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THE FUTURE OF TRANSPORT: SUSTAINABILITY AND INNOVATIVE POLICIES IN THE EUROPEAN UNION

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ABSTRACT

While road transportation contributes significantly to economic growth, it causes serious problems in terms of environmental sustainability. This study examines the environmental and economic impacts of road transportation in European Union countries within the framework of sustainable development. The study consists of three stages: theoretical framework, literature review and data analysis. In the theoretical part, the environmental impacts of transportation systems and economic sustainability are discussed. The literature review includes the evaluation of the findings from existing research. In the analysis using Eurostat data, greenhouse gas emissions, energy consumption and economic contributions of road transport are analyzed graphically. The results show that fossil fuels are still widely used, but the transition to renewable energy and the spread of electric vehicles in some countries have had positive effects. In terms of economic sustainability, environmental taxes vary across countries and investments in environmental protection support economic growth. The study provides policy recommendations for aligning road transport with sustainable development goals.

***Keywords:**: Road Transportation, Sustainable Development, Economic Sustainability, Greenhouse Gas Emissions*

***Jel Codes:**: R41, Q01, Q56, Q53*

TAŞIMACILIĞIN GELECEĞİ: AVRUPA BİRLİĞİ'NDE SÜRDÜRÜLEBİLİRLİK VE YENİLİKÇİ POLİTİKALAR

ÖZ

Karayolu taşımacılığı, ekonomik büyümeye önemli katkılar sağlarken, çevresel sürdürülebilirlik açısından ciddi sorunlara yol açmaktadır. Bu çalışma, Avrupa Birliği ülkelerinde karayolu taşımacılığının çevresel ve ekonomik etkilerini sürdürülebilir kalkınma çerçevesinde incelemektedir. Çalışma, teorik çerçeve, literatür incelemesi ve veri analizi olmak üzere üç aşamadan oluşmaktadır. Teorik kısımda, taşıma sistemlerinin çevresel etkileri ve ekonomik sürdürülebilirlik ele alınmıştır. Literatür incelemesi, mevcut araştırmalardan elde edilen bulguların değerlendirilmesini içermektedir. Eurostat verileri kullanılarak yapılan analizlerde, karayolu taşımacılığının sera gazı emisyonları, enerji tüketimi ve ekonomik katkıları grafiksel olarak incelenmiştir. Çalışma sonuçları, fosil yakıtların hâlâ yaygın olarak kullanıldığını, ancak bazı ülkelerde yenilenebilir enerjiye geçiş ve elektrikli araçların yaygınlaşmasının olumlu etkiler yarattığını göstermektedir. Ekonomik sürdürülebilirlik açısından, çevresel vergilerin ülkeler arasında farklılık gösterdiği ve çevre koruma yatırımlarının ekonomik büyümeyi desteklediği görülmüştür. Çalışma, karayolu taşımacılığının sürdürülebilir kalkınma hedeflerine uygun hâle getirilmesi için politika önerileri sunmaktadır.

***Anahtar Kelimeler:** Karayolu Taşımacılığı, Sürdürülebilir Kalkınma, Ekonomik Sürdürülebilirlik, Sera Gazı Emisyonları*

***Jel Kodları:** R41, Q01, Q56, Q53*

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1.INTRODUCTION

Road transportation is recognized as one of the most important logistics elements of modern economies. Thanks to its flexibility and wide accessibility, especially in the trade and transportation sector, it contributes significantly to the economic growth of countries. However, this growth also brings serious problems in terms of environmental sustainability. According to European Union (EU) data, road transport accounts for about 20% of total greenhouse gas (GHG) emissions, which contradicts sustainable development goals (Rigogiannis et al., 2023: 768). In this context, the road transport sector should be re-evaluated in a sustainable manner, taking into account its energy consumption and environmental impacts.

