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Modeling the Consumption of Main Fossil Fuels in Greenhouse Gas Emissions in European Countries, Considering Gross Domestic Product and Population

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Abstract: Poland ranks among the leading European countries in terms of greenhouse gas (GHG) emissions. Many European countries have higher emissions per capita than the EU average. This research aimed to quantify the complex relationships between the consumption variables of the main fossil fuels, accounting for economic indicators such as population and gross domestic product (GDP) in relation to GHG emissions. This research attempted to find similarities in the group of 16 analyzed European countries. The hypothesis of an inverted U-shaped environmental Kuznets curve (EKC) was tested. The resulting multiple regression models showed similarities in one group of countries, namely Poland, Germany, the Czech Republic, Austria and Slovakia, in which most of the variables related to the consumption of fossil fuels, including HC and BC simultaneously, are statistically significant. The HC variable is also significant in Denmark, Estonia, the Netherlands, Finland and Bulgaria, and BC is also significant in Lithuania, Greece and Belgium. Moreover, results from Ireland, the Netherlands, and Belgium indicate a negative impact of population on GHG emissions, and in the case of Germany, the hypothesis of an environmental Kuznets curve can be accepted.

Keywords: GHG emission; fossil fuel; GDP; environmental Kuznets curve; multiple regression; EU; modeling

1. Introduction and Literature Review

Economic progress, increasing consumption and the unsustainable exploitation of the natural environment contribute to the emission of many dangerous pollutants. Changes occurring in the environment affect entire ecosystems, from changes in biodiversity [1]; the extinction of plants [2] and animal species [3]; the poisoning of water, soil and air [4]; and threats to human health and life [5,6]. Broadly understood sustainable development and the rational management of natural resources are particularly important today. The emission of greenhouse gases as a result of human activities increases the greenhouse effect. The rising atmospheric temperature and global warming have been attracting the attention of scientists and researchers in research centers around the world for many years [7]. A variety of modern methods and tools are widely used to assess [8,9], prevent [10], reduce [11,12] and predict the volume of GHG emissions [13,14]. The main sources of greenhouse gases are the combustion of fossil fuels for energy generation and transportation, industry, deforestation, agriculture, water bodies (wetlands) and urban activities [15]. A particularly important source of GHG emissions is the use of fossil fuels by the energy sector.

In some European countries, the consumption of fossil fuels is still high (Figure 1).

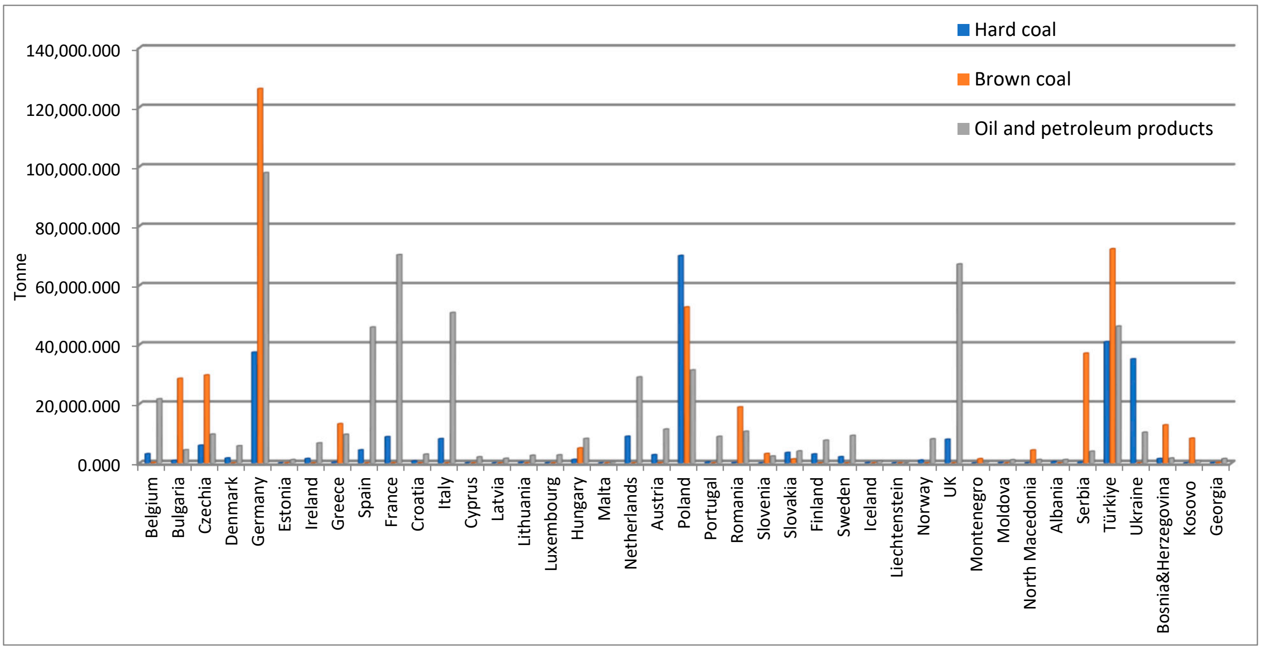


Figure 1. Consumption of basic fossil fuels in geopolitical terms in Europe in 2021 [16].

