# Financial, Economic, Educational, and Technological Determinants of Environmental Sustainability

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Edited by

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# INTRODUCTION

Many countries have achieved significant improvements in economic growth and development, welfare, and life expectancy as of the Industrial Revolution, but serious environmental problems such as air and water pollution, global warming and climate change, resource depletion, biodiversity loss, and deforestation have accompanied these economic and social improvements. In this context, especially international institutions and developed countries have directed their attention towards the environmental problems after deaths resulting from air and water pollution and chemical gas leaks and natural disasters as of 1950s. Therefore, environmental sustainability has become one of the critical common problems of humankind and the researchers and policy-makers have focused on factors underlying environmental problems. In this regard, specification of financial, economic, and educational factors behind environmental sustainability becomes more of an issue to arrange the environmental policies. The main objective of this edited book is to explore the financial, economic, educational, and technological determinants of environmental sustainability from a global perspective.

In this context, Chapter 1 investigates the effect renewable energy consumption and GDP per capita on carbon emissions in Turkiye through cointegration analysis and uncovers that renewable energy use has a negative effect on carbon emissions in the long run, but GDP per capita has a positive effect on carbon emissions in the long run. On the other hand, Chapter 2 evaluates the sustainability of the transport sector in European Union countries through Cumulative Proportionality Assessment method and Hierarchical Clustering approach and their results reveal that European Union countries such as Germany, Latvia, Italy, Spain and France are facing problems with the growth of greenhouse gas emissions resulting from the transport sector and this finding underlines the crucial role of the transport sector in influencing the greenhouse gas emissions and environmental sustainability of these countries.

Chapter 3 examines the causal interplay among international trade freedom, government size, and $CO_2$ emissions in the sample of BRICS countries via JKS (2021) causality test and reveals a bidirectional causal interaction between government size and $CO_2$ emissions, but insignificant causal association between international trade freedom and $CO_2$ emissions.

In other words, there exists a feedback interaction between government size and $CO_2$ emissions. Chapter 4 analyzes the interaction between tax revenues and carbon emissions in 10 big emerging markets during the period 2000-2020 by means of causality and discovers a bidirectional causality between environmental taxes and environmental sustainability. Therefore, environmental taxes and environmental sustainability affects each other.

Chapter 5 examines the awareness of consumers about the impact of their purchases on the environment, and their willingness to transform their values, change their consumer habits and lifestyle, and live a sustainable lifestyle in sample 182 respondent from Croatia and suggests that green marketing and lifestyle are significant factors for sustainable future. Chapter 6 investigates the relationship between GDP per capita and $CO_2$ emissions in G20 economies for the period of 2000-2022 through cointegration and causality analyses and reveals a positive effect of GDP per capita on $CO_2$ emissions and a bilateral causal interaction between GDP per capita and $CO_2$ emissions.

Chapter 7 evaluates the relationship between renewable energy sources and sustainable development and suggests that switching from fossil-based power generation and consumption to renewable energy will contribute to the sustainable development. Chapter 8 suggests a business meta-model that respects environmental sustainability through polymathic approach for enterprise transformation projects. On the other hand, Chapter 9 investigates the causal interplay between financial development and $CO_2$ emissions in the MINT countries through causality analysis and concludes that financial sector development has a significant effect on $CO_2$ emissions.

Chapter 10 discusses the relationship between Market Place of Morality (MOM), Passions of Property (POP), and corporate responsibility through different dimensions of greenwashing and suggests that adoption of the principles of transparency and sincerity is vital for the companies. On the other hand, Chapter 11 evaluates the role of education on environmental sustainability awareness and perception through bibliometric analysis and reveals a significant rise in societal awareness and public interest in environmental sustainability. Chapter 12 develops a sustainability index for different school bus fleets through TOPSIS approach and the findings of the Chapter indicates that gasoline buses demonstrate a frugal economic narrative, diesel buses exhibit a reduced environmental impact post-normalization and electric buses emerge as environmentally conscious, striking a harmonious balance

Chapter 13 examines the literature about recycled products and purchase intentions through bibliometric analysis and reveals a significant shift towards environmentally conscious consumption practices and consumers' growing awareness of the environmental impact of their purchasing decisions. On the other hand, Chapter 14 evaluates the sustainable risk management and sustainable disaster risk management and makes suggestions about the effective management of these sustainability issues. Chapter 15 assesses the indicators of sustainable production systems through a multicriteria decision-making approach. Economic and managerial criteria are found to be the most important.

Chapter 16 focuses on the sustainable leadership and emphasizes that sustainable leadership can lead to benefits such as continuous innovation, development, competitive advantage, and long-term success. On the other hand, Chapter 17 examines the sustainability and green campus strategies in universities and states that achieving full sustainability on university campuses is a lengthy and challenging process, and raising awareness among the university population and stakeholders about sustainability is one of the most important steps of this process. Last, Chapter 18 draws the attention to the dilemma between impulsive buying behavior and sustainable consumption and suggests that the dilemma between impulsive buying and sustainability lies in the potential negative impacts that impulsive consumption habits can have on the environment and society.

