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Environmental Sustainability and Freight Transport Performance in the EU – An Autoregressive Conditional Heteroscedasticity (ARCH) Model Analysis

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ABSTRACT

Transportation, which is a significant facilitator of global trade and development, faces a serious problem with respect to sustainability. Firstly, there is the need to minimise greenhouse gas emissions while maintaining profitability and social responsibility. Transportation will be totally decarbonised by consistently moving towards a more sustainable, diverse and resilient range of transportation modes with advanced vehicle technologies. However, what impact this will have on the economic performance of transport service providers remains a big question. The aim of this study is to examine the short-run relationship between environmental sustainability in road freight transportation and the economic performance of the road freight transport sector in the European Union using an autoregressive conditional heteroscedasticity (ARCH) model. The analysis was conducted using annual data spanning from 2008 to 2021. The results indicate that energy taxes on transport and storage, biodiesel consumption and vehicle capacity utilisation have a positive and significant impact on freight transport performance (FTP). The findings suggest that policymakers could use energy taxes and incentives to promote the use of biodiesel in the transportation sector to increase FTP. Additionally, efforts to improve vehicle capacity utilisation could significantly increase FTP and have positive environmental implications such as reducing traffic congestion and emissions.

KEYWORDS

freight transport performance; capacity utilisation; energy taxes; sustainable transportation.

1. INTRODUCTION

The freight transport sector plays a crucial role in facilitating economic growth and trade by ensuring the efficient movement of goods. However, the negative impacts of transportation on the environment and society are becoming increasingly evident. To address these challenges, there is a growing need to transition towards sustainable transportation practices that balance economic performance with environmental responsibility.

This research aims to empirically analyse the impact of environmental sustainability practices on the economic performance of the freight transport sector in the European Union. By examining the relationship between sustainability and economic indicators, this study seeks to provide valuable insights into the effectiveness of sustainable transportation strategies in achieving both environmental goals and economic viability. The importance of conducting this research lies in the urgency to reduce greenhouse gas (GHG) emissions and achieve the European Commission's net-zero GHG emission target by 2050, as outlined in the Green Deal. The freight transport sector, being a significant contributor to GHG emissions, plays a crucial role in the overall success of this target. Understanding the impact of environmental sustainability on the economic performance of the sector will help stakeholders make informed investment decisions and develop effective policies and strategies to facilitate the transition towards a carbon-free transport sector.

To ensure the reliability and validity of the research findings, rigorous methods were employed. Data from reliable sources, such as Eurostat, were utilised for quantitative analysis. Statistical techniques, such as regression models, were employed to establish relationships between sustainability practices and economic performance indicators. The results were subjected to robust statistical tests to verify their significance and reliability.

This research differs from previous studies in several aspects. While previous research has discussed the importance of sustainable transportation and its impact on various factors, including policy instruments, decision-making and GHG emissions, there is a need for empirical evidence that specifically examines the impact of sustainable transportation practices on the economic performance of the freight transport sector in the EU. Previous studies have employed different methodologies, including the categorisation of policy instruments, the development of sustainable transport system models and decomposition analysis. However, this research aims to fill the gap by conducting an empirical analysis that explicitly focuses on the economic performance of the sector and the impact of sustainability practices, using reliable data sources and rigorous statistical methods.

By providing empirical evidence on the economic implications of sustainability practices in the freight transport sector, this research will contribute to the development of functional and policy-driven roadmaps. It will help stakeholders make informed investment decisions, devise effective strategies and formulate sustainable transportation policies at both the regional and country levels. Ultimately, the findings of this research will support the ongoing efforts towards a smooth and successful transformation of the EU's freight transport sector towards environmental sustainability.

2. LITERATURE REVIEW

At the macro-economic level, transportation and the mobility it confers are linked to a level of output, employment and income within a national economy [1]. An efficiently designed logistics and transportation system minimises costs and creates multiple channels for easy and unlimited access to a wide variety of goods at competitive prices. It has transformed the retailing business for the better, from e-commerce platforms to digital markets and mobile stores; the reliance on transport services and support keeps growing. Nevertheless, the negative impact of transportation on the society is also evident. Environmental degradation, health problems, migration and road accidents by heavy-duty trucks are examples of the social costs and effects associated with transportation activities. Traffic congestion is also a negative externality associated with transport service providers. Its influence can directly determine waiting time, driving time and trickle down to operating costs. Thus, in order to clearly understand the significance of freight transport and logistics from an economic perspective, a closer look at these economic indicators is important.

The EU freight transport sector has seen sustained growth over the past decade. This is in line with the observed relationship between economic growth and road freight transport in the EU Member States, thus, we can safely generalise that freight transport and logistics will remain an important part of the European economy for the foreseeable future [2].

Between 2008 and 2021, freight transportation within the EU averaged over 9 billion tonnes of transported goods as shown in *Figure 1*. E-commerce giants such as Amazon, Otto, Zalando and Apple have been the pioneers of innovation in logistics over the past few years. By the year 2050, transportation will be totally decarbonised by consistently moving towards a more sustainable, diverse and resilient range of transportation modes with advanced vehicle technologies [3, 4].

