63	0.00	0.055	0.310
GDP	78.67	0000	0.939	0.939
TO	62.19	0.00	0.742	0.743
Know × Gov	4.4	0.000	0.053	0.295

Note: RE stands for renewable energy in total primary energy supply; Innov means patents in environment-related technologies; Know stans for knowledge spillover; Gov means environmental regulation; GDP is gross domestic product per capita; TO is trade openness; Know × Gov means interconnection between Know and Gov.

The results of the *p* value in Table 3 allow rejecting the null hypothesis on the existence of the cross-sectional independence and accepting alternative–cross-sectional dependence for the panel data analyzed. Thus, *RE, Know, Gov, GDP, TO*, and *Know×Gov* have a cross-sectional dependence. Table 4 contains the empirical results of the Breusch-Pagan LM and Pesaran scaled LM tests. The calculated probability (Table 4) is less than 0.5, which does not allow rejecting the null hypothesis that there is no cross-sectional dependence.

Table 4. The results of Breusch-Pagan LM and Pesaran scaled LM tests.

Types of the Model	Breusch-Pagan LM		Pesaran Scaled LM	
	Statistic	Prob.	Statistic	Prob.
Model 1	992.3272	0.0000	24.20534	0.0000
Model 2	1014.086	0.0000	25.02658	0.0000
Model 3	5378.843	0.0000	189.7637	0.0000
Model 4	4332.475	0.0000	150.2711	0.0000
Model 5	4094.391	0.0000	141.2852	0.0000
Model 6	4085.767	0.0000	140.9597	0.0000

If the data are stationary with cross-sectional dependence, the Westerlund ECM panel cointegration test [99] could be provided. The results of the cointegration test are shown in Table 5.

Table 5. The results of Westerlund ECM panel cointegration tests.

Types of the Models	Gt		Ga		Pt		Pa	
	Value	*p* Value	Value	*p* Value	Value	*p* Value	Value	*p* Value
Model 1	−2.863	0.000	−10.576	0.011	−17.227	0.000	−12.180	0.000
Model 2	−3.016	0.000	−4.213	1.000	−14.902	0.000	−6.809	0.311
Model 3	−1.973	0.002	−6.679	0.208	−8.754	0.002	−5.366	0.001
Model 4	−2.963	0.000	−13.109	0.201	−15.770	0.000	−12.854	0.000
Model 5	−2.152	0.012	−6.444	0.872	−9.638	0.017	−5.935	0.085
Model 6	−1.973	0.002	−6.679	0.208	−8.754	0.002	−5.366	0.001

Note: Gt and Ga are mean among groups; Pt and Pa are the panel tests.

Based on the findings in Table 5, the null hypothesis (no cointegration) can be rejected for all selected models. This means that cointegration exists among the variables for all models at 1% statistical significance. At the next stage, heterogeneous parameter models with FGLS techniques are applied. The findings (Table 6) demonstrate the positive effect of Innov on knowledge spillover for all the analyzed countries, which confirms Hypothesis 1. Thus, the growth of patents in environment-related technologies leads to an increase in knowledge spillover by 0.004, with a significance level of 10%. At the same time, Gov has a negative moderating effect on the interconnection between innovation and knowledge spillover. The growth of Gov reduces the knowledge spillover by 0.001. Such results allow rejecting the second hypothesis that environmental regulation has a positive moderating effect on the interconnection between innovation and knowledge spillover.

Table 6. The estimation results by heterogeneous parameter models: FGLS.

Variable	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.
Innov	0.004	0.099	0.004	0.003	0.042	0.004	0.035	0.036	0.031	0.094	0.030	0.096
Know	–	–	–	–	–	–			−0.009	0.804	0.006	0.881
Gov	–	–	−0.001	0.012	–	–	−0.048	0.251	−0.072	0.125	0.449	0.438
GDP	0.018	0.022	0.019	0.008	0.108	0.045	0.168	0.003	0.196	0.001	0.194	0.001
TO	0.061	0.000	0.061	0.000	−0.081	0.423	−0.147	0.171	−0.191	0.081	−0.190	0.084