Editors

# 1

# $CO_2$ EMISSIONS, CLEAN ENERGY AND GROWTH: EVIDENCE FROM ARDL BOUNDS TEST APPROACH FOR TURKIYE

CANAN ŞENTÜRK

## Introduction

Today, 'Industry 4.0' technologies such as artificial intelligence, big data, and the IoT (internet of things) are accelerating industrialization through better efficiency and effectiveness. Increasing awareness of resource consumption and global warming is directing economies towards developing and using clean energy-based processes on a global scale to reduce dependence on fossil fuels and tackle future climate crisis (Mathiesen et al., 2015). In the last term, there have been transformations in production processes, from production-based operations to international networks and collaboration among supply chain partners. The intense environmental degradation caused by high-density industrialization makes it difficult to achieve a balance between industrialization and sustainability (Shi et al., 2021; Shi et al., 2023).

Because linear industrial systems are not sustainable for growth and development when taking into account their environmental effect (Shi et al., 2023). In a linear economic process, an increase in energy consumption implies a larger output of materials that can be recycled or cannot be recycled, resulting from industrial production, for greater economic growth. The use of primary energy sources negatively affects sustainability as an extension of the current economic growth process, which operates linearly (Neves and Marques, 2022). In this perspective, the use of renewable energy is associated with sustainability in terms of reducing greenhouse gas (GHG) emissions and carbon footprint. Especially in discussions related to the effects of climate crisis, transitioning from fossil fuels to renewable energy is emphasized. Renewable energy consumption and the implementation of new generation technologies are considered as low-carbon and resource-efficient systems based on a closed-loop system. Utilizing hybrid renewable energy helps reduce dependence on fossil fuels for energy production and supports the creation of a sustainable economy with a low carbon footprint (Bist et al., 2020). Thus, especially EU member countries, China, Japan, South Korea and many OECD countries are developing various action plans, roadmaps, and platforms to direct their economies towards low-carbon processes based on resource efficiency (EC, 2015a; 2015b; EC, 2018; EC, 2020; OECD, 2022). Therefore, changes/transformations in legislation, increasing company and individual awareness, improving clean energy use and recycling infrastructure, and taking steps to reduce emissions/carbon values in designing related processes for sustainable economy and green growth are also important for Turkey.

In this context, the study aims to analyse the relationship between carbon emissions in the axis of environmental degradation, clean energy and economic growth in the axis of environmental degradation. Analysis is carried out with the ARDL bounds test approach using 1990-2020 data for Turkey for the relevant variables. It is thought that the study subject and the results of the analysis will provide preliminary information about designing related processes for sustainable economy and green growth in Turkey. In this context, the next stages of the study are organized in such a way that part two includes the literature review, part three includes the definition of variables and research findings, and the last part includes discussion and conclusions.

## Literature Review

The increase in welfare caused by growth and lower $CO_2$ levels may seem to have a positive linkage at first glance. Because economic growth is one of the basic dimensions of sustainability, it speeds up the sustainability process. A country with a high-income level is expected to not only have a strong economy but also be socially developed and have low environmental degradation. This is due to the ability of these economies to sustain environmental and social institutions and/or projects. However, more intensive examination focuses on the timeline of wealth and reveals the dangerous consequences of growth based on linear processes. It is thought that behind the prosperity scene lies economic growth, which requires the consumption of natural resources and energy, threatens the process of sustainability and environment (Grossman and Krueger, 1991; 1998).

Environmental pollution firstly increases and then decreases following the economic development process (Grossman and Krueger, 1991; 1998; Selden and Song, 1994; Dinda, 2004). This view can be based on the environmental Kuznets curve (EKC). Thus, the linkage between the increase in per capita income, which is considered as a welfare indicator, and carbon emissions can be explained accordingly. On the other hand, the use of renewable/clean energy is associated with reducing greenhouse gas (GHG) emissions and carbon emissions in the literature on the axis of sustainability. In this respect, selected studies in the literature are briefly presented in Table 1.

**Table 1.** A Summary of Selected Studies in the Literature.

| **Authors (Year)** | **Period Analysed and Country/ Region** | **Method** | **Result** |
|---|---|---|---|
| Menyah and Wolde-Rufael (2010) | 1960-2007 USA | Toda-Yamamoto Causality Test | No causality was found from RE consumption to $CO_2$. |
| Farhani and Shahbaz (2014) | 1980-2009 MENA Countries | Pedroni cointegration, FMOLS | RE consumption increases $CO_2$ emissions. The results support the EKC hypothesis. |
| Bölük and Mert (2015) | 1960-2010 Turkey | ARDL | RE consumption reduces $CO_2$ emissions. The results support the EKC hypothesis. |
| Al-Mulali et al. (2015) | 1990–2013 EU Countries | Pedroni cointegration, FMOLS | RE consumption reduces $CO_2$ emissions. |
| Bilgili et al. (2016) | 1977-2010 OECD Countries | Pedroni cointegration, FMOLS | RE consumption reduces $CO_2$ emissions. The results support the EKC hypothesis. |
| Cerdeira et al., (2016) | 1960-2011 Italy | ARDL | RE consumption reduces $CO_2$ emissions. |

