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Achieving Sustainability: Energy and Emission Metrics in the European Union, Bulgaria, Hungary, Italy, Poland and Romania's Fossil Fuel-dependent Transportation

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Article

Achieving Sustainability: Energy and Emission Metrics in the European Union, Bulgaria, Hungary, Italy, Poland and Romania's Fossil Fuel-dependent Transportation

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Abstract Given the transport sector's significant contribution to global greenhouse gas emissions and pollution, sustainable transportation is essential in mitigating climate change and environmental degradation. This study examines the final energy consumption and greenhouse gas emissions from fuel combustion in the transport sector of the European Union (EU), Bulgaria, Hungary, Italy, Poland, and Romania. It aims to offer a concrete tool for assessing the impact of transport on emissions by employing a quantitative analysis and ordinary least squares (OLS) models. Only the EU, Hungary and Romania's results met the assumptions necessary for a valid linear regression model, thus elucidating the complex relationships between the analysed indicators.

Keywords energy consumption; greenhouse gas emissions; transport sector; moving average; linear regression

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1. Introduction

The transition towards a green economy is a priority of the European Union (EU) member states since the effects of climate change are becoming more visible nowadays, underlining the need for a transition from a linear to a circular, sustainable economic model. The transport sector ranks second in the emission of greenhouse gases and environmental pollution. Therefore, researching this sector's energy consumption and emissions is important for understanding how its environmental impact can be mitigated.

The study contributes to this ongoing discussion, offering insights into trends, changes, and relations in the transport sector's energy consumption and emissions. Focusing on the EU, Bulgaria, Hungary, Italy, Poland, and Romania, it seeks to identify statistically significant relationships and econometric models that are useful in the analysis of the impact of transport on emissions.

It aims to answer the following questions:

- Is there a decoupling between the final energy consumption in transport (FECT) and the greenhouse gas emissions from fuel combustion in transport (GHGET) in the selected countries? The assumption is that decoupling is not achieved in the analysed countries.
- What was COVID's impact on the two selected indicators? The assumption was that both would decrease.

2. Literature Review

The analysis begins with examining existing literature about the topic and identifying areas in need of further research. To this end, we used the Web of Science portal.

There are three important ways to reduce the emissions from transport: using efficient vehicles, technological advancements in vehicles and fuels, and modifying urban and interurban travel modes. Further reductions would require large-scale interventions, including low-carbon fuels, fiscal strategies, and e-work [1].

Only eight EU countries (Italy, Sweden, Germany, Greece, United Kingdom, Finland, Netherlands, and France) achieved an absolute decoupling of transport-related greenhouse gas (GHG) emissions and economic growth between 1997–2017, while others achieved only a relative decoupling (Bulgaria, Hungary, Poland, and Romania, among them), a partial success since emissions are rising but slower than economic growth [2].

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Economic development can naturally reduce pollution through energy efficiency and tax policies. Robust economic growth could lead to investments in environmental R&D and cleaner practices. However, each country's level of development affects its potential GHG trajectories, requiring additional ecological measures for those that have yet to reach the environmental Kuznets' curve turning point [3].

While there has been an increase in the use of passenger cars, there has also been a decrease in annual energy consumption and GHG emissions due to advancements in conventional internal combustion engines and hybrids. To lower emissions to a minimum, we must heavily rely on battery electric vehicles and hydrogen fuel cell vehicles powered by renewable energy [4].

Romania and Poland experienced higher emissions due to increased individual transport based on diesel fuel and the slow adoption of electric vehicles and related infrastructure [5].

To meet the Tyndall carbon budget, substantial measures must be taken, including reducing car travel by 72% by 2025, phasing out fossil fuel cars by that same year, generating 100% of electricity for electric vehicles from renewable sources, retrofitting one-third of discarded fossil fuel cars with electric engines, reducing the weight of new vehicles by 40%, and implementing stringent standards for the manufacturing of electric cars [6]. It is unclear how the ambitious goals regarding reducing GHG emissions will be met at the sectoral level. Policies regarding private car transport could be effective if they control car usage by introducing new technologies and green fuels [7].