It is estimated that energy accounts for more than three-quarters of total GHG emissions globally [17]. This problem concerns both developing countries [18–20] and developed, modern economies [21]. The European Union (EU) is a pioneer in the fight against pollution and climate change, having established the United Nations Framework Convention on Climate Change and introducing a range of pollution and energy measures to reduce greenhouse gas emissions. Air pollution remains a major challenge for most EU countries, including those located in Central and Eastern Europe [22]. Many scientific centers undertake research on processes and issues associated with emissions from the energy sector in order to reduce GHG emissions. In the research conducted by Wu, J., et al. [23], the authors analyze the marginal impact of energy price and economic freedom on Europe's CO_2 emissions using the extended Stochastic Impacts by Regression on Population, Affluence and Technology ecology model together with the spatial econometric models. In another study, researchers analyzed a set of selected German and French cities in terms of their relative ecological efficiency, calculated as the ratio of their GDP to CO_2 emissions [24]. The study conducted by Wenlong, Z., et al. [25] attempts to empirically analyze the environmental impact of certain important factors, e.g., energy efficiency, technological innovation, trade openness and institutional quality, in 10 Asian economies over the period 1995–2018. The researchers Forsius, M., et al. [26] integrated the results of three spatially distributed modeling systems (FRES, PREBAS, Zonation) to assess the potential to achieve carbon neutrality by 2035 in Finland at both national and regional scales, by simultaneously considering the conservation goals included in the EU biodiversity strategy. In another study, researchers examine how population growth, wealth and energy technology factors influence CO_2, CH_4 and NO_2 emissions from the power sector in Bangladesh. This study applied extended stochastic effects through regression to a population, wealth and technology model using ridge regression for the analysis. The study also examined the presence of an environmental Kuznets curve (EKC) for greenhouse gas emissions [27]. The research carried out by Fatima, T., et al. [28] aimed to determine the main factors influencing CO_2 emissions in Chinese industry in the period 1991–2016. Based on the logarithmic Divisa index (LMDI) method, the change in industry-related CO_2 emissions was decomposed into the energy structure effect, income effect, energy intensity effect, carbon dioxide emissions effect and labor effect. In the study [29], the authors discuss activities promoting energy efficiency implemented in the socio-economic sectors: electricity, construction, logistics and transport, along with their impact on the carbon footprint. Using the Crystal Ball simulation model, [30] estimates the cumulative increase (35%) in CO_2 emissions over ten years without nuclear power in Ghana's energy mix. After including nuclear power in the country's energy mix, the model estimates a reduction in CO_2 emissions of 12.5% over the same period and 18.2% over 20 years. Of the 21 EU countries that reduced their emissions, only 6 also decreased their GDP (Czech Republic, Estonia, Lithuania, Luxembourg, Hungary and Poland), which means 15 EU countries (Portugal, Croatia, Belgium, Malta, France, Spain, the Netherlands, Germany, Austria, Romania, Italy, Cyprus, Greece, Slovenia and Bulgaria) managed to reduce emissions while increasing their GDP [31].

The availability of modern computational techniques and advanced statistical methods allows the study of correlations on a scale that previously seemed impossible. Ecological Kuznets curves have also been subject to countless verifications. Scientists have analyzed greenhouse gas emission factors and the impact of urbanization on environmental degradation and tested the U-Kuznets curve hypothesis in various configurations. All possible measures of environmental devastation are correlated with GDP per capita indicators. Indeed, it is often possible to match the observed patterns with an inverted letter "U" [32–34]. An example confirming the existence of a correlation is the study of the relationship between income and CO_2 emissions for 26 high-income OECD countries and 52 emerging countries [35]. The results of research conducted for 17 OECD countries confirm the EKC hypothesis and indicate that GDP per capita and GDP per capita squared have a positive and negative impact on CO_2 emissions, respectively, and that renewable energy consumption has a negative impact on CO_2 emissions [36]. The results of research on Croatia also prove the existence of the U-Kuznets curve hypothesis between CO_2 emissions and economic growth in the long run [23]. In other studies, using Turkey as an example, the overall results showed that the level of GDP per capita that could reduce environmental pollution has not been achieved, and the use of renewable energy is not a solution to reducing CO_2 emissions [37]. Another study in Kenya found that fossil fuel energy use, GDP, urbanization and openness to trade increase air pollution in the long- and short-term. However, renewable energy consumption mitigates air pollution in the long- and-short term. Moreover, financial development also reduces air pollution, but only in the long run [38]. There are also critical voices and some studies that question the existence of the effect postulated by the environmental Kuznets curve [39]. The data generally do not support the concept of classical or environmental Kuznets curves, which are the inverse of the U. Rather, they emphasize that there is a trade-off between environment and equity [40].

Compared to European countries, Poland ranks highly in terms of GHG emissions (Figure 2). Countries such as Germany, the UK and Poland, which occupy the leading positions in terms of GHG emissions (Figure 2), are characterized by the highest consumption of hard coal and/or brown coal in the EU.

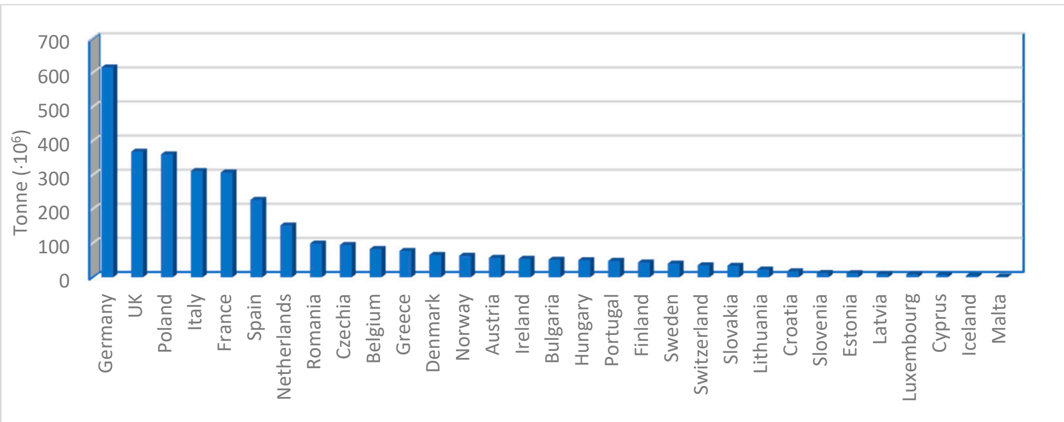


Figure 2. Annual greenhouse gases in CO_2 equivalent 2021 [16,41].

Additional information about the scale of emissions in European countries is provided by data on GHG emissions per capita (Figure 3).

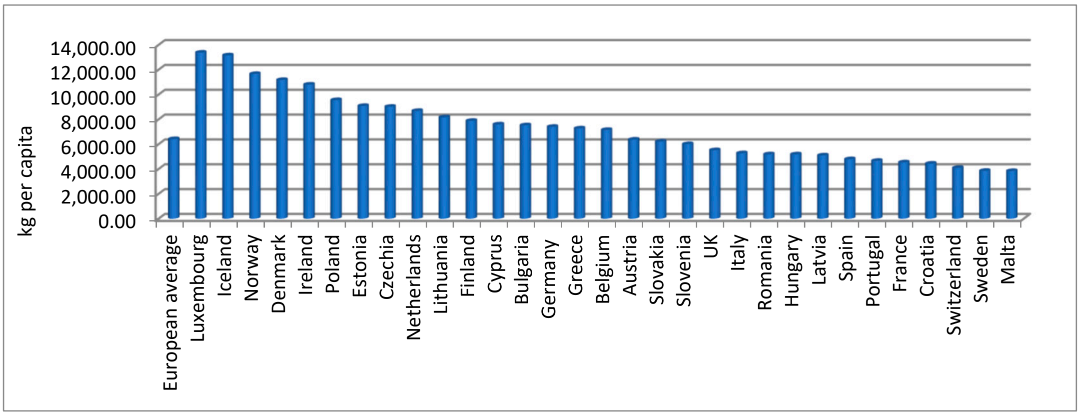


Figure 3. GHG emissions in kg per capita in Europe 2021 [16,41].

