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The Impact of Innovation and Information Technology on Greenhouse Gas Emissions: A Case of the Visegrád Countries

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Abstract: The rapid growth of negative consequences from climate changes provokes divergent effects in all economic sectors. The experts proved that a core catalyst which bootstrapped the climate changes was greenhouse gas emission. This has led to a range of social, economic, and ecological issues. Such issues could be solved by extending innovation and information technology. This paper aimed to check the hypothesis that innovation and information technology allowed for a reduction of greenhouse gas emissions. The author used such methodology as OLS, fully modified OLS (FMOLS), dynamic OLS (DMOLS), Dicky-Fuller and Phillips-Perron tests. The research is informed by the report of the World Economic Forum, World Data Bank, Eurostat for the Visegrád countries (Hungary, Poland, Check Republic, Slovakia) for the period of 2000–2019. The findings were confirmed in models without control variables, and an increase of 1% of patents led to reducing greenhouse gas (GHG) emissions by 0.28% for Poland, 0.28% for Hungary, 0.38% for the Slovak Republic and 0.46% for the Czech Republic. At the same time, for the models with control variables, only Hungary experienced a statistically significant impact. There, an increase of patents by 1% led to reduction of GHG emissions by 0.22%. The variable R&D expenditure was statistically significant for all countries and all types of models (with and without control variables). The increase of R&D expenditure provoked a decline of GHG emissions by 0.29% (without control variables) and 0.11% (with control variables) for Poland, by 0.26% (without control variables) and 0.41% (with control variables) for Hungary, by 0.3% (without control variables) and 0.23% (with control variables) for the Slovak Republic and by 0.54% (without control variables) and 0.38% (with control variables) for the Czech Republic.

Keywords: emission; carbon dioxide; Internet; climate change

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1. Introduction

Climate changes are global issues which provoke irreversible negative consequences in all sectors. The core catalysts of climate changes include an increasing volume of greenhouse gas emissions. World experts have been trying to overcome these issues through implementing the principles of sustainable development. The European Commission has accepted the Green Deal Policy under the updated Cohesion policy. The Green Deal Policy aims to decarbonize the economy by reducing greenhouse gas emission (GHG emission) by implementing smart technologies, green energy and extending principles of the green economy. Further, the European Commission has already developed incentive mechanisms to urge the coal region to achieve the indicated goals.

Scientists around the world have been trying to empirically confirm the impact of a huge range of variables on reducing greenhouse gas emission with the goal of finding effective solutions and relevant instruments which guarantee a positive effect. Thus, the authors Lange et al. (2020) tried to confirm the hypothesis that information and communication technologies (ICT) allowed a decline in energy demand. At the same time, they highlighted that digitalization led to increasing energy consumption. In this case, the scientists received a vice versa circle. Nair et al. (2020) confirmed that expenditure on

R&D and ICT infrastructure had a statistically significant positive impact on long-term economic growth. For a calculation, they used a dataset for OECD countries and the GMM approach. Nair et al. (2020) used telephone landlines, mobile phones, composite index of ICT infrastructure, internet users, internet servers and fixed broadband as the variables for estimating ICT. The same conclusion was obtained by Majeed and Ayub (2018). These authors used additional indicators to explain the ICT, such as an e-government index, telecommunication and online service.

Asongu and Odhiambo (2019) used the GMM approach to confirm that FDI generates an increasing level of the mobile and internet penetration. In addition, they used mobile and internet penetration as the core determinants of ICT development in a country. On the contrary, the scientists Chimbo (2020) and Raheem et al. (2020) proved that ICT has a negative impact on GDP and CO_2 emissions. Further, Chimbo (2020) confirmed that, for African countries, spreading of ICT led to an increase of energy consumption. Chimbo (2020) and Raheem et al. (2020) estimated ICT by the following variables: telephone landlines, mobile phone penetration and internet penetration. Siddiqui and Singh (2020) estimated a link between the ICT penetration and the economic growth using the Breusch–Pagan Lagrange Multiplier (LM) test, Pooled OLS, and fully modified OLS (FMOLS). The ICT penetration was estimated by principal component analysis (PCA) through the following indicators: individuals using the Internet (as a percentage of population); fixed broadband, telephone, and mobile subscriptions (per 100 people); ICT trade in goods.