EU countries have adopted a number of policies and strategies to reduce the environmental impacts of road transport. In particular, the integration of renewable energy sources into the transport sector and the promotion of low carbon emission vehicles are critical in achieving these goals (Merkisz-Guranowska et al., 2013: 508). However, road transport should be assessed not only for its environmental impacts but also for its economic contributions. For example, the transportation sector supports economic development by accelerating trade flows as well as creating employment (Mayer et al., 2012: 26).Another important issue that needs to be addressed in the context of sustainable transportation is traffic-related noise pollution. This environmental factor has negative impacts on human health, especially in urban areas, and is considered an important parameter in understanding the impact of transportation systems on quality of life (Ongel, 2016: 183).

This paper aims to examine the economic and environmental impacts of road transport in European Union countries within the framework of sustainable development. The study follows a methodology based on theory, literature review and data analysis. First, the theoretical framework explaining the relationship between road transport and sustainable development will be presented. This section will address the concepts of environmental impacts of transportation systems, economic sustainability, and green logistics. Then, the literature on the subject will be analyzed and the findings of existing studies will be evaluated. The third part of the study will include a graphical analysis of the economic and environmental impacts of road transport based on post-2020 data from the Eurostat database. In this analysis, only European Union countries for which data are available are considered. Indicators such as greenhouse gas emissions, energy consumption and economic contributions of road transport will be discussed in detail in the context of sustainable development. This structure allows the study to comprehensively address both theoretical and applied aspects.

2. THEORETICAL FRAMEWORK

Road transport is a dynamic element of modern economies and an important sector that needs to be aligned with environmental sustainability goals. The environmental impacts of transport systems are assessed through various factors such as greenhouse gas (GHG) emissions, energy consumption, air and noise pollution. In the European Union (EU), the transport sector accounts for a significant share of GHG emissions, making it difficult to meet the carbon reduction targets of the Paris Agreement (Rigogiannis et al., 2023: 768). Sustainable transport requires mitigating these environmental impacts while maintaining economic and social contributions.

Sustainable transportation theory envisages that environmental, economic and social dimensions should be considered as a whole. In this context, it is essential to optimize transport systems with environmental solutions such as energy efficiency and integration of renewable energy sources (Merkisz-Guranowska et al., 2013: 508). In particular, the use of hybrid and electric technologies in vehicle engines has the potential to reduce fuel consumption and carbon emissions (Mayer et al., 2012: 27).

In addition to environmental impacts, the economic sustainability of road transport is also of critical importance. Its ability to create jobs, accelerate trade flows and provide cost advantages make it an indispensable element of economic development. However, balancing infrastructure costs and environmental damages is important for economic sustainability goals (Osorio-Tejada et al., 2018: 213).

Noise pollution is another important factor to be considered in the sustainability assessment of road transportation. Noise has both negative impacts on human health and reduces the overall quality of life. In this context, the inclusion of noise impacts in the environmental performance of transportation systems enables sustainability goals to be addressed in a broader perspective (Ongel, 2016: 184).

3. LITERATURE REVIEW

Road transportation is an area that has been extensively studied in terms of economic and environmental sustainability. The literature focuses particularly on environmental impacts, economic contributions and solutions for the development of sustainable transportation systems. Studies have enriched the theoretical and applied contributions in this field by addressing different aspects of transportation from past to present. The literature is listed below in this context.

Early studies focused on the environmental impacts of road transportation and examined the consequences of these impacts on human health. Osuntogun and Koku (2007) highlighted the negative impacts of road transport on air pollution and environmental degradation, especially in urban areas. The research is one of the rare studies in which air pollution, noise pollution and traffic density are evaluated together. Similarly, Chauhan et al. (2008) assessed the impacts of greenhouse gas emissions from road transportation on climate change and emphasized the importance of emission control policies to mitigate these impacts.

In 2009, Basbas et al. analyzed the economic cost of negative impacts such as traffic accidents and noise pollution caused by road transport and stated that these costs constitute a serious obstacle to achieving sustainable development goals. Castellano et al. (2010) emphasized that energy efficiency and the use of environmentally friendly fuels are key to sustainability in road transport.

Macias and Gadziński (2013) compared the level of adoption of sustainable transport policies in EU countries and discussed the impact of innovative traffic management solutions in reducing emissions. Merkisz-Guranowska et al. (2013) proposed that both environmental and economic benefits can be increased by regulating traffic flow and optimizing infrastructure. Karlson et al. (2014) discussed the application of energy efficiency technologies to reduce environmental impacts in the transportation sector.