| **Authors (Year)** | **Period Analysed and Country/ Region** | **Method** | **Result** |
|---|---|---|---|
| Doğan and Şeker (2016) | 1985-2011 40 Countries | Panel Cointegration, FMOLS DOLS | RE consumption reduces $CO_2$ emissions. The results support the EKC hypothesis. |
| Zoundi (2017) | 1980-2012 25 African Countries | | RE consumption reduces $CO_2$ emissions. The positive relationship per capita income and $CO_2$ emissions. |
| Balsalobre-Lorente et al., (2018) | 1985-2016 EU-5 | PLS | RE consumption reduces $CO_2$ emissions. The results support the EKC hypothesis. |
| Mahmood et al., (2019) | 1980-2014 Pakistani | 3 stage least square, Ridge Regression | RE consumption reduces $CO_2$ emissions. |
| Aydoğan and Vardar (2020) | 1990-2014 E7 Countries | Granger Causality | RE consumption reduces $CO_2$ emissions. The results support the EKC hypothesis. |
| Namaharo et al. (2021) | 1980-2018 | PMG CCEMG CS-DL | RE consumption reduces $CO_2$ emissions. |
| Chen et al., (2022) | 1995-2015 97 countries | Dynamic panel threshold | RE consumption reduces $CO_2$ emissions. |
| Ali et al., (2023) | 1975-2020 Asian Countries | Panel AMG | RE consumption reduces $CO_2$ emissions. The results support the EKC hypothesis. |

There are a limited number of studies that empirically investigate the interaction between renewable energy consumption, economic growth and CO2 emissions. The majority of these studies conclude that renewable energy has a negative relationship on CO2 emissions (Doğan and Şeker 2016; Zoundi, 2017; Bento and Moutinho, 2016; Balsalabre-Lorente et al., 2018; Namaharo et al., 2021; Chen et al., (2022); Ali et al., 2023). On the contrary, the results of Menyah and Wolde-Rufael (2010) and Farhani and Shahbaz (2014) do not support this hypothesis.

In this regard, the hypotheses of the study are formed as "increase in renewable energy consumption reduces carbon emissions" and "increase in GDP per capita increases carbon emissions".

## Data, Methods and Analysis Results

In the study, the main elements of the model are carbon emissions, GDP per capita and renewable energy consumption. The variables of the model in question for Turkey in the 1990-2020 period are given below.

**Table 2.** Definition of Variables.

| | | |
|---|---|---|
| co | $CO_2$ emissions (mt tonnes per capita) | WDI |
| gdppc | GDP per capita (constant 2015$) | WDI |
| re | Renewable energy consumption | WDI |

The model is presented in the following equation:

$$\mathrm{CO} = f(RE, GDPPC)$$

$$\Delta co_t = \alpha_0 + \sum_{t=1}^{m} \alpha_{1i} \Delta co_{t-i} + \sum_{t=0}^{m} \alpha_{2i} \Delta re_{t-i} + \sum_{t=0}^{m} \alpha_{3i} \Delta gdppc_{t-i} + \alpha_4 co_{t-1} + \alpha_5 re_{t-1} + \alpha_6 gdppc_{t-1} + u_t$$

At this stage, unit root tests developed by Dickey and Fuller (1981) and Phillips and Perron (1988) are used to test the stationarity of the variables included in the model. In case the variables are stationary at the same level [I(1)] or some variables are stationary at the level [I(0)] (regardless of the degree of integration of the series), Pesaran (1997), Pesaran, Shin and Smith (2001) can test the long-term relationship between the series. ARDL-The Autoregressive Distributed Lag developed by is used. Additionally, if cointegration is detected between the variables in the model, the Error Correction Model is estimated to investigate whether the imbalance that may occur in the short term can be corrected in the long term. Stationarity means that the series approaches a certain value over time, in other words, the series has a constant mean and variance as well as covariance depending on the lag level. The fact that the series is stationary, that is, does not contain a unit root, means that these conditions have been reached. At this stage of the study, it is necessary to test stationarity before analysis. For this reason, the results of the most commonly used Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests are presented in Table 3.

**Table 3.** Results of ADF and PP Unit Root Tests.

| | ADF | | PP | |
|---|---|---|---|---|
| | I(0) | I(1) | I(0) | I(1) |
| co | -0.5236 (0.8736) | -5,5510 (0.0001)* | -0.2075 (0.9271) | -7.3063 (0.0000)* |
| re | -1.6061 (0.4672) | -5.3968 (0.0001)* | -1.7240 (0.4094) | -6.3145 (0.0000)* |
| gdppc | 1.9077 (0.9997) | -4.7214 (0.0007)* | 4.2132 (1.0000) | -4.6685 (0.0008)* |

Note: *, **, *** indicate stationary variables at 0.01, 0.05 and 0.10 significance levels, respectively. Values in parentheses show probability values.