Arshad et al. (2020) checked the impact of ICT, trade, economic growth, financial development and energy consumption on carbon dioxide emissions using the Unit root tests, DOLS and GM-FMOLS. In this case, they used the sum of the fixed telephone and mobile subscription data per 100 people as the variables for evaluating ICT. Tsaurai (2020) showed that ICT has an impact on financial development for African countries. Tsaurai (2020) estimated ICT by share of the total population using the Internet. Many scientists (Bogachov et al. 2020; Dzwigol et al. 2020; Kuzior et al. 2019; Kwilinski 2018a; Kwilinski et al. 2019; Kwilinski and Kuzior 2020; Miskiewicz 2019a, 2019b, 2020a; Miśkiewicz and Wolniak 2020) showed that implementing artificial intelligence allowed boosting the achievement of sustainable development goals.

Dkhili (2018) confirmed the link between environmental performance and the country's development using GDP as a key indicator of economic growth. Pająk et al. (2017), Miskiewicz (2018), Kwilinski et al. (2020a, 2020b), Dzwigoł et al. (2019) and Saługa et al. (2020) analysed energy security as the key indicator of the economic growth.

Vasylieva et al. (2019) and Bilan et al. (2019) confirmed that the spread of renewable energy reduces GHG emissions. They also proved that a decline of corruption allowed a reduction in air pollutions. Khan et al. (2020) proved that ICT in green infrastructure allowed cutting GHG emissions. The summary of the approaches to estimate the link among ICT, economic growth and GHG emissions is showed in Table 1.

Table 1. The Approaches to Estimating the Link among ICT, Economic Growth and GHG Emissions (Source: developed by the author).

Author	Period, Country	Methodology	Variable	Findings
		ICT and Economic growth		
Nair et al. (2020)	1961–2018, OECD	GMM approach	RDE, RDR, RDT, TEL, MOB, INU, INS, FIB, CIC, PEG	RDE, RDR, and RDT positive impact on TEL, MOB, INU, INS, FIB, CIC and PEG
Majeed and Ayub (2018)	1980–2015, 149 countries	OLS, Pooled OLS, 2SLS, GMM approach, PCA	TEL, INU, INS, FIB, T, OS, EG, GDP, L, PC, H, I, E	INU, TEL, INS, FIB, T, OS, EG Positive impact on GDP
Asongu and Odhiambo (2019)	1980–2014, Sub-Saharan Africa	GMM approach	GDP, GDP per capita, real GDP MP, IP, FDI	FDI generate the increasing MP and IP, MP and IP positive impact on GDP, GDP per capita, real GDP
Siddiqui and Singh (2020)	2001–2018, developed and developing countries	Breusch–Pagan Lagrange Multiplier (LM) test, Pooled OLS, FMOLS	TR, FDI, ICTp, FD, GDP per capita	ICT positive impact on TR and GDP per capita
		ICT, Economic growth and GHG emissions		
Raheem et al. (2020)	1990–2014, G7 countries	PMG	TEL, MOB, P, TR, CO_2, URB, FD, GDP	ICT positive long-run effect on CO_2, ICT and FD negative impact on GDP in long-term
Chimbo (2020)	2001–2015, African countries	Fixed effects, random effects, pooled OLS and the dynamic GMM	ICT, E, GDP, HD, P, FDI	ICT and E negative impact on GDP, FDI, P, HD positive impact on GDP
Arshad et al. (2020)	1990–2014, South and Southeast Asian	Unit root tests, DOLS and GM-FMOLS	ICT, TR, GDP per capita, FD, U, CO_2	FD and ICT deteriorated the environment quality, bidirectional causality between CO_2 and E, unidirectional causality from TR, GDP per capita, FD, and ICT to CO_2
Tsaurai (2020)	2001–2015, Africa	Dynamic GMM	ICT, HD, P, E, GDP per capita, U, TR, FDI, IN	ICT and E significant impact on FD (board money)
Bilan et al. (2019)	1995–2015, EU	FMOLS, DOLS, VECM	RESs, CO_2, GDP, L and K	linking RESs, CO_2, L, K and GDP
Vasylieva et al. (2019)	2000–2016, EU and Ukraine	Panel unit root tests, FMOLS, DOLS	RE, GHG, GDP and CC	Increasing RE decline GHG, CC decline
Khan et al. (2020)	1990–2017, 91 countries	PCA, PCSE	ICT, CO_2	ICT reduce CO_2