Many European countries have emissions that are higher than the EU average. The highest in 2021 were recorded in Luxembourg, Iceland, Norway, Denmark and Ireland. These are highly industrialized countries and high consumerism is probably reflected in GHG emissions per capita.

In Poland, the main sources of air pollution are emissions from fuel combustion, mainly from the energy industry and individual households and transportation [42]. Poland is among the leading countries in Europe in geopolitical terms with the highest inland consumption of hard coal in 2021, with consumption totaling 69,981,742 thousand tonnes, followed by Turkey at 40,926,606 thousand tonnes, Germany at 37,372,647 thousand tons and Ukraine at 35,110.9 thousand tonnes. In the case of the inland consumption of brown coal, Germany dominates with a consumption of 126,182,054 thousand tonnes followed by Turkey with 72,255,627 and Poland with 52,614,807 [16].

The research aimed to quantify the complex relationships between the consumption variables of the main fossil fuels (hard coal, brown coal, crude oil, natural gas), taking into account economic indicators such as population and GDP, in relation to the volume of GHG emissions. The study attempts to group the 16 European countries considered in terms of similarities in the importance of the studied variables. The research was conducted using multiple regression analysis. Based on the obtained models, simulations and forecasts of GHG emissions can be carried out. Most countries achieve reductions in CO_2 emissions, with most maintaining or increasing GDP adequately. Another novelty of the study is obtaining information on the correlation of GDP with GHG emissions in the group of European countries examined in terms of the existence of the environmental Kuznets curve hypothesis. The study of the Kuznets curve aims to confirm the existence of a negative correlation of the above-mentioned variables, while also answering whether the theory of environmental decoupling takes place in EU countries.

2. Data Source and Methodological Framework

The input material was data from international public statistics databases of the Eurostat and OECD [16,41]. The selection of data for research is not accidental. The main source of CO^2 emissions is the burning of fossil fuels, which is still practiced in many European countries. For this reason, the group of explanatory variables includes the consumption of fossil fuels in the analyzed EU countries. However, in order to examine the existence of the environmental Kuznets curve, i.e., to determine whether GHG reduction is negatively correlated with the level of GDP, data on GDP and population size were taken into account.

The research was conducted based on data from the period 1995–2021. The group of explanatory (independent) variables included data on the consumption of the main fossil fuels (hard coal, oil and petroleum products, natural gas, brown coal, gas) and economic data (i.e., gross domestic product and population). The explained (dependent) variable is GHG emissions (GHG). The research group consisted of 16 EU countries where GHG emissions per capita are higher than the EU average: Luxembourg, Denmark, Ireland, Poland, Estonia, Czech Republic, the Netherlands, Lithuania, Finland, Cyprus, Bulgaria, Germany, Greece, Belgium, Austria and Slovakia (Figure 4). This research was conducted using the Statistica v. 13 statistical package.

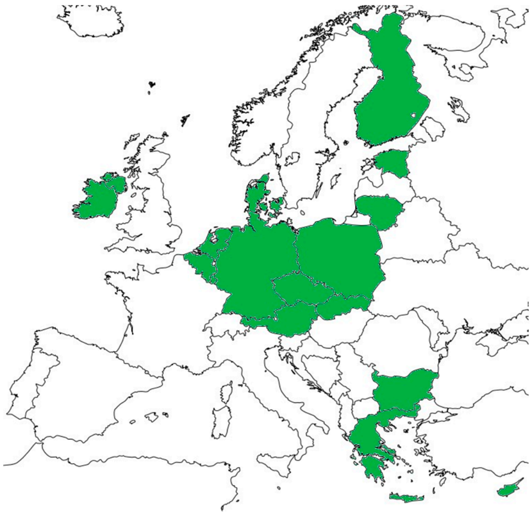


Figure 4. Countries included in the study.

Descriptive statistics of the data set for analyzed European countries are presented in Table 1.

Table 1. Statistical description of the data.

Variable	**Mean**	**St. Dev.**	**Min.**	**Max.**
Luxemburg				
OPP *	2617.1	392.7	1775.0	3104.5
HC *	117.1	50.0	57.2	242.0
NG *	990.7	259.3	636.0	1402.8
GDP **	32,191.6	12,517.9	13,123.3	55,797.4
Pop ***	505,154.2	71,780.6	408,625.0	640,064.0
GHG ****	10,828.3	1227.4	8590.9	12,993.8
Denmark				
OPP	7595.7	1036.5	5727.8	9445.0
HC	6326.1	3228.1	1237.1	15,009.0
NG	4146.4	813.4	2827.8	5150.0
GDP	168,566.2	42,782.3	99,481.0	256,566.4
Pop	5,516,857.7	187,415.6	5,227,861.0	5,850,189.0
GHG	65,647.1	12,948.4	44,483.8	92,928.7
Ireland				
OPP	7287.9	857.1	5529.0	8486.0
HC	2282.6	655.6	588.2	3002.0
NG	4513.7	747.3	2875.0	5501.8
GDP	163,753.6	79,151.1	57,259.9	362,050.6
Pop	4,320,267.7	455,518.8	3,601,300.0	5,011,460.0
GHG	64,917.7	4360.6	58,852.5	71,814.5