As a result of ADF and PP tests, it was determined that the variables were cointegrated in I(1) and the ARDL test was used in the study. ARDL accepts I(0) and I(1) stationarity levels in the stationarity levels of the series, but it is important that there is no second-order stationarity (I(2)) in the variables. Therefore, in terms of ARDL, it is important to examine whether the series has a second-degree stationary variable rather than whether it contains a unit root. In the study results, it is observed that the variables become stationary at most at I(1). Model construction and evaluation are made using data from Turkey between 1990-2020 and the appropriate model was determined as ARDL (1,0,1).

**Table 4.** ARDL (1,1,0) Model Estimation Results.

| Model: ARDL (1,1,0)<br>Dependent Variables: co | | |
|---|---|---|
| Variables | Coefficient | t-statistic |
| co(-1) | 0.4829 | 3.4935 (0.0018)* |
| re | -0.0867 | -4.9859 (0.0000)* |
| re(-1) | 0.0598 | 2.7398 (0.0112)** |
| gdppc | 0.0001 | 3.7960 (0.0008)* |
| c | 1.2693 | 2.9170 (0.0074)* |
| $R^2$ | 0,986147 | |
| Adjusted-$R^2$ | 0,983930 | |

Note: *, **, *** indicate significant variables at 0.01, 0.05 and 0.10 significance levels, respectively. Values in parentheses show probability values.

At this stage, boundary testing application is important. The bounds test null hypothesis is based on 'there is no cointegration relationship between variables'. If the F statistic value is greater than the upper limit at critical values, the null hypothesis is rejected, that is, there is a cointegrated relationship. If the F statistic value is less than the lower limit at critical values, the null hypothesis cannot be rejected. If it is between the lower and upper bounds, no comment can be made as to whether there is a cointegrated relationship.

**Table 5.** ARDL Bound Test Results.

| ARDL (1,1,0) | | |
|---|---|---|
| F statistic | 5.6046 | |
| k | 2 | |
| Significance Level | Critical Bound Values | |
| | Lower | Upper |
| 0,01 | 2.91 | 3.69 |
| 0,05 | 3.53 | 4.42 |
| 0,10 | 5.15 | 6.26 |

When the values in Table 5 are examined, according to the results of the bounds test for cointegration, since the calculated F-statistic is higher than the upper critical value at the 5% significance level (5.60 > 4.42), there is a long-term relationship between the variables. Long-term forecast results are given in Table 6.

**Table 6.** ARDL (1,1,0) Long-Run Results.

| Dependent Variable: co | | |
|---|---|---|
| Variables | Coefficient | t-statistic |
| re | -0.0535 | -3.3692 (0.0024)* |
| gdppc | 0.0002 | 8.8546 (0.0000)* |
| c | 2.4550 | 5.0139 (0.0000)* |

Note: *, **, *** indicate significant variables at 0.01, 0.05 and 0.10 significance levels, respectively. Values in parentheses show probability values.

According to the long-term results, the coefficient of the renewable energy variable (re) in the model is negative and significant at the 0.01 significance level. The national income per capita variable (gdppc) is statistically positive and significant at the 0.01 significance level.

**Table 7.** Error Correction Model Results.

| Dependent Variable: co | | |
|---|---|---|
| Variables | Variables | Variables |
| Δ(re) | -0.0867 | -5.8539 (0.0000)* |
| CointEq(-1)* | -0.5170 | -5.0108 (0.0000)* |
| Diagnostik Testler | | |
| $R^2$ | 0.734102 | |
| Adjusted $R^2$ | 7.24606 | |
| Normality, Jarque- Bera | 0.548965 (0,7599) | |
| Breusch-Godfrey Serial Correlation LM | 0.609181 (0,5523) | |
| Heteroskedasticity (Breusch-Pagan-Godfrey) | 0,927544 (0.4638) | |
| Ramsey Reset Test | 0,340674 (0,7363) | |

Note: *, **, *** indicate significant variables at 0.01, 0.05 and 0.10 significance levels, respectively. Values in parentheses show probability values.

Error correction model results show that there is a statistically significant relationship between the renewable energy consumption (re) variable and the ‘co’ variable (CO2 emissions) in the short term. The direction of the relationship between the variables in question is negative and the coefficient is 0.08. Accordingly, a one-unit increase in ‘re’ will reduce carbon emissions by 0.08 units. The coefficient of the error correction term (CointEq (-1)) was determined as -0.5170. The error correction term is statistically significant and has a negative sign, as expected. When the error correction coefficient is evaluated, it can be said that a deviation from the equilibrium in the short term will correct after 1.93 years and converge to the long-term equilibrium. In other words, it shows that 51% of the deviation in the long-term balance following short-term shocks can be eliminated after a period, meaning that the adaptation process is slow. Breusch-Godfrey LM, normality and heteroskedasticity tests are performed as diagnostic tests of the model. The results show that there is no autocorrelation, the error terms are normally distributed, and there is no heteroscedasticity problem. And finally, a model with the correct features was established according to the Ramsey Reset Test results. Therefore, the results support that the prediction results obtained are reliable. Additionally, to test the stability of ARDL long-term coefficients, Brown et al. CUSUM and CUSUMsq tests developed by (1975) are used. These tests are used to test the presence of structural breaks using the squares of the error terms, and the results are presented below.