RDE—R&D expenditure; RDR—R&D researchers; RDT—R&D technicians; TEL—telephone landlines, MOB—mobile phones; INU—internet users; INS—internet servers; FIB—fixed broadband; CIC—composite index of ICT infrastructure; PEG—per capita economic growth; T—telecommunication; OS—online service; EG—e-government index; GDP—gross domestic product; L—labour; PC—physical capital; H—human capital; I—inflation rate; E—energy consumption; MP—mobile phone penetration; IP—internet penetration; FDI—foreign direct investment; HD—human development; P—population; TR—trade openness; CO_2—carbon emissions; URB—urban population; FD—financial development; ICTp—ICT penetration; U—unemployment; IN—infrastructure development; CC—control corruption.

Lyulyov and Pimonenko (2017) analysed the investment as a drive for innovation development using the Lotka-Volterra synergy model. Kendiukhov and Tvaronavičienė (2017) proved that innovation development boosts achievement of sustainable economic growth.

The results of the analysis showed that the researchers used different approaches to estimating the relation among ICT, economic growth and GHG emissions. Scientists used several approaches to evaluating ICT. Mostly, scientists explained ICT by means of the following indicator: individual users of Internet (as a % of the population). At the same time, the indicator GDP per capital was mostly used to explain the countries' economic growth.

Considering the findings, the scientists confirmed the positive impact of ICT on the country's economic growth and ecological development. However, the range of the papers proved that developing ICT increased energy consumption and GDP, which provoked the rapid growth of GHG emissions. It should be noted that the conclusions mostly relate to the sample of the countries as the object of the research. Considering the EKC hypothesis, economic growth is the main force to improve the quality of life and reduce the negative impact on the environment (Kuznets 1955). Developed countries have more options to finance innovations and informational technologies development. Thus, the core hypothesis of the paper is that economic growth influences GHG emissions which could be reduced by implementing innovations and informational technologies.

2. Materials and Methods

Among the EU countries, Poland and the Czech Republic were among the top 10 polluters with GHG emissions. In 2018, Poland produced 415,858.2 thousand tons or 9% of the GHG emissions of the EU-28. Additionally, Poland and the Czech Republic are the European regions with coal-dependent economies. Considering the Green Deal Policy, the EU is aiming to become the climate-neutral in 2050, supporting the most affected regions (such as Poland and the Czech Republic) will be necessary. In this case, considering the above-mentioned tendencies on extending the innovations and informational technologies with the purpose of reducing the negative consequences of climate changes is topical and important.

In the framework of this research, the following EU countries were chosen: Hungary, Czech Republic, Slovak Republic and Poland for the period of 2000–2019. The Visegrád countries joined the EU in 2004 and have common historical roots. The core indicators of the Visegrád countries selected for analysis are showed in Table 2.

Table 2. Explanation of the variables (Source: developed by the author).

Variables	Abbreviations	Source
Greenhouse gas emission	GHG	Eurostat
Research and development expenditure (% of GDP)	RD	World Data Bank
Patent applications, residents	PA	World Data Bank
Labour force participation rate, total (% of total population ages 15–64) (modelled ILO estimate)	HC	World Data Bank
Individuals using the Internet (% of the population)	Inv	World Data Bank

The GDP and labour force participation rate were used to explain the economic growth of each country. The innovation and information technologies were explained by indicators as follows: individuals using the Internet, research and development expenditure, and patent applications. GHG emissions were a dependent variable which, besides CO_2, combined all types of contaminants.

The findings proved that production activities provoked degradation of the environment and imbalances of the ecosystem. Traditionally, scientists (including Kuznets 1955;

Bilan et al. 2019; Dementyev and Kwilinski 2020; Kwilinski et al. 2020b; Vasylieva et al. 2019; Khan et al. 2020) described such a relationship using the quadratic function:

$$E = F\left(Y,\ Y^2, Z\right) \tag{1}$$

where E is environmental pollution, Y is output and Z are the explanatory variables.