Transport is the most energy-intensive activity in logistics management [5]. The concept of increasing capacity utilisation as an initiative for improving energy efficiency in logistics is often associated with loading capacity. Loading capacity is defined as the physical ability of a vehicle to carry freight during a certain time and is most simply expressed as a load factor or fill rate [6]. Capacity utilisation directly affects the environmental impact of logistics systems [7].

Figure 2 displays the total number of commercial freight vehicle movements (total VKM) including loaded and empty commercial freight vehicle movements, as compared with the loaded VKM within the EU. The annual capacity utilisation rate for road freight transportation has recorded an increase from 79% to 82% between the years 2008 and 2021 as shown in *Figure 3*. This leaves about 18% of underutilised capacity which constitutes economic and environmental costs therefore creating room for efficiency optimisation. The common use of the term efficiency broadly relates to a ratio between resources and products, costs and benefits or, generally

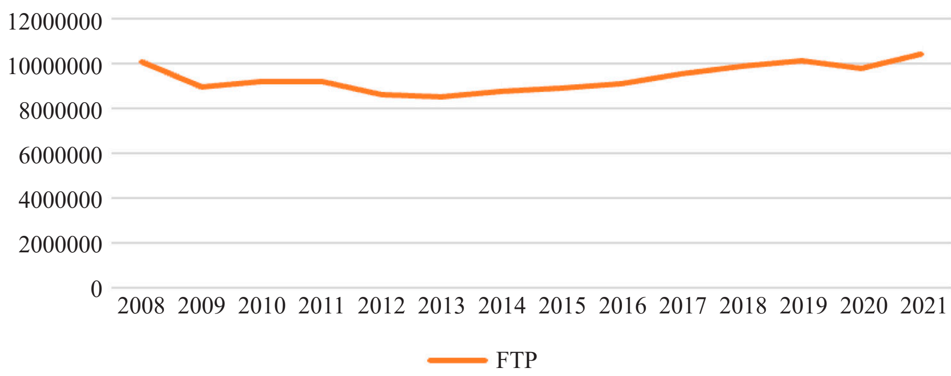

Figure 1 – Annual total commercial (hire or reward) road freight transport performance (FTP) in the EU in thousand tonnes (based on Eurostat data from 2008 to 2021)

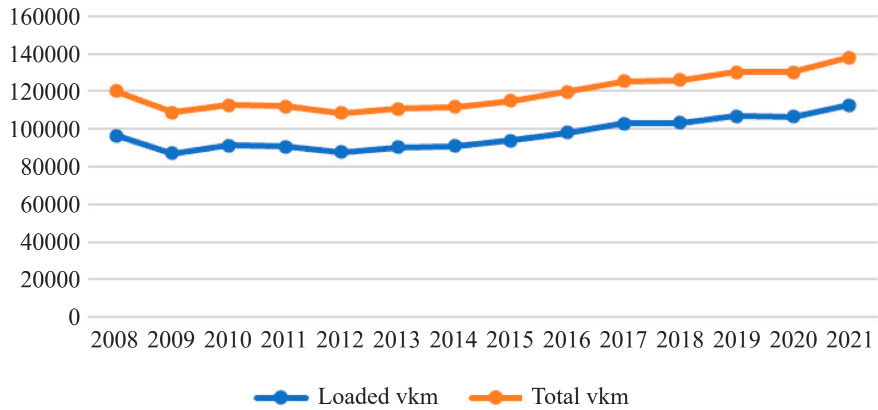

Figure 2 – Annual total commercial (hire or reward) road freight transport vehicle movements in the EU in million vehicle-kilometres (based on Eurostat data from 2008 to 2021)

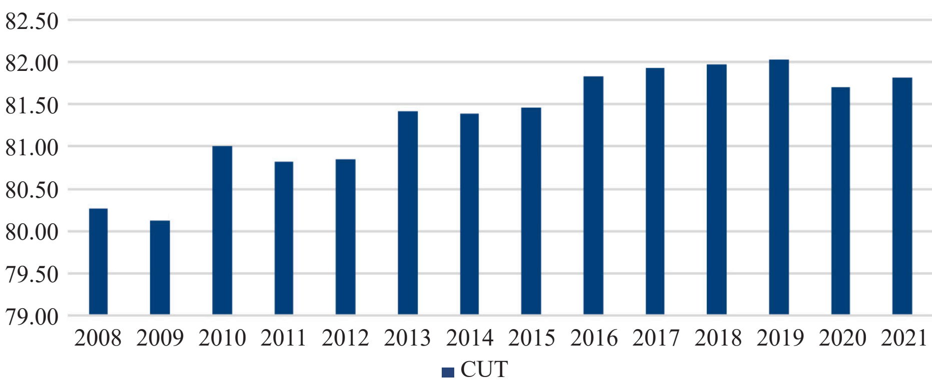

Figure 3 – Annual capacity utilisation rate (CUT) of road freight transport in the EU in percentage (based on Eurostat data from 2008 to 2021)