**Figure 1.** CUSUM Test.

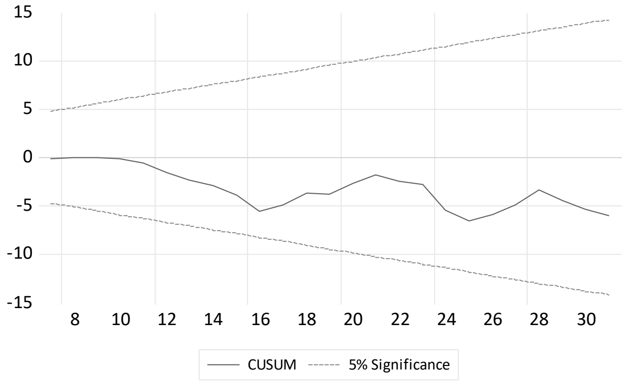
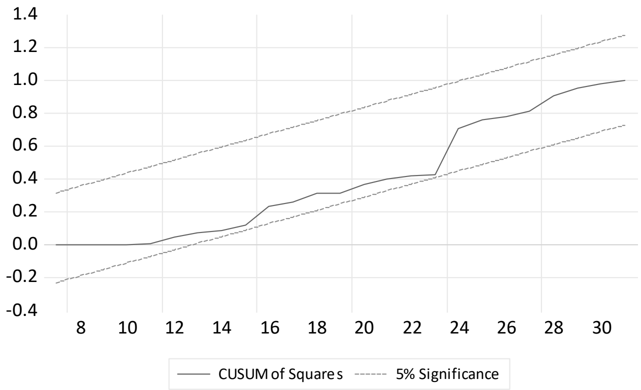



**Figure 2.** CUSUMsq Test.




If the statistical values remain within the critical limits at the 0.05 significance level, the null hypothesis that the coefficients in the model are stable will be accepted (Bahmani-Oskooee and Ng, 2002). According to the results in Figure 2, the estimated parameters are stable since the curves obtained as a result of the test statistics for the error terms are between the critical limits at the 0.05 significance level.

## Conclusion

According to the findings of the study, in the long term, the coefficient of the renewable energy variable (re) is negative and significant at the 0.01 significance level. The national income per capita variable (gdppc) is statistically positive and significant at the 0.01 significance level. In the short term, the sign of the error correction term is statistically significant and negative, as expected. When the error correction coefficient is evaluated, it is concluded that after a period of deviation in the long-term balance following short-term shocks, 51% of the effect of the shock in question can be eliminated, that is, the adaptation process is slow.

The results of the study reveal results consistent with Dogan and Seker (2016); Bento and Moutinho, (2016); Zoundi, (2017); Namaharo et al., (2021); Chen et al., (2022) and Ali et al., (2023) in the literature. The long-term results of the study show that carbon emissions decrease as renewable energy consumption increases. In addition, increasing per capita income creates more carbon emissions. This situation shows that most of the current economy has an economic structure based on production systems based on linear processes. It is known that in recent years, many countries, especially EU member countries, are in the process of creating and implementing policies for production processes based on closed-loops and steps towards a circular economy with the principle of sustainability. In this regard, it can be said that Turkey needs green economy and green growth-oriented transformations, especially on the axis of sustainable development.

Attributing more importance to the requirements and restrictions of environmental protection in the global industrialization process, ecological requirements in the industrialization process, and supporting closed-loop approaches in the design of production systems will contribute to achieving this balance. However, it is not yet clear to what extent ecological requirements are observed in the industrialization process. Therefore, a clear guide is needed that includes the co-adaptation and evolution of sustainability, industrialization and digitalization. In the transition to clean energy, the development of recycling content and technologies in the sectors that clean energy depends on is important in the long term. Policy efforts in this direction play an important role in creating a solid foundation for the transition to a sustainable system.

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# 2

# ASSESSING TRANSPORT SUSTAINABILITY IN THE EUROPEAN UNION COUNTRIES

DANGUOLĖ OŽELIENĖ AND AUŠRA KATINIENĖ

## Introduction

The transportation of goods and services is a key area of supply chain management. A carefully maintained logistics infrastructure enables an organisation to optimise its performance and achieve the highest levels of efficiency. The transport sector accounts for 5% of the European Union's GDP and employs around 10 million people (*European Commission*, 2022). In 2020, the logistics market was valued at US$ 8.6 trillion (*Statista*, 2022). However, the transport sector is one of the biggest environmental polluters. Greenhouse gas emissions from the transport sector account for 25% of the European Union's total emissions (*European Commission*, 2021). Greenhouse gas emissions, air and water pollution, noise, car accidents, congestion and biodiversity loss have a negative impact on the public health and well-being and the ecosystem. To meet climate targets, effective transformation of the transport sector is required, including a substantial reduction in greenhouse gas emissions (Brynolf et al., 2022).