Table 1. *Cont.*

Variable	Mean	St. Dev.	Min.	Max.
Poland				
OPP	22,409.6	4968.4	13,449.0	31,345.3
HC	82,553.3	11,075.0	63,475.6	110,131.0
BC *	59,827.1	4321.0	46,107.0	65,934.0
NG	16,683.4	3099.5	12,196.0	23,541.9
GDP	550,045.3	207,974.3	248,423.3	956,864.9
Pop	38,310,532.6	135,324.3	38,115,909.0	38,533,789.0
GHG	404,308.5	20430.1	371,312.4	460,383.5
Estonia				
OPP	1135.7	83.2	893.0	1309.0
HC	68.7	31.7	3.5	130.0
NG	703.0	175.6	420.7	992.0
GDP	21,109.3	8882.8	7796.6	38,356.9
Pop	1,351,716.3	34,022.8	1,314,545.0	1,436,634.0
GHG	18,818.5	2570.8	11,407.1	22,046.4
Czech Republic				
OPP	8944.9	672.0	7799.0	9913.0
HC	8985.7	2260.0	5288.9	14,180.0
BC	43,757.8	6204.3	29,675.2	52,723.0
NG	8940.5	634.5	7522.0	9895.0
GDP	208,737.0	61,304.4	119,877.0	317,766.8
Pop	10,412,272.3	153,547.5	10,200,774.0	10,700,155.0
GHG	140,656.1	12,640.1	113,072.1	161,709.7
The Netherlands				
OPP	31,706.1	2087.1	27,475.6	34,899.2
HC	13,006.5	2126.0	6492.9	17,977.0
BC	26.9	12.7	6.0	56.6
NG	47,421.9	3711.1	40,073.1	55,951.3
GDP	530,235.0	118,950.4	303,567.7	749,498.1
Pop	16,487,267.3	583,278.3	15,459,004.0	17,533,048.0
GHG	206,412.1	19,310.8	164,367.8	241,662.1
Lithuania				
OPP	2240.2	386.7	1696.0	3213.0
HC	175.2	126.0	1.0	372.0
BC	96.6	126.0	0.0	392.0
NG	2664.4	386.9	2137.0	3553.0
GDP	45,773.6	18,389.4	18,025.7	81,312.8
Pop	3,187,915.6	286,946.3	2,794,137.0	3,629,102.0
GHG	21,277.2	1461.3	19,493.7	24,730.0
Finland				
OPP	9270.3	733.0	7649.0	10,509.0
HC	5574.1	1555.2	2726.0	8862.0
NG	3779.8	855.5	2353.0	5036.0
GDP	145,954.8	32,807.1	83,792.3	201,196.3
Pop	5,326,196.2	144,144.4	5107,787.0	5,541,020.0
GHG	67,762.9	10,595.3	47,756.3	85,490.4
Cyprus				
OPP	2335.1	243.9	1893.0	2822.0
HC	29.1	20.2	0.0	66.4
BC	0.4	0.5	0.0	1.0
GDP	17,780.3	5051.8	9319.5	26,501.9
Pop	781,973.4	81,219.5	650,860.0	900,357.0
GHG	8640.1	748.3	6972.2	10,025.4

Table 1. *Cont.*

Variable	Mean	St. Dev.	Min.	Max.
Bulgaria				
OPP	4217.1	471.9	3308.0	5233.0
HC	2859.3	1347.3	828.0	4916.0
BC	28,976.3	3304.8	22,283.0	36,996.0
NG	3456.7	752.9	2645.0	5794.0
GDP	76,051.6	25,793.3	39,843.9	128,169.2
Pop	7,575,279.5	470,148.8	6,877,742.5	8,406,067.0
GHG	60,642.2	5608.4	47,984.6	72,615.2
Germany				
OPP	116,180.3	9687.8	97,879.0	132,781.0
HC	61,297.3	10,534.1	31,197.7	75,362.0
BC	170,692.3	18,930.8	107,429.6	194,811.0
NG	91,270.0	5193.7	76,897.0	97,389.0
GDP	2,370,100.6	497,805.5	1,612,022.5	3,256,792.8
Pop	82,079,774.9	749,883.4	80,274,981.0	83,196,076.0
GHG	957,161.4	103,495.8	730,922.7	1137,869.0
Greece				
OPP	13,489.6	2451.1	9168.6	16,754.0
HC	677.1	400.7	265.6	1480.0
BC	54,110.4	16,202.7	13,213.7	70,855.0
NG	3199.6	1690.3	36.0	6446.4
GDP	206,312.7	32,851.6	136,520.1	265,211.8
Pop	10,859,677.0	168,322.1	10,562,160.0	11,121,344.0
GHG				
Belgium				
OPP	22,195.8	838.4	19,987.5	23,621.6
HC	6804.3	2909.0	2863.3	11,859.0
BC	189.2	219.9	0.0	730.0
NG	17,146.2	1672.7	12,792.0	20,476.0
GDP	309,968.5	74,820.6	190,570.7	452,167.7
Pop	10,770,320.6	478,660.1	10,136,814.0	11,552,615.0
GHG	113,438.3	17,955.9	75,464.5	136,748.1
Austria				
OPP	12,052.7	768.0	10,383.0	13,522.5
HC	3652.3	428.3	2749.9	4328.0
BC	659.3	676.9	59.6	1743.0
NG	8843.3	547.7	7844.3	9921.8
GDP	256,426.9	60431.8	157,751.2	355,971.0
Pop	8,357,953.1	322485.5	7,948,278.0	8,951,520.0
GHG	82,768.9	4683.3	73,910.8	92,588.6
Slovakia				
OPP	3526.1	265.7	3066.0	4045.0
HC	4359.3	676.4	2594.0	5330.0
BC	3560.0	1512.2	1306.0	7221.0
NG	6052.2	959.5	4535.0	7633.0
GDP	85,709.0	28,715.5	39,059.4	124,676.7
Pop	5,407,179.9	25,951.2	5,363,676.0	5,458,827.0
GHG	46,566.7	4807.4	37,187.9	53,180.0

* Thousand tonnes, ** Euro per capita, *** number, **** Thousands tonnes of CO_2 equivalent.

Linear multiple regression was used for modeling, because it allows for the searching and quantitative description of complex relationships. The built multiple regression model allows for the examination of the influence of many independent variables (X_1, X_2, . . ., X_k) on one dependent variable (Y). The most frequently used type of multiple regression is linear regression. It is an extension of linear regression models based on Pearson's linear correlation coefficient. It assumes a linear relationship between the studied variables. The linear multiple regression model takes the following form:

$$Y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \ldots + \alpha_n X_n + \epsilon \quad (1)$$

where:

Y—dependent variable;
$X_1, X_2, \ldots, X_n$—independent variables;
$\alpha_1, \alpha_2, \ldots, \alpha_n$—parameters;
ϵ—random component (the rest of the model).

Multiple regression analysis allowed us to test complex models that examine how multiple explanatory variables predict the values of a single variable. The backward stepwise regression analysis method was used in this research. This method involves, in its first step, the construction of a model that includes all potential explanatory variables, and then gradually eliminates them in order to maintain the model with the highest determination coefficient, while maintaining the significance of the parameters. For example, in Denmark, where Pearson's linear correlation coefficient showed the statistical significance of five independent variables (Table 2) as a result of the stepwise regression analysis, three variables are ultimately included in the regression model (the table in Section 3). Finally, the accuracy of the obtained models is confirmed based on the values of the regression coefficients (R, adj. R^2) and other statistics (F, p). Based on the obtained model, a forecast of the dependent variable—GHG emissions—is made.