speaking, inputs and outputs of a defined process [8]. Underutilised capacity is defined as "the operational underutilisation of resources" and "a signal that efficiency improvements are possible" [9]. Indicators for underutilised capacity in logistics systems include low vehicle fill rates, the number of insolvencies amongst LSPs, low prices for logistics services and low earnings**.** However, it is predicted that emissions from road transportation will continue to rise until 2030, while emissions from the rail industry are projected to remain constant. On a global scale, the performance of road freight transportation, which is measured in metric tonne-km, is expected to increase in both the EU and the US, indicating the necessity for better energy efficiency and the use of at least three different types of policy measures: technological, operational and modal [10]. The existing research provides alternative tools for managing the interrelationship between those indicators for evaluating energy efficiency, including frameworks, key performance indicators, life cycle assessments and balanced scorecards [11].

Previous research in the area of sustainable transportation has centred on the adaptation potentials of transport service providers in the drive towards sustainability. The study conducted by [12] aimed to categorise policy instruments for promoting sustainable road transport into three groups: physical policies, soft policies and knowledge policies, all of which aimed to bring about changes in consumer and firm behaviour, albeit in different ways. The research revealed that increasing the use of public transport and reducing the use of private cars could significantly reduce traffic congestion and carbon dioxide emissions, as public transport typically emits less CO_2 per passenger kilometre than private cars. Soft policies like car sharing and car clubs also have the potential to reduce CO_2 emissions, although the overall impact on congestion and emissions has not been accurately measured in the studied literature.

Research by [13] focused on the creation of a sustainable transport systems model and provided basic guidelines for developing such a model. The objective was to design transport systems that minimise the negative environmental impact of vehicles and ensure the efficient utilisation of the road transport network. The study highlights that creating sustainable transport systems involves complex decision-making, which encompasses legal, organisational, economic and environmental considerations. The study revealed that the current approach to decision-making in transport network development prioritises economic efficiency, with environmental impact being assessed primarily through intuition. Therefore, there is a need for decision-support tools that can aid decision-makers in diagnosing the current state and selecting optimal criteria while factoring in the existing constraints and boundary conditions.

Sobrino and Monzon [14] conducted a study that examined the impact of the economic crisis and policy actions on greenhouse gas (GHG) emissions from road transport in Spain. The researchers used a modified Laspeyres index decomposition to assess the influence of significant drivers of the changes in GHG emissions from road transport in Spain between 1990 and 2010. The study found that economic growth was closely linked to the rise in GHG emissions. The researchers also analysed the changes in mobility patterns and GHG emissions during the economic crisis, which led to the first-ever decrease in Spanish road traffic emissions. The reduction in road transport and improvement in energy efficiency were identified as powerful contributors to this decrease, demonstrating the effectiveness of energy-saving measures.

Zhang and Cheng [15] investigated the impact of international oil prices on CO_2 emissions in China's transportation sector through the use of a regression model of partial least square. The research revealed that the CO_2 emissions of the transportation industry increase alongside an increase in the international price of oil, in line with the findings of [16] and [17]. In the same vein, [18] investigated the relationship between the price of oil, energy consumption and carbon dioxide emissions for the period of 1971 to 2013 in Ecuador through the use of the ARDL approach. The research revealed that an increase in the price of oil has an increasing effect on carbon dioxide emissions.

In their study, [1] reviewed the literature on how environmental sustainability and intermodal transport are considered in transport mode decisions. They found that this is still a relatively new and emerging area of discussion in the literature, with most focus having been on utility and cost efficiency in the past**.** However, there has been a recent shift towards considering environmental sustainability and intermodal transport as important factors in transport mode selection criteria, RfQs/tenders and transport contracts.

Solomon et al. [19] explored the relationship between social performance and the success of resilient green freight transportation (RGFT). They developed a model based on institutional theory and included social performance as one of the decision-making factors. Data from a sample of 107 freight transporters in South East Europe (SEE) were used to test the model through path analysis. The study found that three institutional pressures had a positive impact on the implementation of RGFT practices, but this relationship was only significant when the successful implementation of RGFT practices had a moderating effect. RGFT practice implementation was found to have a positive impact on social performance, which in turn had a positive effect on both economic and environmental performance. Overall, the results suggest that social performance can be a useful indicator of success in RGFT.

Shen et al. [20] conducted a study on a new method for assessing sustainable road transport by comparing three different approaches for including negative factors in the evaluation. The proposed model was found to be superior to the others. The study used data on exposure to road passenger and freight transport, as well as desirable achievements (such as turnover) and undesirable costs (such as GHG emissions and road fatalities) to compute an overall sustainability score for 28 EU countries. This score was then divided into two efficiency scores, one for desirable achievements and one for undesirable costs. The results showed that only Sweden achieved a score of one for both factors, indicating that other countries were underperforming in at least one aspect. The study also used clustering analysis to group countries with similar practices and identified a set of benchmark countries for those with poor performance. This information can be useful for decision-makers aiming to improve the sustainability of their road transport systems.