Table 6. *Cont.*

Variable		Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
		Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.
Know × Gov		–	–	–	–	–	–	–	–	–	–	−0.123	0.367
constant		4.023	0.000	4.034	0.000	2.146	0.000	1.774	0.000	1.718	0.009	1.658	0.012
Wald	chi2	28.43		32.77		15.32				22.88		23.56	
	Prob.	0.000		0.000		0.0016				0.0004		0.0006	

Note: RE means renewable energy in total primary energy supply; Innov stands for patents in environment-related technologies; Know means knowledge spillover; Gov stands for environmental regulation; GDP is gross domestic product per capita; TO is trade openness; Know × Gov stands for the impact of interconnection between Know and Gov.

The empirical results (Table 6) confirm Hypothesis 3 that innovation positively connects with renewable energy. This means that the growth of patents in environment-related technologies enhances renewable energy. In addition, environmental regulation does not have a statistically significant impact on the interconnection between innovation and renewable energy. This allows rejecting the fourth hypothesis. Furthermore, knowledge spillover does not have a statistically significant impact on the interconnection between innovation and renewable energy, and environmental regulation strengthens this relationship. This means that Hypothesis 5 could not be confirmed. The interconnection between environmental regulation and knowledge spillover does not have a statistically significant positive effect on the interconnection between innovation and renewable energy. This allows Hypothesis 6 to be rejected. The results of the FMOLS long-run analysis are shown in Table 7, which demonstrates the impact of *Innov, Know, Gov, GDP*, and *TO* on *RE* within each country.

Table 7. The results of FMOLS long-run analysis.

Country	Innov		Know		Gov		GDP		TO		R^2
	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.
Austria	0.413	0.000	0.144	0.010	−0.293	0.807	0.012	0.001	0.261	0.095	0.874
Belgium	1.685	0.000	−0.868	0.876	2.710	0.000	−0.790	0.005	0.381	0.649	0.884
Bulgaria	0.597	0.003	−1.114	0.322	−0.365	0.117	0.951	0.000	−0.348	0.491	0.914
Croatia	−0.217	0.000	2.693	0.000	0.582	0.000	0.087	0.000	0.050	0.183	0.659
Cyprus	−0.427	0.000	0.840	0.108	−1.298	0.000	2.168	0.000	6.328	0.000	0.935
Czech Republic	−0.327	0.154	−2.640	0.662	1.499	0.004	0.176	0.565	3.353	0.000	0.719
Denmark	1.306	0.000	1.279	0.000	0.758	0.026	0.709	0.000	0.765	0.019	0.870
Estonia	0.064	0.209	1.110	0.002	−0.040	0.334	0.350	0.000	0.159	0.001	0.703
Finland	0.071	0.008	0.605	0.089	−1.670	0.000	0.227	0.007	−0.280	0.515	0.570
France	−0.096	0.719	−7.972	0.534	1.498	0.070	−0.347	0.212	3.237	0.000	0.809
Germany	−0.073	0.693	1.639	0.263	0.871	0.103	3.259	0.000	2.405	0.000	0.928
Greece	0.031	0.536	−1.836	0.377	1.419	0.000	−0.191	0.033	0.540	0.018	0.897
Hungary	−0.169	0.344	−0.100	0.256	0.239	0.321	1.118	0.000	4.819	0.000	0.891
Ireland	0.589	0.000	0.320	0.001	−0.347	0.079	0.489	0.000	4.569	0.000	0.948
Italy	1.003	0.000	−0.354	0.769	2.946	0.000	0.219	0.093	0.979	0.000	0.952
Latvia	0.086	0.000	−0.822	0.516	−0.092	0.119	0.004	0.854	0.564	0.000	0.761
Lithuania	0.048	0.115	−1.583	0.541	−0.339	0.000	0.500	0.000	1.078	0.000	0.800
Luxembourg	−0.323	0.336	0.149	0.234	2.419	0.196	−0.262	0.733	8.688	0.000	0.850
Malta	0.014	0.687	−0.042	0.243	−1.685	0.000	2.395	0.000	2.801	0.000	0.683
The Netherlands	1.405	0.000	0.503	0.356	−4.156	0.000	0.289	0.179	0.773	0.245	0.928
Poland	0.425	0.000	−1.920	0.715	0.410	0.025	0.336	0.000	1.935	0.000	0.958
Portugal	0.051	0.096	0.807	0.066	0.253	0.487	0.158	0.006	1.256	0.000	0.551
Romania	0.039	0.329	−0.417	0.449	0.068	0.529	0.193	0.001	0.827	0.000	0.862
Slovak Republic	0.058	0.615	−3.822	0.651	−1.943	0.001	0.163	0.511	2.279	0.000	0.792
Slovenia	0.110	0.000	−0.580	0.201	0.225	0.011	0.151	0.029	0.731	0.000	0.644