Some researchers argue that:

- Introducing battery electric vehicles (BEVs) decrease GHG emissions due to their lower energy consumption and ability to use renewable energy sources [8].
- Fuel prices do not significantly impact GHG emissions, raising questions about fuel taxes' effectiveness in reducing emissions in the short term [9].
- Using carbon-based fuels in the transport sector increases transport CO_2 emissions and decreases the quality of the environment [10].
- Reducing the current fleet's internal combustion engine fuel consumption significantly impacts NO_2 concentrations, between 35.3% and 44.0%, depending on the applied scenario [11].
- In Warsaw, electric rail transport modes are the least energy-intensive, while motors and passenger cars are the most energy-intensive [12].
- Carbon taxation has a short-term impact, but emission standards have long-term benefits. In Ireland, rising carbon taxes have not curbed land freight transport demand, but vehicle energy efficiency standards effectively reduce emissions. Freight transport requires unique policy considerations for transitioning to a low-carbon sector [13].
- Transportation emissions need to be carefully monitored. Access to timely published national data on consumption patterns could improve progress tracking and analysis of carbon footprints, ultimately helping achieve global carbon neutrality by 2050 [14].
- Transport electrification harms economic growth due to its high implementation costs. The same applies to renewable fuels despite their positive environmental impacts. It could also increase the CO_2 emissions if the electricity is produced by burning hydrocarbons [15].
- Increasing subway train occupancy rates significantly reduces global warming potential and cumulative energy demand. Compared to other transportation means, the subway performs better regarding the two mentioned indicators despite the significant emissions during construction [16].
- Among the Visegrad countries (Czechia, Hungary, Poland, and Slovakia), the relationship between CO_2 emissions, road transportation, economic growth and energy consumption is very heterogeneous despite their similar economic circumstances and all these countries should invest in green transportation and develop railways and inland sailing [17].

Research funding is currently focused on liquefied natural gas (LNG) refuelling stations, biofuels for road transport, and alternative aviation fuels. Although economically viable fuels provide limited environmental benefits, renewable fuels show promise. However, Europe's availability, viability, and infrastructure challenges present obstacles to these fuels. Electrofuels may advance faster than third-generation biofuels [8]. Biofuel mixtures, particularly those with higher biofuel content, show clear advantages in reducing GHG emissions and saving fossil energy compared to fossil fuels, with biodiesel from waste oils performing the best [18].

Some authors suggest that policies should focus on:

- Informing the public on the effects of climate change, emphasising the need to reduce the use of cars and to develop green transport infrastructure, and educating the citizens to choose alternatives that reduce transport emissions [5].
- Implementing emission regulations, supporting market penetration of green transportation means, enabling investment in charging infrastructure, in new green technologies, providing financial incentives, and optimising the relationship between the energy producers and transport sector to promote electric vehicles [8].
- Reducing solid fuel consumption and considering country-specific variations in the impact of the determinants of GHG emissions could contribute to the effectiveness of the European mitigation policies [9].

Strictly related to the topic of the research, the literature analysis revealed that in Poland, a unidirectional relationship was identified between the CO_2 emission from road transport and oil products' final consumption in transport, indicating that an increase in CO_2 emissions by road transport implies an increase in the use of oil products [17]. Also, there is a solid positive long-run bi-directional relationship between road sector energy consumption and CO_2 emissions from the transport sector in Italy and Hungary [19].

2. Materials and Methods

The study involved gathering data on final energy consumption and greenhouse gas emissions from the transport sector of the EU, Bulgaria, Hungary, Italy, Poland, and Romania. The data, spanning 12 years, was extracted from Eurostat. The analysis aimed to compare the performances of Romania against its neighbours from the EU, namely Bulgaria and Hungary.

Poland was selected as the country with the best economic performance among the Eastern European countries and the highest energy consumption in transport. Italy is the representative of the "Old Europe", ranking closer to Poland regarding energy consumption in transport.

A quantitative analysis examined the trends in energy consumption and emissions related to transport. This facilitated a deeper understanding of the energy-emission dynamics in the studied entities.

Ordinary least squares regression was employed to model the relationship between FECT and GHGET, and diagnostic tests using Excel and Gretl were used to look for linearity, homoskedasticity, normality, and lack of autocorrelation.

3. Results

3.1. Quantitative Analysis

Italy registered the highest GHGET among the analysed countries, though experiencing a noticeable dip in 2020 due to the impact of the COVID-19 pandemic (See Table 1). The dip was evident in all the analysed countries. Between 2010 and 2021, GHGET in Italy decreased by 11%. Poland's emissions were the second highest, increasing by 38% in the same timeframe. In this order, Romania, Hungary, and Bulgaria showed significantly lower emissions than Italy and Poland, with increases of 38%, 19%, and 24%, respectively, between 2010 and 2021.