Most cases of the reviewed empirical literature have shown that sustainability is a complex subject with a knowledge base that incorporates natural, physical and social sciences, thus, requiring an interdisciplinary approach [21]. The European Union through the European Commission has devised many strategies and action plans as means to reduce the unhealthy rise in GHG emission, especially from the road transport sector.

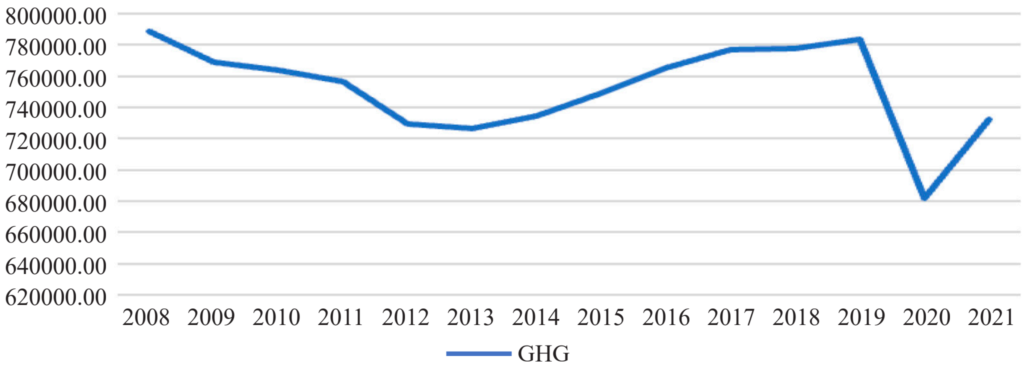

Figure 4 – Annual GHG intensity from road freight transport in the EU in thousand tonnes (based on Eurostat data from 2008 to 2021)

To achieve the EU's net-zero GHG emission by 2050 as outlined in the new European Commission's Green Deal, the EU economy will be required to decarbonise at the rate of nearly 8% per year [22]. Achieving this target will require significant transformation from the present transportation business models, given its share contribution to the overall GHG emission by EU Member States. The investment decisions taken by stakeholders in the EU transport sector will determine the level of success of this target.

Considering the limitations of previous studies in sustainable transportation, the need for a study that empirically reveals the impact of these sustainable transportation strategies on the economic performance of the freight transport sector cannot be overemphasised [23], given its share contribution to the overall GHG emission as well as its contribution margin to the economic growth of the Union. Such an aggregated perspective on the economic effect of the transformation towards environmental sustainability in transportation is essential for understanding and overcoming existing limitations in order to develop a functional and policy-driven roadmap backed by data-driven strategies and new business models and decisions for a smooth transformation towards a carbon-free transport sector. This study is paramount given the need for aggregated regional and country-wise sustainability action plans for policies that can be implemented at the micro level. However, in order to clearly understand the impact of environmental sustainability on transport performance from an economic perspective, a closer look at these external environmental and economic indicators is important [24]. Empirically establishing these indicators as impactful variables in sustainable transportation is pertinent in determining the success potentials of the action plans that will effectively point investment decisions in the right direction and for further studies in this field [4]. Therefore, this research aims to empirically analyse the impact of environmental sustainability practices on the economic performance of the freight transport sector in the EU.

3. MATERIALS AND METHODS

The primary aim of every economic-related research is to arrive at a conjunction of economic theory. Analysis hinges on the theory using techniques of statistical inference as the matching bridge [25]. Thus, the systems theory will be the focus paradigm in this research paper. Systems here refer to a way of understanding complex phenomena by examining the relationships between the parts of a system and how they interact with each other. This approach recognises that individual elements of a system are interdependent and that changes to one part of the system can affect the entire system [26]. This direction of the research is based on understanding the extent of the relationship between sustainable transportation practices and its impact on the economic performance of the freight transport sector [27]. The emphasis on the research methodology adds value and gives substance to any research. It must also be stated here that different research methodologies exist such as the survey method and econometrics method. However, due to the nature of this research, the econometric research methodology was adopted.

Firstly, a stationarity test was performed on the time series data in order to determine whether the statistical properties of a time series remain constant over time. A stationary time series is one whose statistical properties, such as mean, variance and autocorrelation, do not change over time. The Augmented Dickey-Fuller (ADF) stationarity test was performed and the test results revealed that the target variable (freight transport performance) is stationary while our predictor variables (energy taxes, biodiesel consumption and capacity utilisation) are non-stationary. Non-stationary time series can cause a common problem known as spurious regression, where a significant relationship is observed between variables, although no true relationship exists. To address this issue, we employed the cointegration technique. The Johansen cointegration test was performed to test whether a cointegrating relationship exists between the variables and estimate the long-run equilibrium relationship between them. The cointegration test results revealed that there exists no stable, long-run equilibrium relationship between the variables. Given that the variables are not cointegrated, it may be concluded that they are not related to each other in any meaningful way, or their relationship is too complex to be captured by a simple linear model. It may also be because one or both variables have a structural break, which can affect their relationship over time. In this case, the short-term relationship between the variables can be accurately analysed using a correlation or regression technique.