The concept of sustainable transport is closely linked to the development of sustainable transport modes, infrastructure and activities. It should be defined as the ability to meet the mobility needs of society with the least possible environmental impact.

The EU Green Deal is a transformational change plan that aims to make Europe the first climate-neutral continent by 2050. EU Member States have committed to reducing emissions by at least 55% below 1990 levels by 2030 (*European Commission*, 2021). In the transport sector, two thirds of the measures to achieve the Green Deal targets are related to fuel efficiency or fuel reduction (promoting electrification of cars), and around one third of the measures are related to changing travel behaviour (promoting ecodriving, maximising public transport). It also promotes the replacement of diesel and petrol cars with biofuel, cellulosic ethanol and biodiesel cars (Gota et al., 2019). The European Green Deal aims to make the transport sector fossil-free, which is why the Fit for 55 package was announced in 2021 (*European Commission*, 2021).

One of the goals of sustainable development is to ensure that the pollution and negative effects of transport on the environment do not increase as the economy grows. EU countries have to primarily face the unsustainable development of the transport sector in order to meet the requirements of the EU Green Deal and become climate-neutral countries.

The purpose of this research is to assess the sustainability of the transport sector in European Union countries and provide recommendations to sustainability policy and decision makers.

Research object – ES transport sector. Research objectives: to examine the impact of transport on the environment and society; to identify the indicators for the transport sector that have an impact on the environmental sustainability; to carry out a multi-criteria analysis of complex proportionality assessment (COPRAS) and cluster analysis, and assess the sustainability of the EU transport sector.

## Literature Review

As the economy develops and the social situation of the population changes, the need for mobility increases, leading to higher urban traffic flows, noise levels and air pollution. The rapid increase in the number of vehicles in the world and the associated increase in atmospheric and ambient air pollution, causing global atmospheric changes, have forced many scientists to address environmental protection issues related to climate change ecosystems in recent decades (Malhi et al., 2020; Weiskopf et al., 2020), the occurrence of fires (Abram et al., 2021), ocean temperature changes (Hobday et al., 2016), the management of transport infrastructure (Wang et al., 2020), and greenhouse gas mitigation (Soeder, 2021). As the number of petrol and diesel vehicles increases, air quality is rapidly deteriorating due to increased emissions of gaseous pollutants and particulate matter (Kinnon et al., 2019). Biological, physical and chemical types of air pollution have a negative impact on human health. According to the World Health Organization, particulate matter (PM), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$) and ground-level ozone ($O_3$) are the most harmful for the human health (WHO Regional Office for Europe OECD, 2017). Ambient air pollution increases the incidence of circulatory and respiratory diseases and weakens the human immune system.

Transport pollution can have a significant impact on water quality. For example, emissions from the motor vehicles settle on the surfaces and roads as several particles of rubber, oil and other pollutants. In the rain, these pollutants are washed out into the surrounding areas. In some cases, rainwater may flow through the sewer directly into a river, a lake or a bay, or may contaminate groundwater or water in a swamp (Hlaváč et al., 2019). Transport has a negative impact not only on the people but also on nature. Vegetation plays an important role in cleaning the atmosphere and reducing air pollutants. Gases, including nitrogen oxides, carbon monoxide, volatile organic compounds and methane, bind in the atmosphere and form the tropospheric ozone layer. Ozone on the surface of the Earth limits the photosynthesis of plants, reducing the ability of plants to grow. According to Unger (2020), the ecosystems of the Earth are currently slowing global warming, storing about 30% of carbon dioxide emissions each year. However, this carbon capture is undermined by the depletion of the ozone layer.

The biggest losses in plant productivity are in eastern US, Europe and eastern China, where the ozone layer is severely depleted. New research suggests that if emissions of gases, that deplete the ozone layer, are reduced, it would improve conditions for plants, allowing them to grow faster and absorb more carbon dioxide (Unger et al., 2020).

Wild animals are also vulnerable to the air pollution (Malhi et al., 2020). Air pollution affects wildlife by entering into the food chain and damaging food supplies (Kamble, 2011).

It can be noted that greenhouse gas emissions have twofold consequences: they affect human health and the environment. Emissions from the transport sector threaten air quality and public health. At the same time, these emissions are contributing to the rapid deterioration of the environment and to climate change, which is a growing global concern. Recognizing the importance of this dual challenge, it is evident that promoting the sustainable development of the transport sector is not just a choice but a necessity. A balance that allows for continued economic growth while mitigating negative impacts on human health and the environment is an ethical and pragmatic path to sustainable development.