Table 1. Greenhouse gas emissions from fuel combustion in transport (GHGET), in million tonnes, between 2010 and 2021.

Year	EU	Bulgaria	Hungary	Romania	Italy	Poland
2010	817.639	7.983	11.773	14.220	115.909	49.374
2011	808.240	8.152	11.146	14.346	114.909	49.969
2012	778.707	8.506	10.817	15.231	107.527	48.024
2013	772.714	7.431	10.092	15.047	104.428	45.168
2014	778.078	8.416	11.255	15.597	109.269	45.540
2015	793.240	9.198	12.276	15.707	106.694	48.040
2016	810.749	9.300	12.305	16.792	105.610	54.744
2017	824.981	9.438	13.100	17.935	101.538	63.217
2018	826.483	9.651	13.925	18.427	105.134	65.040
2019	832.733	9.809	14.764	18.917	106.340	66.042
2020	720.182	9.225	12.637	18.358	86.560	63.082
2021	782.101	9.921	13.996	19.557	103.280	68.351

Italy's FECT was also the highest among the selected countries, registering a decrease of almost 9% between 2010–2021, lower than the decrease in emissions, suggesting the transport sector in Italy may have become more energy efficient (See Table 2).

The same applied to Bulgaria, Romania, and Hungary, which consumed significantly less energy for transport than Italy and Poland. Poland steadily increased its FECT (37% between 2010–2021).

In Poland's case, the FECT increase rate was inferior to the increase in emissions (37% against 38%), indicating that maybe there was a shift towards more carbon-intensive fuels in the transport sector.

Table 2. Final energy consumption in transport (FECT), in thousand tonnes of oil equivalent, between 2010 and 2021.

Year	UE	Bulgaria	Hungary	Romania	Italy	Poland
2010	279992.442	2694.753	4089.374	4965.841	38566.288	17187.318
2011	278951.010	2759.922	3812.948	5212.550	38572.097	17408.462
2012	269187.624	2914.390	3692.233	5314.735	36348.734	16680.367
2013	265449.955	2620.341	3459.986	5188.743	35701.272	15744.034
2014	268808.993	2916.487	3873.295	5266.333	37009.372	15804.963
2015	272463.417	3211.585	4181.253	5337.702	36374.374	16561.073
2016	278736.337	3268.077	4261.597	5738.034	35814.501	18557.186
2017	284509.207	3324.915	4496.778	6149.188	34525.408	21431.698
2018	285944.665	3374.736	4790.228	6303.748	35579.484	22349.398
2019	288722.807	3413.546	5070.454	6571.907	35861.202	22782.296
2020	251439.587	3209.758	4459.534	6460.800	28976.458	21778.636
2021	274834.948	3433.309	4897.618	6879.222	35290.318	23537.388

3.2. The Impact of COVID-19 on the Transportation Sector

Figure 1 shows a decrease in both emissions and energy consumption across the board, with GHGET decreasing more than FECT in the EU, Hungary, Romania, and Poland, which suggests that during the COVID-19 pandemic, the transportation sector became slightly more carbon-efficient in these regions.