Table 2. Pearson's correlation coefficients between studied variables and the dependent variable, GHG emissions.

	Country	OPP	HC	NG	BC	GDP	Pop
1	Luxemburg	**0.707**	−0.165	**0.919**	**-**	0.048	−0.08
2	Denmark	**0.934**	**0.968**	**0.775**	**-**	**−0.948**	−0.963
3	Ireland	**0.876**	**0.585**	−0.17	**-**	−0.371	−0.484
4	Poland	**−0.483**	**0.886**	**−0.507**	**0.424**	**−0.544**	−0.178
5	Estonia	0.343	**0.525**	0.385	-	−0.327	0.068
6	Czech Republic	**−0.412**	**0.912**	**0.451**	**0.979**	**−0.894**	−0.851
7	The Netherlands	−0.039	**0.452**	**0.742**	−0.077	**−0.944**	−0.963
8	Lithuania	**0.455**	−0.172	**0.411**	**0.437**	**−0.439**	0.524
9	Finland	**0.752**	**0.922**	**0.891**	**-**	**−0.733**	−0.85
10	Cyprus	**0.877**	0.291	**-**	**0.63**	**0.629**	0.424
11	Bulgaria	**0.536**	**0.667**	**0.778**	0.332	**−0.597**	0.69
12	Germany	**0.941**	**0.927**	0.205	**0.734**	**−0.955**	−0.205
13	Greece	**0.462**	**-**	**−0.514**	**0.952**	0.161	0.952
14	Belgium	0.214	**0.946**	**−0.566**	**0.576**	**−0.948**	−0.98
15	Austria	**0.831**	**0.877**	**0.481**	**0.438**	**−0.42**	−0.495
16	Slovakia	**−0.305**	**0.945**	**0.917**	**0.834**	**−0.922**	−0.897

Explanation: hard coal—HC; oil and petroleum products—OPP; natural gas—NG; brown coal—BC; gross domestic product—GDP; population—Pop.

3. Results and Discussion

Table 2 contains the results of Pearson's linear correlation with respect to the studied variables. Empty fields in the table ("-") mean that the specified source is not used by the country. The variables statistically significant are for $p < 0.05$ are indicated in bold and these variables were used in further analysis.

Table 3 presents the results of the multiple linear regression analysis. The values of the determined R^2 coefficient refer to the model fitted to the data. Introducing too many variables may result in the model over-fitting the data. Therefore, in addition to the adjusted R^2 coefficient, the result of Fisher's test (F), which is particularly important when comparing models, can also be used. The higher the F test value, the better the fit of the model. The values of the F statistics and the corresponding level of test probability *p* indicate a significant linear relationship (exception: Estonia).

Table 3. The results of multiple linear regression.

	Country	R	R^2	Adjusted R^2	F (Fischer)	Significance Level *p*
1	Luxemburg	0.930	0.866	0.855	77.390	0.000
2	Denmark	0.998	0.995	0.994	901.012	0.000
3	Ireland	0.956	0.914	0.903	81.847	0.000
4	Poland	0.986	0.971	0.964	141.782	0.000
5	Estonia	0.529	0.280	0.220	4.668	0.019
6	Czech Republic	0.997	0.995	0.993	629.450	0.000
7	The Netherlands	0.994	0.988	0.986	458.309	0.000
8	Lithuania	0.973	0.947	0.935	75.611	0.000
9	Finland	0.995	0.989	0.987	388.783	0.000
10	Cyprus	0.974	0.949	0.940	102.424	0.000
11	Bulgaria	0.909	0.827	0.785	20.042	0.000
12	Germany	0.994	0.988	0.985	442.695	0.000
13	Greece	0.995	0.990	0.987	405.966	0.000
14	Belgium	0.991	0.982	0.978	227.175	0.000
15	Austria	0.985	0.970	0.961	108.503	0.000
16	Slovakia	0.994	0.987	0.984	328.888	0.000

A rejection of statistically insignificant variables results in a higher coefficient of determination (Adj. R^2). The coefficients of determination indicate a compatibility model fits to the actual data and a proportion of the total variability of the dependent variable is explained by the resulting model. The value of adj. R^2 is usually smaller than the previous R^2. The coefficients of determination in most cases are very high (Adj. $R^2 > 0.9$ for Denmark, Ireland, Poland, Czech Republic, the Netherlands, Lithuania, Finland, Cyprus, Germany, Greece, Belgium, Austria, abd Slovakia) or high (Adj. $R^2 > 0.8$ for Luxembourg) and explain the variance of the GHG emission variable. High values of model fit coefficients to real data seem to be justified, because fuel fossil combustion is the main source of CO_2 emissions. The difference in individual countries lies in the type of fuels. For example, the resulting model for Poland explains over 96% of the variability of GHG emissions. The remaining 4% can be explained by other variables not included in this study. The obtained results indicate the highest proportion of HC. Attention should be paid to the case of Estonia, where the obtained parameter values Adj. $R^2 = 0.22$, F test = 4.67 and $p = 0.019$ indicate that there is no linear relationship between the analyzed variables. It should be assumed that other, perhaps non-linear methods would give a more satisfactory result. In the case of Bulgaria, due to the low value of the F-test result, it can also be assumed that a more satisfactory result could have been obtained using another method.

Table 4 summarizes the obtained equations for GHG emissions in individual countries.

Table 4. The regression equations for GHG emissions.

	Country	Regression Equation
1	Luxemburg	Y = 0.8NG + 5519.8
2	Denmark	Y = 0.23OPP + 0.18NG + 0.58HC
3	Ireland	Y = 0.8OPP − 0.23Pop + 4225.7
4	Poland	Y = 0.16OPP + 1.42HC + 0.5NG + 0.14BC + 0.48GDP + 50,708.8
5	Estonia	Y = 0.47HC + 15,309.4
6	Czech Republic	Y = 0.12OPP + 0.35HC + 0.09NG + 0.64BC + 860,627
7	The Netherlands	Y = −0.54Pop + 0.25HC + 0.33NG + 400,730
8	Lithuania	Y = 0.97OPP + 0.65NG + 0.39BC