Researchers use a variety of strategies to select sustainability indicators. There are researchers who group indicators according to sustainability dimensions (Mathrani et al., 2023; Karobliene & Pilinkiene, 2021). Another possible model for measuring sustainable development is the environmental, social and governance (ESG) approach (Du Rietz, 2018; Taliento et al., 2019). Companies monitor and analyze ESG in order to make the right investment decision. ESG factors help to identify the environmental and societal impacts of companies, and identify how ESG policies can affect a company's resilience and profitability (Ouni et al., 2020). The assessment of ESG factors enables the identification of prevailing problems in a company and the protection against risks. Moreover, the identification of ESG factors provides an opportunity for further development of sustainability, such as the implementation of the Green Deal or environmental standards. ESG is driving companies to embrace digitalization, a comprehensive programme that affects all business processes, including transport (Du Rietz, 2018). The digitization of transport allows for faster and more efficient performance of certain functions and is more environmentally friendly.

Several EU documents on transport sustainability also refer to certain indicators. For instance, OECD reports show that different countries use different indicators to measure sustainable development. However, by monitoring commonly accepted standard indicators, they can produce comprehensive sustainability monitoring reports that aim to measure and demonstrate progress more effectively. The European Commission's (2021) Sustainable and Smart Mobility Strategy sets out a roadmap for action to guide European transport towards a sustainable and smart future. To turn the vision into reality, 10 priority initiative areas and an action plan have been identified to guide work in the coming years.

It is important to underline that the EU has identified energy consumption and the share of GDP generated by the transport sector as key common indicators for sustainable transport. However, relying on these two indicators alone does not allow for a holistic assessment of transport sustainability. The diversity of EU countries, including factors such as geography, natural resources, governance and economic policies, means that a tailored set of indicators must be adopted to measure sustainability.

Daimi & Rebai (2023) remark that environmental sustainability is the most common topic in the transport sustainability literature, focuses on reducing the consumption of energy and natural resources, optimizing the use of renewable alternatives and reducing the release of harmful air pollutants into the environment. Chatti & Majeed (2022) claim, that the passenger transportation activity can affect environmental sustainability with regard to carbon emission reductions.

Summary of the possible sets of indicators developed under the dimensions of sustainable development is presented in Table 1.

**Table 1.** Indicators of sustainable development.

| Indicators of Environment | Indicators of Economic Development | Indicators of Social Development |
|---|---|---|
| Greenhouse gases emitted into the atmosphere;<br>Amounts of other pollutants emitted into the atmosphere;<br>Maximum annual average concentrations of some pollutants in urban air;<br>Use of renewable energy sources;<br>Use of multi-modal transport | Labour productivity in the transport sector;<br>Share of GDP generated by the transport sector;<br>Energy consumption in the transport sector;<br>Number of passenger cars per 1000 inhabitants;<br>Share of old cars in the transport sector;<br>Comparison of cargo turnover with GDP. | Number of accidents per year;<br>Number of people killed in traffic accidents per year;<br>Number of people injured in traffic accidents per year;<br>Digital business systems to monitor drivers' work/rest balance. |

De Souza et al. (2018), Nouni et al. (2021) identified types of national vehicles, conducted experiments, evaluated and compared the environmental impact of vehicles in the Brazilian and Indian context. Brynolf et al. (2022) in their study examines the planned e. fuel options for each transport mode, transport unit cost (e.g. vehicle km) and carbon mitigation costs, evaluates and compares with conventional options and highlights prospects and challenges.

It should be noted that when examining the sustainability of transport, scientific publications often distinguish between the modes of transport: road (light and heavy), maritime, air, and a number of indicators corresponding to these modes. According to Our World in Data (2020), road transport (cars and trucks) is the largest contributor to $CO_2$ emissions, accounting for 74.5% of total transport emissions. Compares with air transport (11.6%) and maritime transport (10.6%) rail transport is one of the most sustainable modes of transport, accounting for just 1% of total $CO_2$ emissions from the transport sector. Rigogiannis et al. (2023) systematically examined methodologies and strategies aimed at mitigating fuel consumption and minimizing greenhouse gas emissions. The authors categorized these approaches into vehicular and non-vehicular domains,

thereby offering valuable insights into the potential for fostering a more environmentally sustainable future within the realm of road transport.
In conclusion, a lot of factors must be taken into account when assessing the sustainability of the transport system. However, environmental sustainability is at the core of transport. This means making a focused effort to reduce energy consumption, promote the use of renewable resources and, in particular, reduce air emissions, with a particular focus on reducing carbon dioxide, which is a key factor in climate change. Passenger transport plays an important role in environmental sustainability and has a significant impact on carbon dioxide emissions. In terms of environmental impact, road transport is the most polluting mode of transport, followed by air and maritime transport. In contrast, rail transport is a more environmentally friendly mode of transport as its emissions are significantly lower.

# Data and Methodology

## *Data*

This section sets out the basic framework on which the research is based. It describes the data sources, research methodologies and tools used to investigate transport sustainability. This section provides the basis for further discussion and conclusions, ensuring the reliability of the research. The data in Table 2 have been carefully compiled from the Eurostat (*Eurostat,* 2021) and Statista (*Statista*, 2022) databases.