In the second step of the methodology, the impact of sustainable transportation practices (including capacity utilisation, biofuel consumption and energy taxes; on freight transport performance as highlighted in the reviewed literature) was empirically analysed using the maximum likelihood regression technique by building an autoregressive conditional heteroskedasticity (ARCH) model in order to establish their short-run level of significance on the reduction of CO_2 emissions from transport. The third and final step of our methodology is the model evaluation. Statistical tests for model evaluation such as the Lagrange multiplier (LM) test and the F-test were used to test for the presence of heteroscedasticity. The D'Agostino-Pearson Omnibus normality test was performed to confirm that the residuals are normally distributed. This will guide this research from making nonsense conclusions. The purpose of this criteria is to check whether the results obtained from this empirical study conform to a priori expectation (or what the theory says). For the purpose of this research, Python programming language and supported libraries were used on Jupyter Notebook software to explore, visualise and estimate the parameters.

3.1 Model specification

Autoregressive conditional heteroskedasticity (ARCH) models are used to model multiple time series variables that may be interdependent. The ARCH model is a type of time series model that captures the time-varying nature of volatility, also known as conditional heteroscedasticity. The basic idea behind the ARCH model is to model the variance of the time series as a function of its past values, with the assumption that the volatility of the time series is autocorrelated. Specifically, the ARCH model assumes that the variance of the time series at time t (conditional on its past values) is a linear function of the past squared errors or residuals. This model can help to account for the time-varying nature of the relationship between the variables and can provide more accurate estimates of the short-term relationships between them. Additionally, they can be used to forecast short-term values of the dependent variable based on the independent variables. The functional form of our model is given by:

$$FTP_t = \beta_0 + \beta_1 ETX_t + \beta_2 BDC_t + \beta_3 CUT_t + \varepsilon_t$$

where:

FTP_t – freight transport performance at time t

ETX_t – energy tax at time t

BDC_t – biodiesel consumption at time t

CUT_t – capacity utilisation at time t

β_0 – the constant term (the intercept)

β_1, β_2, *and* β_3 – coefficients of the independent variables

ε_t – the error term, assumed to be normally distributed with a mean of zero and variance that varies over time (hence the ARCH model).

Gujarati [28] defines the ε_t as a random variable that has well-defined probabilistic properties. The stochastic error term captures all other factors that affect sustainability but is not taken into account. The use of the stochastic error term for this is also in line with Occam razor's principle of parsimony which states that: if we can explain the behaviour of Y (which is the dependent variable, FTP) with two or three variables and if our theory is not strong enough to suggest what other variables might be included then we should not introduce more variables. He suggests we use the stochastic error term (ε_t) to represent all other variables. In doing this, we should make sure that the relevant and important variables are not excluded in order to keep the regression model simple.

3.2 Definition and justification of variables

The dependent variable "GHG" refers to the annual total greenhouse gas intensity from road transport fuel combustion within the EU measured in thousand tonnes of CO_2 equivalent [29]. Freight transport performance (FTP) is defined here as the annual total commercial (hire or reward) road freight transport in the EU, measured in thousand tonnes [30]. Energy consumption taxes (ETX) are defined as the annual tax rate on energy consumption levied on transportation and storage in the EU [31]. This value is measured in percentage. Biodiesel consumption (BDC) is the annual final consumption of pure biodiesels by the transport sector, measured in thousand tonnes of oil equivalent [32]. Capacity utilisation rate (CUT) is defined here as the annual total number of fully loaded road commercial (hire or reward) freight transport vehicle movements as a percentage of the annual total number of road freight transport (including loaded and empty) vehicle movements in the EU, measured in million vehicle-kilometres (VKM) [33].

	FTP	ETX	BDC	CUT
count	1.400000e+01	14.000000	14.000000	14.000000
mean	9.360598e+06	11.160714	423.080714	81.330000
std	6.057976e+05	0.696170	97.200528	0.624007
min	8.532044e+06	10.270000	197.490000	80.130000
25%	8.903775e+06	10.735000	372.932500	80.890000
50%	9.195488e+06	11.030000	448.000000	81.440000
75%	9.864759e+06	11.557500	487.380000	81.825000
max	1.039004e+07	12.740000	551.970000	82.030000

Figure 5 – Annual GHG intensity from road freight transport in the EU in thousand tonnes (based on Eurostat data from 2008 to 2021)

4. RESULTS AND DISCUSSION

4.1 Stationarity (unit root) test

The augmented Dickey-Fuller (ADF) test was used to test for stationarity in the individual variable. Decision rule: If the calculated ADF test statistic is less than the critical values at 5% level of significance, we reject the null hypothesis of non-stationarity and accept the alternative hypothesis of stationarity and otherwise [34]. The results for the augmented Dickey-Fuller test for unit root are summarised in *Table 1*.

Given that all but one of our variables are non-stationary in level form, we go further to carry out a cointegration test. The essence is to determine whether our variables have a long-term relationship or equilibrium between them even though they are non-stationary series. That is, whether the variables are cointegrated.