Table 4. *Cont.*

	Country	Regression Equation
9	Finland	Y = 0.44Pop + 0.01OPP + 0.48HC + 0.22NG + 188,493.2
10	Cyprus	Y = 0.46Pop + 0.61OPP + 0.88GDP + 5218
11	Bulgaria	Y = 0.53HC + 1.07NG
12	Germany	Y = 0.06OPP + 0.08HC + 0.13BC − 0.34GDP +402,191.8
13	Greece	Y = 0.48OPP + 0.16NG + 0.6BC
14	Belgium	Y = −1.69Pop + 0.14NG + 0.24BC + 0.78DGP + 623,443
15	Austria	Y = 0.4OPP + 0.41HC + 0.26NG + 0.28BC
16	Slovakia	Y = 0.2Pop + 0.59HC + 0.47NG + 0.4BC – 190,009

The obtained results were interpreted for Poland as an example:

- When the consumption of OPP increases by 1 thousand tonnes, GHG emissions will increase by 0.16 thousand tonnes of CO_2 equivalent, if other variables remain unchanged;
- When HC consumption increases by 1 thousand tonnes, GHG emissions will increase by 1.42 thousand tonnes of CO_2 equivalent, if other variables remain unchanged;
- When NG consumption increases by 1 thousand tonnes, GHG emissions will increase by 0.5 thousand tonnes of CO_2 equivalent, if other variables remain unchanged;
- When BC consumption increases by 1 thousand tonnes, GHG emissions will increase by 0.14 thousand tonnes of CO_2 equivalent, if other variables remain unchanged;
- When GDP increases by 1 thousand tonnes, GHG emissions will increase by 0.48 thousand tonnes of CO_2 equivalent, if other variables remain unchanged.

Most variables related to the consumption of fossil fuels were statistically significant in the following countries: Poland, Czech Republic, Finland, Germany, Austria and Slovakia, including HC and BC in most of the countries in the above group except Finland. The HC variable is also significant in Denmark, the Netherlands, Finland and Bulgaria, and BC in Lithuania, Greece and Belgium. The results obtained from the regression analysis can be largely justified by observing the per capita consumption of hard coal and lignite in the studied group of countries (Figure 5).

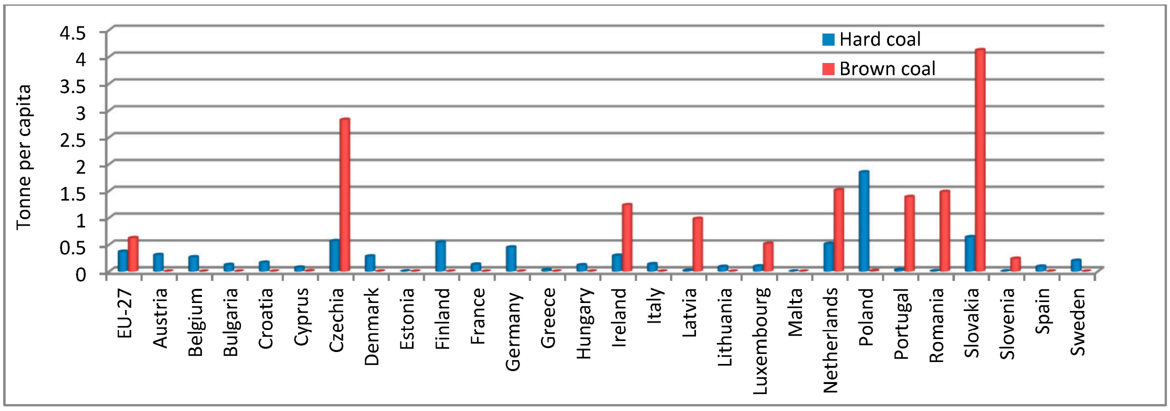


Figure 5. Inland consumption of hard coal and brown coal per capita in 2021; authors' own calculations based on [16,41].

Different characteristics were observed in Ireland, the Netherlands and Belgium, where the variable population negatively correlates with GHG emissions. Other studies also indicate that the impact of population growth on emissions is negligible for certain old EU Member States [43]. The results also showed that in Germany, the GDP variable correlates negatively with GHG emissions, which means that as GDP increases, GHG emissions decrease. On this basis, the hypothesis of an inverted U-shaped environmental Kuznets curve in Germany can be accepted.

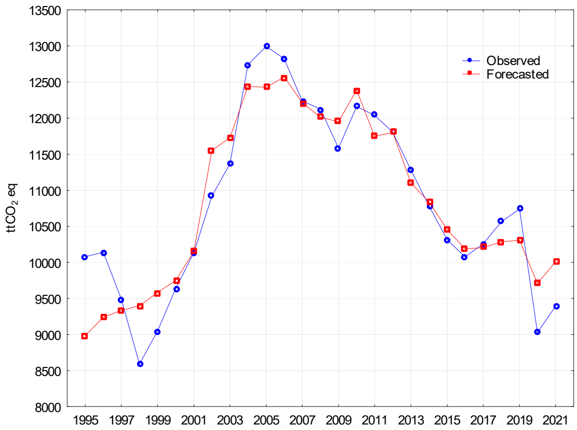
In several analyzed countries (Finland, Czech Republic, Germany, the Netherlands, Greece, Belgium) a noticeable trend towards systematic reduction in GHG emissions can be observed (Figure 6). Concurrently, an increase in emissions in 2021 was observed in each of the analyzed countries. The analysis of the data indicates that in all countries in 2021, compared to previous years, there was an increase in the consumption of one or several fossil fuels (for example, the consumption of hard coal increased in Denmark, Luxemburg, Ireland, Poland, the Netherlands, Czech Republic, Lithuania, Finland, Cyprus, Bulgaria, Germany, Greece, Belgium and Slovakia). Generally, GHG emission reductions in EU member states result from the countries' obligations towards EU policy, which involves, among others, the phasing out of fossil fuels, trading in CO_2 emission allowances and promoting and implementing renewable energy sources.

Based on the generated model, a forecast of GHG emissions was made and compared with actual values (Figure 6). In most cases, the obtained models indicate a very good fit to real values (except Estonia). In the case of Bulgaria, although the model deviates slightly from the actual values, it can generally be assumed that it averages and follows the observed tendency.