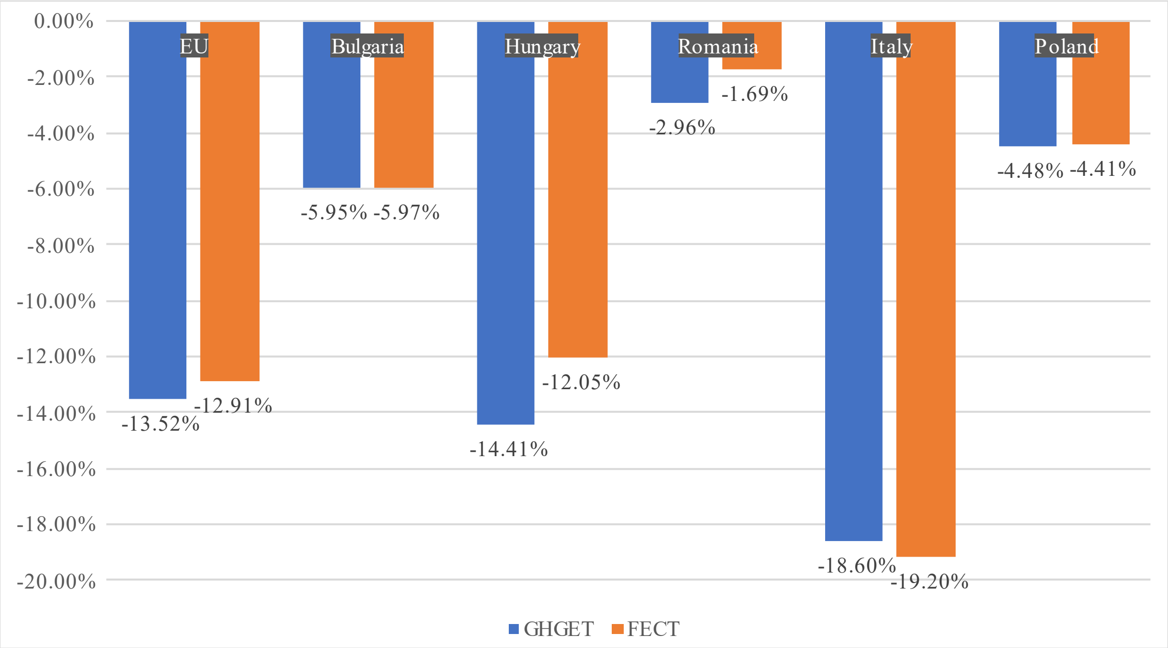

Figure 1. Covid impact on greenhouse gas emissions from fuel combustion transport and final energy consumption in transport, the percentage change between 2019–2020.

In Italy and Bulgaria, the energy decreased less than the emissions, because the remaining transport was less energy-efficient.

3.3. Econometric Analysis

To explain how the econometric analysis was conducted, the example of the relationship between the final energy consumption in transport and the GHG emissions from fuel combustion in transport in the EU was presented. The results for all the analysed countries are displayed at the end of this example.

The correlation coefficient (Pearson's *r*) is very high (0.9845), almost close to 1. This means a robust linear relationship between FECT and GHGET (dependent variable) with a positive slope. Therefore, if one indicator increases, the other increases too (See Figure 2 and Table 3). While there is some variation in the residual plot, there is no systematic pattern in the residuals. This indicates that a linear model might fit the data well. Thus, there is no decoupling in the EU (Figure 3).

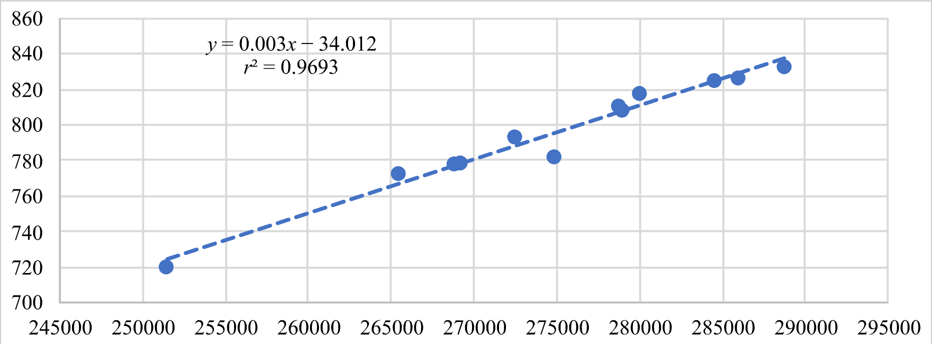

Figure 2. The relationship between FECT and GHGET.

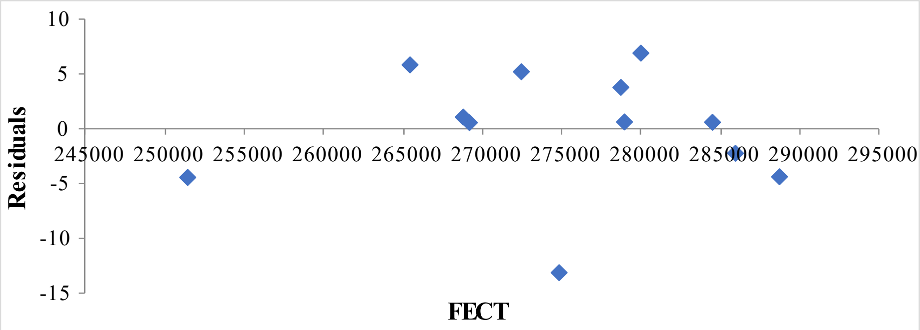

Figure 3. Residual plot.