Table 1 – Augmented Dickey-Fuller (ADF) unit root test

Variable	Critical value (5%)	t-statistic	Result
FTP	-3.2898	-5.8470	Stationary
ETX	-3.3671	-1.7731	Non-stationary
BDC	-3.3671	-1.6683	Non-stationary
CUT	-3.2898	-1.3878	Non-stationary

4.2 Cointegration test

Theoretically, it is expected that a regression involving non-stationary time series variables may produce spurious (non-meaningful) results. Cointegration tests prove that the combination of such variables has a long-term relationship. Two or more variables are said to be cointegrated if they have a long-run or an equilibrium relationship between them [28]. To test for cointegration among the variables, we will use the Johansen test on the data.

Decision rule: The decision rule is to reject the null hypothesis of no cointegration if the eigenvalue is greater than the critical value. The cointegration test result is summarised in *Table 2*.

Table 2 – Johansen cointegration test

Variable	Critical value (5%)	Eigenvalues	Decision
FTP	54.6815	1.0000	The series are not cointegrated
ETX	35.4628	0.9810	The series are not cointegrated
BDC	19.9349	0.4526	The series are not cointegrated
CUT	6.6349	0.3292	The series are not cointegrated

The cointegration test results shown in *Table 2* indicate that our dataset is not cointegrated at 5%; it means that there is no long-term relationship between the variables but there may still be short-term relationships between them. In this case, in order to model the relationship between the variables, we consider the autoregressive conditional heteroskedasticity (ARCH) models and generalised autoregressive conditional heteroskedasticity (GARCH) models. These models can help to account for the time-varying nature of the relationship between the variables and can provide more accurate estimates of the short-term relationships between them [35]. Additionally, they can be used to forecast short-term values of the dependent variable based on the independent variables [36].

4.3 Evaluation of regression results

Coefficient estimates: The coefficient estimates indicate the strength and direction of the relationship between the independent variables and the dependent variable. A positive coefficient indicates that an increase in the independent variable is associated with an increase in the dependent variable, while a negative coefficient indicates the opposite. The regression result is shown in *Table 3*. The dependent variable is FTP, while the independent variables are ETX, BDC and CUT.

Mean model: FTP = -7606.73+ 635570ETX + 3041.15BDC + 946820CUT

- CONSTANT (Const.): The constant term (-7606.73) represents the expected value of the dependent variable, road freight transport performance (FTP) when all the independent variables are assumed to be zero or absent from the model. The negative value of this constant term implies that the mean value of FTP is negative, on average, in the absence of any other factors that may affect its value.
- ETX: Energy taxes on transport and storage (635570) exhibit a positive relationship with FTP as can be seen from the sign of its coefficient. The sign and magnitude of the coefficient of ETX implies that a percentage point increase in energy taxes on transport and storage will increase FTP by 635570 thousand tonnes, holding all other independent variables constant. A positive coefficient on ETX implies that an increase in ETX is associated with an increase in FTP, all else being equal.
- BDC: The coefficient on BDC (3041.15) represents the expected change in FTP as a result of a one-unit increase in BDC, holding all other independent variables constant. A positive sign and coefficient on BDC imply that a unit increase in BDC is associated with an increase in FTP by 3041.15 thousand tonnes, all else being equal.
- CUT: The sign and magnitude of the coefficient on CUT (946820) represents the expected change in FTP as a result of a percentage point increase in CUT, holding all other independent variables constant. A positive coefficient on CUT implies that a percentage increase in CUT is associated with an increase in FTP by up to 946820 thousand tonnes, all else being equal.

Deducing from the results of the ARCH regression analysis displayed in *Table 3*, environmental sustainability practices have a significant impact on the performance of the road freight transport sector as FTP has a neg-

Table 3 – ARCH-X model results

Dependent variable	FTP	R-squared	0.720
Mean model	AR-X	Adj. R-squared	0.636
Distribution	Normal	AIC	146.159
Method	Maximum likelihood	BIC	151.271
		No. of observations	14
Mean model	Coefficient	Std. error	t
const	-7606.7313	1371.566	-5.546
ETX	635570	1.191e+05	5.335
BDC	3041.1536	525.212	5.790
CUT	946820	1.556e+05	6.083

ative value in the absence of ETX, BDC and CUT. Consequently, we reject the null hypothesis of this research paper that environmental sustainability in transportation has no impact on the economic performance of the transport sector. From an economic perspective, an increase in FTP could lead to increased economic activity as it allows for the transportation of goods and services more efficiently. This could be beneficial to both the transport providers and the businesses relying on transportation services to move their goods.

An increase in energy taxes on transport and storage can lead to an increase in the cost of fuel and other energy-related inputs, which can increase the cost of freight transport [37]. This increase in cost may encourage transport providers to adopt more fuel-efficient technologies and practices to reduce their energy consumption, leading to improved freight transport performance [38]. However, the possible implications for freight transport providers will depend on various factors, including the level of energy taxes, the availability and accessibility of alternative transport modes and the competitiveness of the freight transport market [39]. For example, if energy taxes are set at a level that significantly increases the cost of freight transport, it may lead to a reduction in demand for transport services and a decline in the profitability of transport providers. On the other hand, if the taxes are set at a level that is too low, it may not provide sufficient incentives to reduce energy consumption and promote more sustainable transport practices. The positive relationship between biodiesel consumption and road freight transport performance suggests that policies aimed at promoting the use of biodiesel could have positive economic and environmental implications for the transportation sector. The use of biodiesel, which is a renewable source of energy has positive environmental implications as it reduces the reliance on fossil fuels and reduces greenhouse gas emissions.