Table 7. *Cont.*

Country	Innov		Know		Gov		GDP		TO		R^2
	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.
Spain	0.904	0.000	−2.135	0.300	1.130	0.145	−1.270	0.900	2.600	0.000	0.784
Sweden	0.593	0.000	0.489	0.012	−0.062	0.605	0.350	0.000	0.294	0.094	0.927

Note: RE stands for renewable energy in total primary energy supply; Innov means patents in environment-related technologies; Know is a knowledge spillover; Gov stands for environmental regulation; GDP is gross domestic product per capita; TO is trade openness; Know × Gov means impact of interconnection between Know and Gov.

The empirical results show that Innov has a positive effect on renewable energy in the following countries: Austria, Belgium, Bulgaria, Denmark, Finland, Ireland, Italy, Latvia, The Netherlands, Poland, Portugal, Slovenia, Spain, and Sweden. It bears noting that Belgium, Ireland, The Netherlands, and Poland have not achieved the target share of renewable energy in the primary energy supply. This means that the mentioned countries should stimulate green patents, which increase renewable energy by 1.685 points in Belgium, by 0.589 points in Ireland, by 1.405 in The Netherlands, and by 0.425 points in Poland. At the same time, Innov has a negative effect on renewable energy in Croatia and Cyprus. Thus, for those countries, the financing of green patents will not guarantee the extension of renewable energy. At the same time, in the Czech Republic and Luxemburg, Innov also has a negative effect on renewable energy; however, it is not statistically significant.

Knowledge spillover negatively affects renewable energy in Belgium, Bulgaria, the Czech Republic, France, Greece, Hungary, Italy, Latvia, Malta, Poland, Romania, the Slovak Republic, Slovenia, and Spain. However, this effect is not statistically significant. Furthermore, in the following, the further increase in Know will bring the growth of *RE*: Austria, Croatia, Denmark, Estonia, Finland, Ireland, Portugal, and Sweden. It stands to mention that The Netherlands, Belgium, Bulgaria, Italy, Latvia, Poland, Slovenia, and Spain have a large gap between innovation and knowledge spillover, which restricts the growth of *RE*. It is necessary to strengthen the accountability of the social, economic, and ecological effects from attracted knowledge into the countries.

Environmental regulations boost renewable energy in the following countries: Belgium, Croatia, Czech Republic, Denmark, France, Greece, Italy, Poland, and Slovenia. However, environmental regulations decrease renewable energy in Cyprus, Finland, Ireland, Lithuania, Malta, The Netherlands, and the Slovak Republic. This means that the mentioned countries have not developed an effective regulatory framework for spreading renewable energy. For instance, at the first stage, Malta, The Netherlands, Cyprus, and Ireland (countries that have not achieved their targets) should provide appropriate environmental regulations, after which they could provide incentives for attracting investments in green patents and projects that aim to extend renewable energy.

It stands to mention that in most cases, the impacts of *GDP* and *TO* on *RE* are positive and statistically significant. In addition, in general, the growth of *GDP* and *TO* provoked an increase in *RE*, excluding the following case: the growth of GDP by 1 point led to a decline in *RE* by 0.790 in Belgium and 0.191 in Greece. The values of R^2 (Table 6) are higher than the thresholds in all countries. This leads to the conclusion that the obtained findings are useful for interpretation.