Table 3. Correlation coefficient *r* for the EU.

	FECT	*GHG*
FECT	1	
GHG	0.98451248	1

The linear relationship is tested at a 95% confidence level to see if it has statistical significance. The null hypothesis (H_0) implies no statistically significant linear relationship in the EU between FECT and GHGET.

The alternate hypothesis (H_a) supports a statistically significant linear relationship between the two variables.

$$H_0: \rho = 0. \qquad H_a: \rho \neq 0.$$

The regression statistics are displayed in Table 4.

Table 4. Regression statistics for the EU.

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	−34.01239	46.7406355	−0.7276835	0.483496803	−138.15702	70,1322358
Slope	0.00301724	0.00016991	17.7583822	0.0000000068377977	0.00263867	0.00339581

Since the P-value is smaller than the significance level: $\alpha = 0.05$, H_0 is rejected (See Table 4). Therefore, we are 95% confident that there is a statistically significant linear relationship between FECT and GHGET in the EU.

According to the model, for 1000 tonnes of oil equivalent increase in the final energy consumption in transport, the emissions from fuel combustion in transportation in the EU increase by 0.003 million tonnes.

The coefficient of determination (r^2) is 0.969. That implies that the relationship between the analysed variables explains 97% of the variation in the value of GHGET. It does not mean that one variable causes the other.

The model resulting from our sample has a strong explanatory power for the emissions, especially given the high R-squared and the statistical significance.

The linear regression model's assumptions are linearity, homoskedasticity, normality, and no autocorrelation. Since the P-value of the tests is higher than the level of significance ($\alpha = 0.05$), in the EU's case, the assumptions are met (See Table 5).

The same methodology was applied to Bulgaria, Hungary, Romania, Italy, and Poland, and the results are summarised in Table 5.

Table 5. Regression Statistics.

Statistical Indicators	**EU**	**Bulgaria**	**Hungary**	**Italy**	**Poland**	**Romania**
Multiple R	0.985	0.991	0.996	0.992	0.999	0.986
R Square	0.969	0.983	0.992	0.997	0.997	0.972
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Intercept	−34.012	0.645	0.399	−1.2386	−1.5636	0.2628
Slope	0.003	0.003	0.028	0.003	0.003	0.028
Statistical significance at a 95% confidence level	Yes	Yes	Yes	Yes	Yes	Yes
Lagrange Multiplier (LM) test for non-Linearity (squared terms), Null hypothesis: relationship is linear, $\alpha = 0.05$	Test statistic: LM = 0.101718, with P-value = P(Chi-square(1) > 0.101718) = 0.749777, Relationship is linear	Test statistic: LM = 0.101718, with P-value = P(Chi-square(1) > 0.101718) = 0.749777, Relationship is linear	Test statistic: LM = 0.636599 with P-value = P(Chi-square(1) > 0.636599) = 0.424945, Relationship is linear	Test statistic: LM = 8.39972, with P-value = P(Chi-square(1) > 8.39972) = 0.0037528, **Relationship is not linear**	Test statistic: LM = 3.10502, with P-value = P(Chi-square(1) > 3.10502) = 0.0780514, Relationship is linear	Test statistic: LM = 2.75798 with P-value = P(Chi-square(1) > 2.75798) = 0.0967705. Relationship is linear
White's test for heteroskedasticity, Null hypothesis: heteroskedasticity not present, $\alpha = 0.05$	Test statis-tic: LM = 0.62508 with P-value = P(Chi-square(2) > 0.62508) = 0.731586, Homoskedasticity	Test statistic: LM = 9.69528, with P-value = P(Chi-square(2) > 9.69528) = 0.00784689, **Heteroskedasticity present**	Test statistic: LM = 2.43037 with P-value = P(Chi-square(2) > 2.43037) = 0.296655, Homoskedasticity	N/A	Test statistic: LM = 5.21439 with P-value = P(Chi-square(2) > 5.21439) = 0.0737409, **Yes**	Test statistic: LM = 0.911654 with P-value = P(Chi-square(2) > 0.911654) = 0.633924, Homoskedasticity
Test for normality of residuals, Null hypothesis: error is normally distributed, $\alpha = 0.05$	Test statis-tic: Chi-square(2) = 3.45807 with P-value = 0.1774, Error is normally distributed	N/A	Test statistic: Chi-square(2) = 2.09654 with P-value = 0.350544, Error is normally distributed	N/A	Test statistic: Chi-square(2) = 11.8339 with P-value = 0.00269342, **Error is not normally distributed**	Test statistic: Chi-square(2) = 2.57315 with P-value = 0.276215, Error is normally distributed
Breusch-Godfrey test for autocorrelation up to order 3, Null hypothesis: no autocorrelation, $\alpha = 0.05$	Test statistic: LMF = 2.67419 with P-value = P(F(3, 7) > 2.67419) = 0.128132, No autocorrelation	N/A	Test statistic: LMF = 1.12117 with P-value = P(F(3, 7) > 1.12117) = 0.403232, No autocorrelation	N/A	N/A	Test statistic: LMF = 1.54436 with P-value = P(F(3, 7) > 1.54436) = 0.285649, No autocorrelation
Equation of the regression line	$y = 0.003x - 34.012$	N/A	$y = 0.0028x + 0.3999$	N/A	N/A	$y = 0.0028x + 0.2628$