The core sources of environmental degradation are economic sectors which require additional investments for innovation and information technology with the purpose of minimizing the destructive impact on the environment. Considering the analysis of various approaches (Arshad et al. 2020; Bilan et al. 2019; Chygryn et al. 2020; Kharazishvili et al. 2020; Kwilinski 2018b; Majeed and Ayub 2018; Mazurkiewicz and Lis 2018; Miskiewicz 2020b; Zahorskyi et al. 2019; Vasylieva et al. 2019) to estimate the relationships between economic growth and innovation development, information technologies, GHG emissions, scientists mostly use OLS for each country, as well as FMOLS and DMOLS for all selected countries. In this case, to study the impact of innovation and information technology on greenhouse gas emission, the following type of models were used:

- for each country:

$$\text{GHG}_t = \alpha_0 + \alpha_1 GDP_t + \alpha_2 RD_t + \alpha_3 PA_t + \alpha_4 Inv_t + \alpha_5 HC_t + e_t \tag{2}$$

- for all selected countries:

$$\text{GHG}_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 RD_t + \beta_3 PA_t + \beta_4 Inv_{it} + \beta_5 HC_t + e_{it} \tag{3}$$

where $\alpha_0 \ldots \alpha_5$, $\beta_0 \ldots \beta_5$ are estimated parameters of the model, i symbolizes the countries, t is time and e_{it}, e_t are error terms.

All variables of models (2) and (3) were in logarithm with the purpose to eliminate the heteroskedasticity. In addition, stationary time series were used to calculate the unknown parameters of models (2) and (3). The analysis results confirmed that widespread tests for checking the time series stationarity were Dicky-Fuller and Phillips-Perron tests (Akimova et al. 2017; Raheem et al. 2020; Chimbo 2020; Arshad et al. 2020). Thus, the main stage of estimating the impact of innovation and information technology on greenhouse gas emission were:

(1) Stationary testing at the level and first differences of time series of the model (2) using the unit root tests, the ADF-statistic and Phillips-Perron tests. Thus, the ADF technique was based on the following equation:

$$\mathrm{y_t = c + \beta t + \alpha y_{t-1} + \sum_{j=1}^{p} \varphi_{ij} Y_{t-1} + \varepsilon_{i,t-1}} \tag{4}$$

where y takes the meaning of each parameter of Equation (2); $\mathrm{y_{t-1}}$ is a lag 1 of time series; $\mathrm{Y_{t-1}}$ is the first Difference of the series at the time $(\mathrm{t} - 1)$; $\rho_\mathrm{i} = 0$ for all i—the null hypothesis; $\rho_\mathrm{i} < 0$ for at least one i is an alternative hypothesis non-existent of a unit root.

(2) Checking of a long-term relation between the series of Equations (2) and (3) using OLS for each country and the Fully Modified OLS (FMOLS), Dynamic OLS (DOLS) panel cointegration techniques for all selected countries.

3. Results

At the first stage of the research, descriptive statistics for selected variables was done. The findings in Table 3 confirmed that the average and standard deviation of the variables were in the minimum and maximum interval. Therefore, the highest average value of GHG was for the Czech Republic (2.61) and Poland (2.36); at the same time, the lowest level was for Hungary (1.92). The most variables were negatively skewed (63%), while only 37% were positively skewed. In particular, the logarithm of GHG (for all countries), GDP (for all countries), PA (for the Czech Republic, Hungary, Slovak Republic) and Inv (for all countries) were negatively skewed. It means that the average value could not describe a real picture of the country's development. Besides, all variables had a positive level of kurtosis, which confirmed that the variables analysed were possibly leptokurtic in form.

Table 3. Descriptive statistics for GHG, GDP, RD, PA, Inv, FDI, HC.