An increase in vehicle capacity utilisation, which is measured by the CUT variable, increases road freight transport performance by reducing the number of trips required to transport a given amount of freight. This can lead to cost savings for the freight transport provider and potentially lower prices for consumers [40]. Additionally, increased vehicle capacity utilisation can reduce the number of trucks on the road, which can have positive environmental implications such as reducing traffic congestion and emissions. However, there may be economic and environmental trade-offs to consider. For example, if the increase in vehicle capacity utilisation is achieved through overloading vehicles beyond their safe and legal limits, this can lead to safety risks and potential damage to infrastructure. Furthermore, if vehicle capacity utilisation increases to the point where there is excess demand for freight transport services, this can lead to increased congestion and negative environmental impacts such as air pollution and greenhouse gas emissions. Therefore, careful consideration should be given to the optimal level of vehicle capacity utilisation to balance economic benefits with environmental and safety concerns. Thus, creating a potential pathway for the transformation towards carbon-free transportation in the EU requires the careful consideration of the relationship and impact of these sustainability indicators on the economy.

Also, focus was on the regularly mentioned and reviewed indicators of sustainable road transportation in the existing literature as well as those influential variables highlighted by the industry stakeholders. The AIC (Akaike information criterion) value of 146.159 implies that our model provides a good balance between the model's goodness-of-fit and model complexity. This suggests that there could be other underlying factors and variables that significantly impact freight transport performance in the EU, not captured in this analysis. Given that this is a short-run analysis, it is also possible that the relationship between the variables may change over time, so it may be necessary to re-evaluate the relationship periodically.

4.4 Standard error

The standard errors indicate the precision of the coefficient estimates. Lower standard errors indicate higher precision and higher standard errors indicate lower precision. Specifically, for the four coefficients in our model, the standard errors are:

- 1371.566 for the intercept term (-7606.7313)
- 119,100 for the coefficient associated with the variable ETX (635570)
- 525.212 for the coefficient associated with the variable BDC (3041.1536)
- 155,600 for the coefficient associated with the variable CUT (946820).

These standard errors suggest that the estimate for the coefficient associated with the variable ETX has the highest level of uncertainty, as indicated by its relatively large standard error of 119,100. The other three coefficients have smaller standard errors, indicating less uncertainty around their estimated values. However, it is important to note that standard errors are not the only measure of the quality of the estimates. Other measures, such as the coefficient of determination (R-squared), the F-statistic, and the p-values associated with each coefficient, can also provide important information about the overall quality and significance of the regression model.

4.5 T-statistics and p-values

In the regression model results, we can see that all four variables have t-statistics greater than 1.96 and corresponding p-values less than 0.05, indicating that all four coefficients are statistically significant predictors of the dependent variable. Specifically, the intercept term has a t-statistic of -5.540, ETX has a t-statistic of 5.335, BDC has a t-statistic of 5.788 and CUT has a t-statistic of 6.086. Therefore, we can conclude that the estimated coefficients of the independent variables in the model are significant at a 5% level of significance, and we reject the null hypothesis that the coefficients are equal to zero. This suggests that the independent variables have a significant impact on the dependent variable, and we can use the estimated coefficients to make predictions about the dependent variable based on the values of the independent variables.

4.6 R-squared and R-squared adjusted

The R-squared value of 0.720 indicates that approximately 72% of the variation in FTP is explained by ETX, BDC and CUT in the regression model. This suggests that the model fits the data relatively well and that the independent variables are good predictors of the dependent variable. An adjusted R-squared value of 0.636 indicates that the independent variables in the model explain approximately 64% of the variation in the dependent variable, after taking into account the number of independent variables and the potential for overfitting. Overall, an R-squared value of 0.720 and an adjusted R-squared value of 0.636 suggest that the model has some predictive power and fits the data reasonably well.

4.7 Heteroscedasticity test

The Lagrange multiplier (LM) test and the F-test are both statistical tests used to detect the presence of heteroscedasticity in the residuals of a regression model. The null hypothesis of this test is that there is no ARCH effect in the residuals (i.e. the variance of the residuals is constant over time). If the p-value of the LM test or F-test is less than the significance level (0.05), then we reject the null hypothesis and conclude that there is evidence of heteroscedasticity in the residuals.

Table 4 – Lagrange multiplier test for autoregressive conditional heteroscedasticity (ARCH)

Lagrange multiplier test statistic	0.22
P-value for LM test	0.89
F-test statistic for ARCH	0.08
P-value for F-test	0.91

The results of these tests suggest that there is no evidence of heteroscedasticity in our model's residuals**.** The LM test statistic of 0.22 and its associated p-value of 0.89 indicate that there is no evidence of heteroscedasticity in our model's residuals. Similarly, the F-test statistic for ARCH of 0.084 and its associated p-value of 0.91 also suggest that there is no evidence of ARCH effects in the residuals. Therefore, we can conclude that the variance of the errors in our model is constant and does not change with changes in the values of the independent variables. This means that our model is correctly specified and there are no issues related to heteroscedasticity.