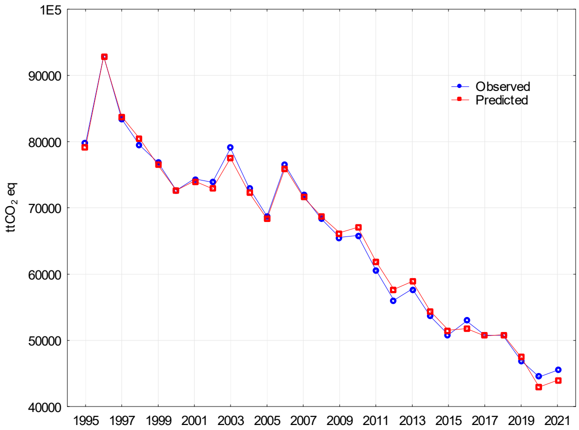
In that countries, it is highly probable that some explanatory variables that were not included in this study may have a significant impact on GHG emissions. It should also be assumed that there is a relationship between the studied variables and GHG emissions, but it is a non-linear relationship; therefore, the use of multiple linear regression analysis in this case did not provide satisfactory results. Perhaps another reason in the case of Estonia is the impact of the hard coal consumption variable, where a very significant decrease was recorded in the analyzed period of 1995–2021 (Table 5).

Table 5. HC consumption in Estonia.

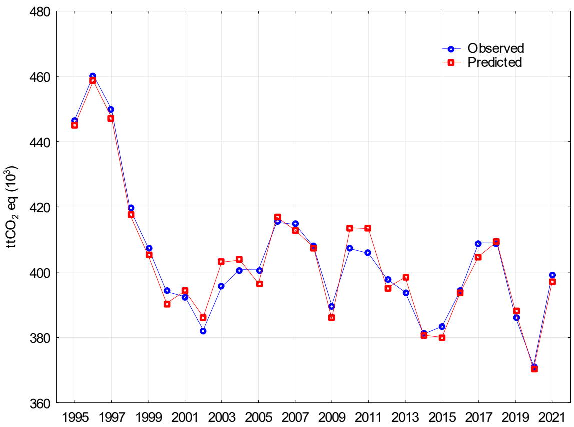
Year	HC Consump. in Thousand Tonnes
1995	103,000
1996	115,000
1997	98,000
1998	75,000
1999	79,000
2000	87,000
2001	109,000
2002	61,000
2003	44,000
2004	58,000
2005	56,000
2006	70,000
2007	130,000
2008	129,000
2009	87,000
2010	60,000
2011	70,000
2012	64,000
2013	61,000
2014	78,000
2015	29,000
2016	27,000
2017	48,000
2018	50,000
2019	50,345
2020	12,280
2021	3500



(**a**) Luxemburg

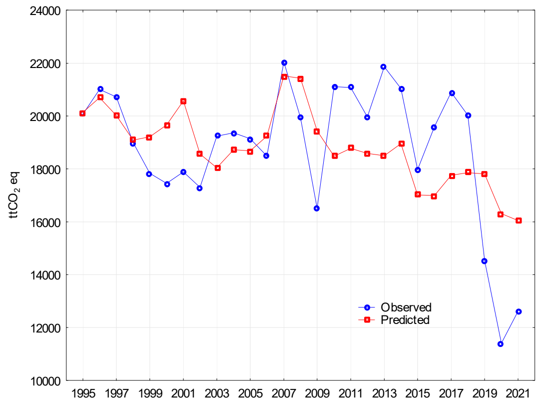


(**b**) Denmark

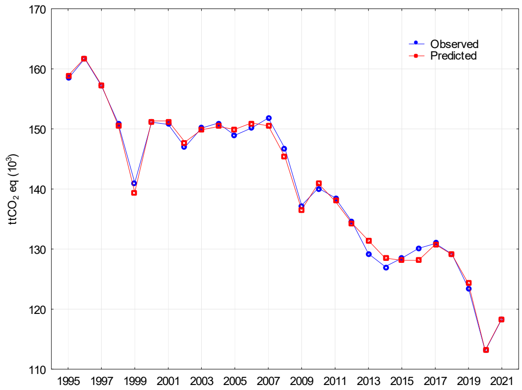


(**c**) Poland

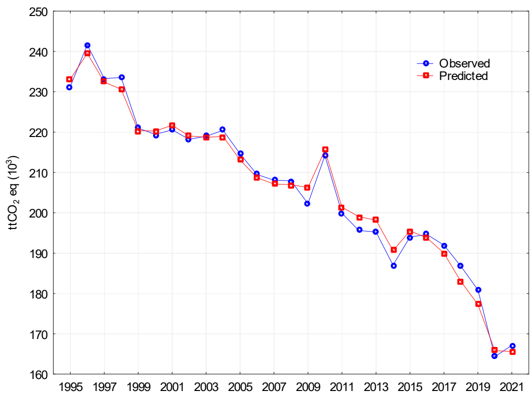
Figure 6. *Cont*.



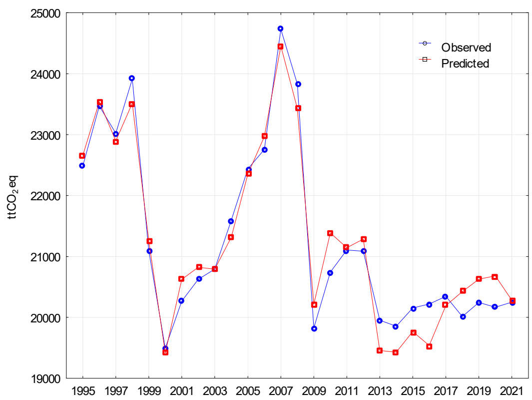
(**d**) Estonia



(**e**) Czech Republic

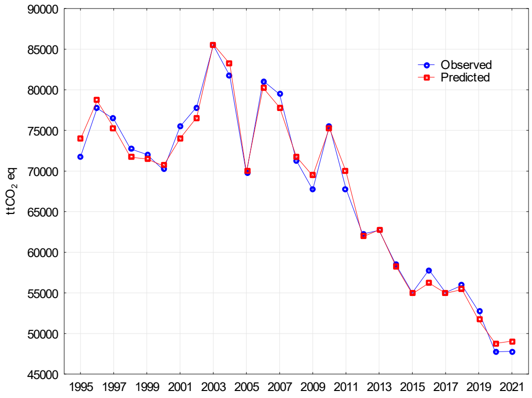


(**f**) The Netherlands

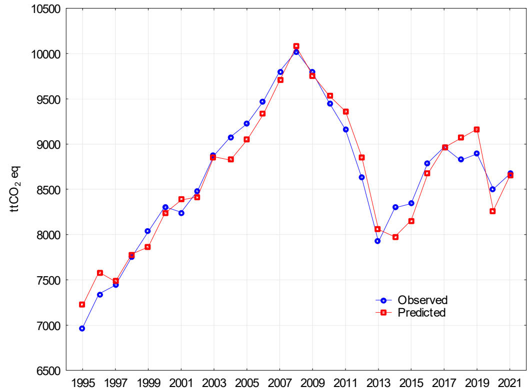


(**g**) Lithuania

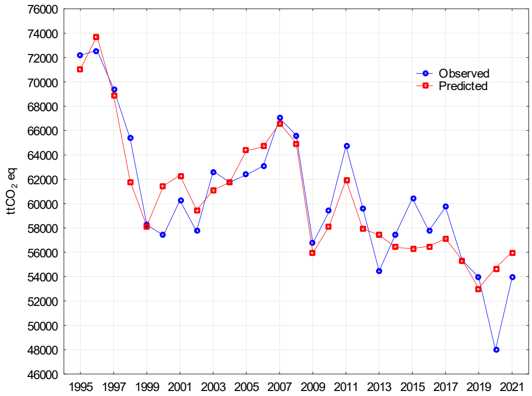
Figure 6. *Cont*.