Variable	Country	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability
lnGHG	1	2.61	2.70	2.50	0.08	−0.18	1.33	2.30	0.32
	2	1.92	2.03	1.76	0.09	−0.21	1.68	1.51	0.47
	3	2.36	2.40	2.31	0.03	−0.16	1.89	1.06	0.59
	4	2.16	2.26	2.03	0.09	−0.16	1.40	2.10	0.35
lnGDP	1	12.87	13.07	12.62	0.13	−0.54	2.25	1.39	0.50
	2	14.98	15.20	14.74	0.12	−0.25	2.85	0.21	0.90
	3	10.48	10.83	10.15	0.22	−0.13	1.75	1.30	0.52
	4	9.39	9.68	8.99	0.22	−0.53	1.95	1.78	0.41
lnRD	1	0.35	0.68	0.10	0.22	0.30	1.42	2.25	0.32
	2	0.09	0.44	−0.24	0.19	0.09	1.85	1.08	0.58
	3	−0.32	0.19	−0.62	0.26	0.46	1.82	1.78	0.41
	4	−0.44	0.16	−0.80	0.28	0.39	2.17	1.02	0.60
lnPA	1	6.58	6.89	6.27	0.19	−0.09	1.84	1.09	0.58
	2	6.50	6.82	6.01	0.19	−0.85	3.79	2.77	0.25
	3	8.02	8.45	7.61	0.30	0.11	1.31	2.31	0.32
	4	5.33	5.56	5.04	0.15	−0.43	2.06	1.28	0.53
lnInv	1	3.88	4.39	2.28	0.61	−1.39	3.96	6.87	0.03
	2	3.80	4.37	1.95	0.70	−1.33	3.67	5.92	0.05
	3	3.75	4.35	1.99	0.68	−1.50	4.22	8.30	0.02
	4	4.00	4.40	2.24	0.61	−2.07	6.13	21.34	0.00
lnHC	1	4.27	4.34	4.24	0.03	1.05	2.66	3.58	0.17
	2	4.15	4.28	4.08	0.06	0.92	2.44	2.91	0.23
	3	4.19	4.25	4.15	0.03	0.58	2.05	1.78	0.41
	4	4.25	4.28	4.22	0.02	0.84	2.65	2.32	0.31

Note: 1—Czech Republic; 2—Hungary; 3—Poland; 4—Slovak Republic.

The next step was to check the data for stationarity using the ADF-statistic and Phillips-Perron tests. The findings of ADF-statistic and Phillips-Perron tests are in Table 4. The empirical results and critical value of t-statistics for variables GHG, GDP, RD, PA and HC were less than the absolute value of thresholds at 1%, 5% and 10% significance levels. Additionally, *p*-value (probability) of the tests were in average 0.744 (74.4%, that is *p*-value > 10%). Therefore, as the minimum probability of existing the unit root in data and the time series—not stationary was 75% (*p*-value > 10%), the hypothesis on existing of a unit root in time series could not be rejected. The findings confirmed the stationarity of series for the Czech Republic, Hungary and Poland at a level only for the variable Inv. The results of Dicky-Fuller and Phillips-Perron tests for time series at the first differences confirmed the stationarity of the modified data. The absolute value of t-statistic was less than the absolute value of thresholds at 1%, 5% and 10% significance levels. Moreover, the *p*-value (probability) was 0.000 (0%, that is *p*-value < 10%). The findings allowed rejecting the null hypothesis-existing of a unit root in the first differences of the time series with minimum probability (in almost 0% of cases out of 100%). Therefore, the time series in the first differences were stationary, and the series at level had the order of integration 1.

Table 4. Findings of ADF-Statistic and Phillips-Perron tests (Source: developed by the author).