5. Discussion & Conclusions

The acceptance of the indicated targets to achieve carbo-neutral development requires renewable energy spillover among all the EU countries. It is necessary to understand whether the EU invests in green patents (as the indicator of innovation) and knowledge and enhances environmental regulation to achieve targets for renewable energy among all the EU countries. Considering the findings, the first, second, and third hypotheses could be confirmed. This means that knowledge spillover is conducive to renewable energy. It bears noting that such conclusions are coherent with the findings of scholars [35,38,50,63]. The growth of innovation (measured by green patents) causes the extension of renewable energy (hypothesis 3), which is also confirmed by the studies [65,70,77]. In addition, the growth of government expenditures on environmental protection promotes the increase in renewable energy among all analyzed countries (hypothesis 2), excluding Cyprus, Finland, Ireland, Lithuania, Malta, The Netherlands, and the Slovak Republic. However, the fourth, fifth, and sixth hypotheses are rejected by the empirical results. The findings show that environmental regulation does not have a positive moderating effect on the interconnection between innovation and renewable energy. Furthermore, knowledge spillover does not have a positive moderating effect on the interconnection between innovation and renewable energy. In addition, environmental regulation does not strengthen this relationship (hypothesis 5). The results justify that the interconnection between environmental regulation and knowledge spillover does not positively affect the interconnection between innovation and renewable energy (hypothesis 6).

Considering the empirical findings, countries that have not achieved targets for renewable energy (Belgium, Malta, The Netherlands, Cyprus, the Czech Republic, France, Hungary, Ireland, Luxembourg, and Poland) should provide proactive policies on innovation development and stimulate innovative projects in countries that bring social, economic, and ecological effects. At the same time, it is necessary to analyze the green practices of countries that are leaders on renewable energy in total energy consumption (Austria, Croatia, Denmark, Estonia, Finland, Germany, Italy, Latvia, Lithuania, Portugal, Romania, Slovenia, Spain, Sweden, Slovak Republic, Bulgaria, and Greece) and implement their incentives and mechanisms in Belgium, Malta, and The Netherlands.

In addition, the EU countries should provide relevant mechanisms to improve the investment climate. This allows attracting additional financial resources to green projects that aim to promote renewable energy. Moreover, this requires providing the accountability and transparency of green investment projects during the whole life circle. It should be noted that the EU countries have already accepted the vast range of normative documents in the energy sector: the Directive on renewable energy sources; the Directive on energy efficiency; the Directive on taxation in the energy sector; etc. [1,11,27]. At the same time, the EU has developed a vast range of incentives to boost renewable energy development: feed-in tariffs, green taxes, green penalties, green credit, etc. [11,20,52,102–104]. However, the EU should provide proactive policies on promoting available financial windows to receive support for renewable energy development.

Despite the rehabilitation results, this study has a few limitations, which could be the direction for further investigations. Indicatively, past studies [11,20,27,105–107] defined that the efficiency of governance plays a core role in spreading renewable energy. In particular, control over corruption, rule of law, and transparency affect the business climate, which is a core determinant for green stakeholders. In future investigations, it is necessary to consider the digitalization impact [108,109] on environmental regulations and renewable energy extension. In addition, they require the further analysis of the existence of nonlinear connections among selected variables. Moreover, for further investigation, it is important to define the most appropriate type of renewable energy, considering the social, economic, political, technological, and environmental climate in the countries.

Author Contributions: Conceptualization, H.D., A.K., O.L. and T.P.; software, H.D., A.K., O.L. and T.P.; formal analysis, H.D., A.K., O.L. and T.P.; research, H.D., A.K., O.L. and T.P.; resources, H.D., A.K., O.L. and T.P.; data curation, H.D., A.K., O.L. and T.P.; writing—original draft preparation, H.D., A.K., O.L. and T.P.; writing—review and editing, H.D., A.K., O.L. and T.P.; visualization, H.D., A.K., O.L. and T.P.; supervision, H.D., A.K., O.L. and T.P.; funding acquisition, H.D., A.K., O.L. and T.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Education and Science of Ukraine within the framework of the grant No. 0121U100468.

Data Availability Statement: Not applicable.

Acknowledgments: The authors are very grateful to the anonymous referees for their helpful comments and constructive suggestions.

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

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