4.8 Normality test

If the p-value is less than the significance level (0.05), then we reject the null hypothesis and conclude that the residuals are not normally distributed. Otherwise, if the p-value is greater than or equal to the significance level, we fail to reject the null hypothesis and conclude that the residuals are normally distributed.

Table 5 – D'Agostino-Pearson Omnibus normality test

Normality test statistic	P-value
1.22	0.54

In this case, since the p-value is 0.54, which is greater than 0.05, we can conclude that there is not enough evidence to reject the null hypothesis that the residuals are normally distributed. Therefore, we can assume that the residuals are normally distributed.

5. CONCLUSIONS

The analysis of the regression results reveals important insights into the relationship between environmental sustainability practices and the performance of the road freight transport sector. The coefficient estimates indicate that energy taxes on transport and storage (ETX), biodiesel consumption (BDC) and vehicle capacity utilisation (CUT) have significant impacts on road freight transport performance (FTP). The positive coefficients for ETX, BDC and CUT suggest that increases in these variables are associated with increases in FTP.

The results highlight the potential economic and environmental benefits of incorporating sustainability practices in the transportation sector. Increased FTP facilitates the efficient movement of goods and services, benefiting both transport providers and businesses relying on transportation services [41]. Moreover, policies promoting energy efficiency and the use of renewable energy sources like biodiesel can reduce reliance on fossil fuels and mitigate greenhouse gas emissions. Additionally, optimising vehicle capacity utilisation can lead to cost savings, lower prices for consumers and positive environmental impacts such as reduced congestion, emissions and overall supply chain risks [42, 43].

However, further research is recommended to deepen our understanding of the complex relationship between sustainability indicators and the economy in the context of road freight transport. The current analysis focused on a limited set of indicators mentioned in existing literature and identified by industry stakeholders. Exploring additional sustainability indicators and considering their potential interactions could provide a more comprehensive understanding of the dynamics at play.

Additionally, given the short-term nature of this analysis, it is important to monitor the relationship between variables over time. Changes in market conditions, policy frameworks and technological advancements may influence the impact of sustainability practices on road freight transport performance. Therefore, regular re-evaluation of the relationship is necessary to ensure the accuracy and relevance of the findings [27].

Furthermore, future research could delve into the specific mechanisms through which sustainability practices affect the economic performance of the transport sector. This could involve analysing the market dynamics, pricing mechanisms, policy frameworks and technological advancements that shape the relationship between sustainability practices and road freight transport performance. Understanding these mechanisms can inform the design of effective policies and strategies to foster sustainable and economically viable transportation systems.

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Zrównoważony Rozwój Środowiskowy a Rezultaty Transportu Ładunków w UE: Analiza Modelu Autoregresji z Heteroskedastycznością Warunkową (ARCH)

Abstrakt

Transport, który znacząco ułatwia globalny handel i rozwój, boryka się z poważnym problemem związanym z zrównoważonym rozwojem. Po pierwsze, istnieje konieczność minimalizacji emisji gazów cieplarnianych, zachowując jednocześnie rentowność i odpowiedzialność społeczną. Transport będzie całkowicie dekarbonizowany poprzez konsekwentne dążenie do bardziej zrównoważonych, zróżnicowanych energetycznie środków transportu z zaawansowanymi technologiami napędu pojazdów. Niemniej jednak, jaki wpływ będzie to miało na wyniki ekonomiczne dostawców usług transportowych, pozostaje wielkim pytaniem. Celem tego badania jest zbadanie krótkoterminowego związku między zrównoważonym rozwojem środowiskowym w transporcie drogowym a wynikami ekonomicznymi sektora transportu drogowego w Unii Europejskiej przy użyciu modelu autoregresji z heteroskedastycznością warunkową (ARCH). Analiza została przeprowadzona na podstawie danych rocznych obejmujących okres od 2008 do 2021 roku. Wyniki wskazują, że podatki od energii w transporcie i magazynowaniu, konsumpcja biodiesla oraz wykorzystanie pojemności pojazdów mają pozytywny i istotny wpływ na wyniki transportu ładunków. Wyniki sugerują, że decydenci polityczni mogliby wykorzystać podatki energetyczne i zachęty do promowania stosowania biodiesla w sektorze transportu w celu zwiększenia wyników transportu ładunków. Dodatkowo, wysiłki mające na celu poprawę wykorzystania pojemności pojazdów mogą znacząco zwiększyć wyniki transportu ładunków oraz przyczynić się do korzystnych efektów środowiskowych, takich jak redukcja zatorów komunikacyjnych i zmniejszenie zanieczyszczenia.

Słowa kluczowe
rezultaty transportu ładunków, wykorzystanie pojemności, podatki energetyczne, zrównoważony transport.