Variable		ADF-Statistic				Phillips-Perron			
		1	2	3	4	1	2	3	4
At Level									
lnGHG	Value	−0.236	−0.921	−2.040	−0.640	−0.186	−1.062	−2.025	−0.627
	Prob	0.917	0.757	0.269	0.838	0.924	0.707	0.275	0.841
lnGDP	Value	−1.313	−0.903	0.273	−1.677	−1.263	−0.990	0.180	−1.780
	Prob	0.600	0.763	0.970	0.425	0.623	0.733	0.963	0.378
lnRD	Value	−0.334	−0.784	1.325	−2.949	−0.334	−0.471	1.163	−0.954
	Prob	0.901	0.799	0.998	0.063	0.901	0.876	0.996	0.746
lnPA	Value	−1.551	0.895	−0.493	−3.807	−1.517	2.696	−0.493	−4.250
	Prob	0.486	0.992	0.871	0.012	0.503	1.000	0.871	0.005
lnInv	Value	−3.995	−5.453	−6.072	−2.239	−20.68	−13.77	−12.09	−11.38
	Prob	0.009	0.001	0.000	0.202	0.000	0.000	0.000	0.000
lnHC	Value	−0.628	2.214	1.204	0.449	1.544	1.817	1.023	0.222
	Prob	0.836	1.000	0.997	0.979	0.999	0.999	0.995	0.966
At 1st Difference									
lnGHG	Value	−3.464	−3.449	−4.338	−5.092	−3.551	−3.455	−4.451	−4.968
	Prob	0.024	0.024	0.004	0.001	0.019	0.023	0.003	0.001
lnGDP	Value	−4.651	−5.809	−4.829	−3.208	−5.483	−6.083	−5.798	−3.217
	Prob	0.003	0.000	0.002	0.037	0.001	0.000	0.000	0.037
lnRD	Value	−2.912	−3.770	−4.706	−4.971	−2.931	−4.438	−9.381	−4.893
	Prob	0.065	0.013	0.003	0.001	0.063	0.003	0.000	0.001
lnPA	Value	−4.005	−4.925	−3.934	−5.853	−4.004	−5.066	−3.934	−6.945
	Prob	0.008	0.002	0.009	0.000	0.008	0.001	0.009	0.000
lnInv	Value	−8.948	−12.14	−11.87	−3.267	−6.055	−4.810	−9.659	−3.208
	Prob	0.000	0.000	0.000	0.033	0.000	0.002	0.000	0.037
lnHC	Value	−5.287	−6.393	−7.151	−3.693	−6.021	−6.440	−14.78	−3.760
	Prob	0.001	0.000	0.000	0.015	0.000	0.000	0.000	0.013

Note: 1—Czech Republic; 2—Hungary; 3—Poland; 4—Slovak Republic.

The findings of the selected variables' impact on GHG emissions are in Table 5. The empirical results confirmed that increasing the research and development expenditure stimulates the decline of greenhouse gas emission as for each and all the Visegrád countries. Thus, the results of FMOSL test allowed identifying the negative relation among RD, PA and GHG emissions at a value of 1%. This means that increasing research and development expenditure by 1% leads to a 0.25% decline of GHG emissions, while the increase of patent applications by 1% provokes a 0.14% decrease of GHG emissions. In addition, an increase in the number of individuals using the internet by 1% leads to a 0.05% reduction of GHG emissions. According to panel DOLS results, a 1% increase of RD, PA, Inv resulted in decreases of GHG emissions by 0.24%, 0.1% and 0.02%, respectively.

It should be noted that in the model without control variables, the variables RD and PA for the Czech Republic had the most statistically significant impact on the decline of GHG emissions. Thus, a 1% increase of RD and PA leads to a decline of GHG emissions of 0.53% and 0.457%, respectively. At the same time, in the model with control variables, the indicator RD had a statistically significant impact at the level of 1%. A 1% increase of RD resulted in a 0.35% decline in GHG emissions.

The findings allow the conclusion that the impact of Inv on GHG emissions at the level of 10% was only for Hungary and Poland in the model with control variables. In Poland, the increase of the variable 'individuals using the Internet' at a 1% level led to a decline of GHG emissions of 0.04%.

Table 5. Results of analysing the impact of the selected variables on GHG emissions (Source: developed by the author).

Variable	Static							
	Without Control Variables				With Control Variables			
	1	2	3	4	1	2	3	4
lnRD	−0.537 (0.000) ***	−0.255 0.124	−0.290 (0.000) ***	−0.298 (0.000) ***	−0.347 (0.000) ***	−0.409 (0.008) ***	−0.113 (0.007) ***	−0.227 (0.000) ***
lnPA	−0.457 (0.000) ***	−0.281 (0.000) ***	−0.280 (0.000) ***	−0.381 (0.000) ***	0.029 0.680	−0.218 (0.028) **	−0.069 0.119	−0.003 0.953
lnInv	−0.053 0.153	0.029 0.470	0.006 0.782	0.001 0.984	−0.067 0.106	−0.062 (0.078) *	−0.046 (0.063) *	−0.004 0.873
lnHC	—	—	—	—	−0.378 0.410	−0.738 0.176	−0.350 0.211	0.909 (0.000) ***
lnGDP	—	—	—	—	0.343 (0.056) *	0.446 (0.022) **	0.431 (0.002) ***	−0.188 (0.033) **
R-squared	0.590	0.432	0.563	0.539	0.626	0.894	0.842	0.626