Aligned with the directives outlined in European Union documents, which advocate the utilization of sustainable development indicators, and recognizing the substantial contribution of the transport sector to carbon dioxide ($CO_2$) as a greenhouse gas, research design has identified the dependent variable, denoted as (Y), as the quantification of greenhouse gas emissions in EU member countries for the year 2021. This selection of (Y) serves as a key measure for evaluating the overall sustainability of the region's transport systems. The independent variables (X1–X9) encompass a set of transport-related indicators tailored to EU countries with a pronounced influence on $CO_2$ emissions and air pollution during the year 2021. These indicators include: the quantity of registered automobiles (X1), the volume of road-borne freight transport (X2), the count of rail passengers (X3), the quantity of rail-borne freight transport (X4), the number of air passengers (X5), the volume of air cargo shipments (X6), the quantity of maritime cargo transport (X7), the number of gasoline-powered automobiles (X8), and the number of diesel-powered automobiles (X9), as detailed in Table 3.

**Table 2.** Primary research data.

| Country | Greenhouse gas emissions | Cars per 1000 inhabitants | Amount of freight transported by road | Passengers transported by rail | Rail freight transported | Passengers transported by air | Air cargo shipments | Cargo transported by sea | Petrol cars | Diesel cars |
|---|---|---|---|---|---|---|---|---|---|---|
| Austria | 9,3 | 562 | 402083 | 12761 | 102835 | 35644188 | 237701 | 4125 | 1520965 | 3459035 |
| Belgium | 10,6 | 511 | 283945 | 9621 | 36922 | 35385188 | 1416428 | 277783 | 2812061 | 3014455 |
| Bulgaria | 8,1 | 407 | 114574 | 1520 | 14226 | 11713068 | 29867 | 30997 | 1742365 | 1057635 |
| Croatia | 6 | 425 | 81125 | 724 | 9985 | 10623239 | 11934 | 20580 | 743923 | 913400 |
| Czech Republic | 11,7 | 554 | 504099 | 10856 | 98034 | 18832696 | 90526 | 6521 | 3475194 | 2313009 |
| Denmark | 8,1 | 455 | 167747 | 6174 | 9383 | 34780127 | 242068 | 93727 | 1813814 | 822181 |
| Estonia | 11,2 | 598 | 28373 | 392 | 25364 | 3258003 | 11475 | 37760 | 477238 | 314979 |
| Finland | 10,1 | 642 | 270462 | 4924 | 36162 | 23287929 | 196810 | 120488 | 2603521 | 927011 |
| France | 6,8 | 482 | 163494 | 98360 | 89107 | 16872678 | 2407878 | 302288 | 1160136 | 2047393 |
| Germany | 10,1 | 574 | 320823 | 100252 | 350105 | 22676408 | 4842716 | 294533 | 3146468 | 1511138 |
| Greece | 8,4 | 504 | 354081 | 1252 | 1094 | 56088527 | 96889 | 194468 | 4528248 | 2264123 |
| Hungary | 6,7 | 390 | 202631 | 8563 | 50047 | 16700750 | 101411 | 5523 | 2529572 | 1199155 |
| Ireland | 12,8 | 454 | 158396 | 2399 | 581 | 37947510 | 156265 | 53251 | 1949944 | 650056 |
| Italy | 7,2 | 663 | 978883 | 56160 | 92949 | 16066793 | 1066221 | 508074 | 1849054 | 1748613 |
| Latvia | 6,1 | 381 | 73755 | 643 | 47819 | 7785726 | 24628 | 59046 | 230617 | 447491 |
| Lithuania | 7,4 | 536 | 100802 | 359 | 47651 | 6504685 | 16779 | 52244 | 367626 | 1016229 |
| Luxembourg | 20,3 | 681 | 55303 | 463 | 4482 | 4365569 | 895004 | 3256 | 182337 | 237641 |
| Netherlands | 11,1 | 499 | 688837 | 11230 | 42615 | 81192507 | 1840419 | 607527 | 7230119 | 1212934 |
| Poland | 10,4 | 642 | 150645 | 21834 | 222523 | 46942771 | 134673 | 93864 | 1281076 | 7622695 |
| Portugal | 6,6 | 530 | 155866 | 5055 | 10259 | 55007894 | 173493 | 85320 | 2358356 | 3060655 |
| Romania | 5,9 | 357 | 256641 | 5735 | 52618 | 21546204 | 45310 | 53101 | 3653648 | 3233944 |
| Slovakia | 7,4 | 439 | 187184 | 3957 | 47548 | 2839787 | 24565 | 7894 | 1256874 | 1912313 |
| Slovenia | 8,2 | 556 | 91775 | 572 | 18595 | 1719039 | 12337 | 22114 | 568597 | 577772 |
| Spain | 7,1 | 519 | 154211 | 28702 | 26504 | 22718901 | 806518 | 496912 | 1092429 | 1351460 |
| Sweden | 5,2 | 473 | 449362 | 14617 | 67479 | 37614259 | 158632 | 170557 | 2868708 | 1744512 |

These variables have been chosen to construct a robust analytical framework and acknowledging their pivotal roles in assessing the environmental consequences of the transportation sector. These indicators are essential tools for measuring the impact of different strategies and policies aimed at improving the environmental performance and overall sustainability of transport systems.