4. Discussion

The EU, Hungary, and Romania's data suggest that the assumptions necessary for a valid linear regression model are met.

Bulgaria, Italy, and Poland's data show statistically significant relationships between FECT and GHGET, but they violate critical assumptions of the linear regression model.

Bulgaria displays signs of heteroskedasticity, Italy shows a non-linear relationship, and Poland's residuals do not follow a normal distribution. These violations suggest that the simple linear regression model is inappropriate for these countries, and further investigation with more complex models is necessary. Transforming variables to stabilise variance might be a solution to deal with heteroskedasticity in Bulgaria. A polynomial or another non-linear model might better explain the relationship for Italy. As for Poland, the residuals differ significantly from a normal distribution, which indicates that this deviation is not random. This finding calls for further investigation and possibly adjustments to model or data.

According to the identified models, for the 1000 tonnes of oil equivalent increase in the final energy consumption in transport, the emissions from fuel combustion in the EU increased by 0.003 million tonnes, while in Hungary and Romania, the emissions increased by 0.0028 million tonnes. The equations give the decision-makers a tool to assess the impact of transport on emissions.

The model allows policymakers and planners to assess the changes in GHG emissions based on changes in energy consumption, aiding in crafting informed, data-driven policies. The equations provide insights into the incremental changes in emissions with energy consumption, effectively informing the allocation of resources for mitigation and adaptation strategies.

5. Conclusions

The analysis suggests a statistically significant linear relationship with a positive slope between final energy consumption and GHG emissions from fuel combustion in transport in the EU, Hungary, and Romania, where assumptions of linearity, independence, homoskedasticity, normality, and absence of autocorrelation are met. That means the decoupling still needs to be achieved.

The COVID-19 pandemic has had a noticeable impact on energy consumption and GHG emissions in the transport sector, with declines observed across the analysed countries. This suggests that the crisis temporarily improved carbon efficiency within the transportation sector.

The literature revealed that policy measures must promote green energy and transportation modes to decouple energy and emissions. The priorities to ensure green transport should be enhancing the penetration of electric and hydrogen fuel cell vehicles supported by renewable energy sources, implementing efficient regulations and standards regarding vehicles and emissions, investing in public transportation and eco-friendly infrastructure, supporting technological innovation and energy efficiency and implementing fiscal strategies and initiatives that drive behaviour change towards environmentally responsible choices. It also suggests that while ambitious goals for GHG emissions reduction are set, clarity on how these goals will be reached at the sectoral level, particularly concerning private car transport, is essential.

The heterogeneities observed in the data, such as the non-linear relationship and heteroskedasticity, indicate that further research using more complex models might provide better insights for Bulgaria, Italy, and Poland.

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Data Availability

The data is available online at https://ec.europa.eu/eurostat/databrowser/view/ENV_AIR_GGE__custom_6822495/default/table (**Table 1.** Greenhouse gas emissions from fuel combustion in transport) and https://ec.europa.eu/eurostat/databrowser/view/TEN00126/default/table (**Table 2.** Final energy consumption in transport).

Conflicts of Interest

The author has no conflict of interest to declare.

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