	Panel Results			
	FMOLS		DOLS	
lnRD	−0.253827 (0.000) ***	−0.34701 (0.000) ***	−0.239 (0.000) ***	−0.320 (0.000) ***
lnPA	−0.149868 (0.000) ***	−0.184359 (0.000) ***	−0.103 (0.017) **	−0.131 (0.004) ***
lnInv	−0.016609 0.4312	−0.051 (0.0415) **	−0.024 (0.097) *	−0.041 (0.065) *
lnHC	—	0.0393 0.108	—	0.381 0.225
lnGDP	—	0.148959 0.1033	—	0.130 0.176
R-squared	0.968047	0.6324	0.968	0.972

Note: 1—Czech Republic; 2—Hungary; 3—Poland; 4—Slovak Republic; *, **, *** represents significance at the 1%, 5% and 10% levels.

4. Conclusions

The Green Deal Policy is aimed at mobilizing the research and fostering innovations on decarbonizing the economy for future sustainable development. Considering "Just Transition Mechanism", all EU members should be involved in achieving the climate-neutral economy. Besides, the most affected regions where coal is a key resource (such as Poland and the Czech Republic) should reorient their internal policy and invest more in innovative technologies which allow replacing coal with a climate-neutral resource and reducing GHG emissions. The achievement of that goal requires supporting the innovation development of the industry, decarbonizing the energy sector and investing in green technologies. Thus, the "Initiative for Coal Regions in Transition" focused on spreading the most effective green technologies among the EU coal regions by developing the stakeholders' network and providing financial resources for green innovations.

The results of the analysis show the GDP effect on GHG, which is similar with conclusions in other papers (Arshad et al. 2020; Bilan et al. 2019; Miskiewicz 2020b; Prokopenko and Miśkiewicz 2020; Vasylieva et al. 2019). Additionally, developing informational and innovation technologies had a statistically significant impact on GHG emissions. Considering the findings in the models without control variables, increasing patents by 1% leads to reducing GHG emissions by 0.28% for Poland, 0.28% for Hungary, 0.38% for the Slovak Republic and 0.46% for the Czech Republic. At the same time, for the models with control variables, the statistically significant impact was only for Hungary. Thus, increasing patents by 1% led to reducing GHG emissions by 0.22%. The variable R&D expenditure was statistically significant for all countries and all types of models (with and without control variables). The increase of R&D expenditure resulted in a decline of GHG emissions by 0.29% (without control variables) and 0.11% (with control variables) for Poland, by

0.26% (without control variables) and 0.41% (with control variables) for Hungary, by 0.3% (without control variables) and 0.23% (with control variables) for the Slovak Republic and by 0.54% (without control variables) and 0.38% (with control variables) for the Czech Republic. At the same time, the findings proved that, for the Visegrád countries, a percentage of the individuals using the Internet did not influence the GHG emissions, excluding two cases of Hungary and Poland for the models with control variables. There were findings opposite to the conclusions in the papers Nair et al. (2020) and Majeed and Ayub (2018). This means that the Czech Republic and the Slovak Republic should focus on developing innovative technologies in the energy and industrial sectors.

The EU "Energy Transition Package" is aimed to support the less developed EU members and to assist them on the way to the reorientation of the national energy system. Poland has already attracted more than 205 million EUR from the European Investment Bank for the transition to a low-carbon economy. The European Investment Bank declared they were going to finance up to 75% of the project cost aimed to increase energy efficiency, extending renewable energies in 10 countries: the Czech Republic, Slovakia, Hungary, Poland, Romania, Bulgaria, Latvia, Croatia, Lithuania and Estonia.

The results of this analysis show that the EU developed a range of mechanisms to support the transition to the carbon-free economy. In this case, the Visegrád countries should integrate their home policy using the supportive options from the European Commission with the purpose of achieving the goals of a carbon-free economy. At the same time, the EU should consider the fact that, for the selected countries, the most effective instruments are green innovative technologies.

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