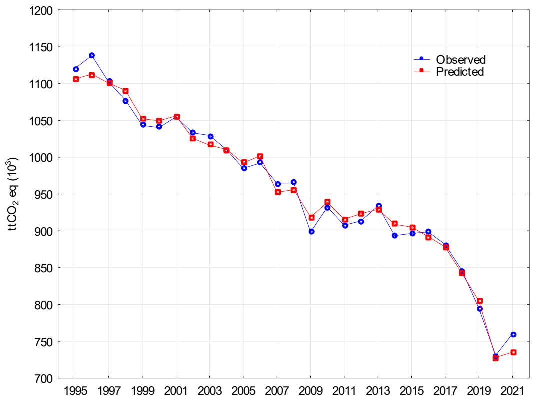
(**h**) Finland



(**i**) Cyprus

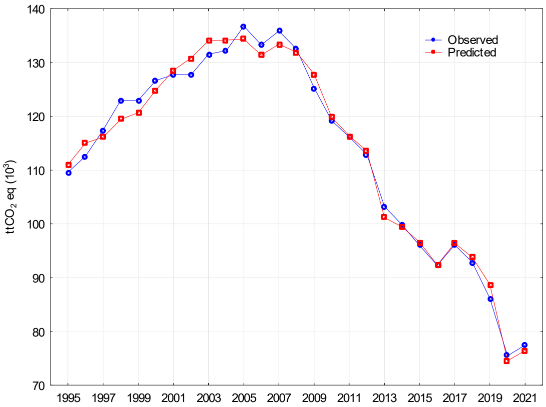


(**j**) Bulgaria

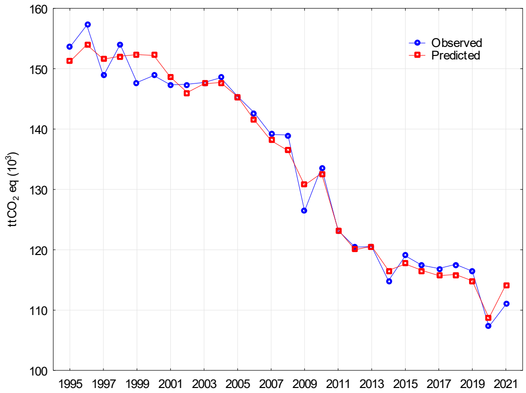


(**k**) Germany

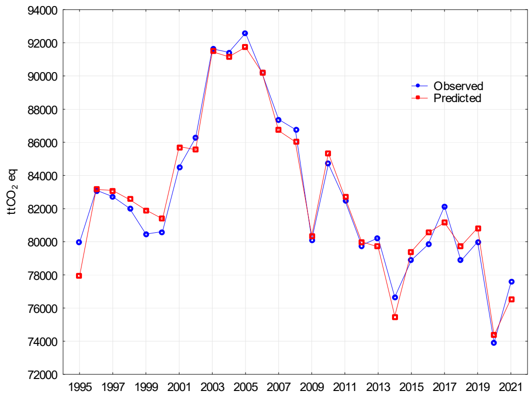
Figure 6. *Cont.*



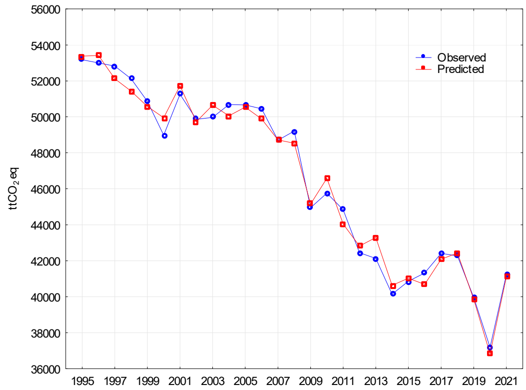
(**l**) Greece



(**m**) Belgium



(**n**) Austria



(**o**) Slovakia

Figure 6. Observed and predicted GHG emissions.

4. Conclusions

Any information that complements knowledge about GHG emissions is a valuable source. The multiple regression analysis used in the study is intended to better understand the quantitative relationships between variables. It was used to confirm or refute the formulated hypotheses regarding the phenomena being studied. Multiple regression provides the opportunity to predict the development and simulation of processes. The significant value of regression models lies in the scientific information contained in the resulting equation. The high value of the F statistic and the corresponding level of test probability *p* confirm a statistically significant linear relationship between selected variables in individual countries and GHG emissions (except Estonia). The models obtained as a result of this research demonstrate a very good fit to actual values (exception: Estonia) and can be used to make GHG emission forecasts. The confirmation of a statistically significant linear relationship between the studied independent variables and the dependent variable is the high value of the F statistics (exceptions are Estonia and Bulgaria) and the corresponding level of test probability p ($p < 0.001$). The resulting adjusted R^2 is high (Adj. $R^2 > 0.8$ for Luxembourg) or very high (Adj. $R^2 > 0.9$ for Denmark, Ireland, Poland, Czech Republic, the Netherlands, Lithuania, Finland, Cyprus, Germany, Greece, Belgium, Austria and Slovakia) and largely explains the variance of the GHG emission variable.

Population in several EU Member States, namely Ireland, the Netherlands and Belgium showed negative correlations with GHG emissions. It is noteworthy that these are countries that joined the EU quite early: Ireland in 1973 and the Netherlands and Belgium in 1958. The results of this study open new opportunities for policymakers to design comprehensive financial, economic and energy policies to minimize the harmful effects of environmental pollution. When determining the allocation of GHG emission quotas for individual EU countries, population dynamics, GDP, incomes and the structure and intensity of energy consumption should all be considered, because the study results indicate that these variables significantly affect the volume of CO_2 emissions in the countries examined.

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