Ongel (2016) considered noise pollution from transportation from a life cycle assessment (LCA) perspective and examined the long-term consequences of these impacts on human health. He stated that noise pollution should be considered more in studies assessing the environmental impacts of the transportation sector. Condurat et al. (2017) showed that restructuring transportation systems for environmental sustainability has great potential to reduce carbon emissions.

Folęga and Burchart-Korol (2017) analyzed the impacts of road transport on economic sustainability and discussed ways in which infrastructure investments can support economic growth while minimizing environmental impacts. Osorio-Tejada et al. (2018) focused on freight transport in the EU and discussed ways to reduce energy consumption and minimize greenhouse gas emissions.

Othman et al. (2019) examined traffic management models for reducing environmental impacts and highlighted the potential of these models to reduce carbon emissions, especially in urban areas. Wang (2019) evaluated the sustainability of transportation systems by considering environmental impacts and safety factors together. The study argues that sustainable transportation policies should be evaluated from both safety and environmental perspectives.

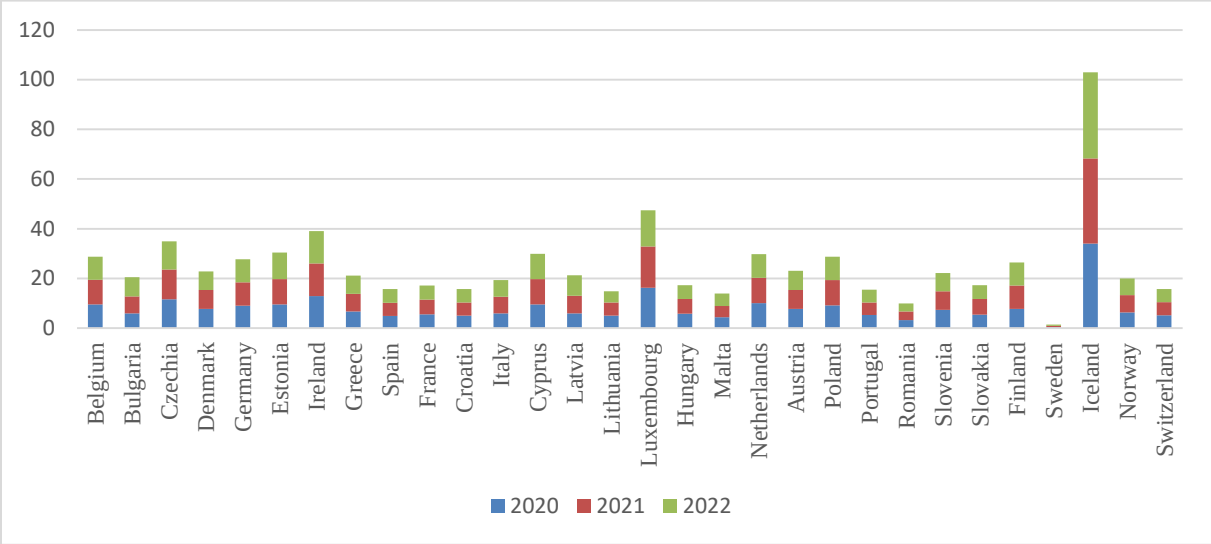
Mavrin et al. (2020) stated that the widespread adoption of electric and hybrid vehicles is an important step towards environmental sustainability. However, the costs and infrastructure needs of these technologies pose significant barriers to widespread use. Rigogiannis et al. (2023) analyzed the EU's efforts to integrate renewable energy sources into the transport sector and the challenges faced by this process. In conclusion, studies in the literature show that road transport has the potential to achieve environmental and economic sustainability goals. However, in order to achieve these goals, policies that balance both innovative solutions for reducing environmental impacts and economic contributions should be developed.

4. ENVIRONMENTAL SUSTAINABILITY

4.1. Net Greenhouse Gas Emissions

Road transport is a significant source of net greenhouse gas (GHG) emissions, which points to a critical challenge in the fight against global climate change. In the European Union, this sector accounts for more than 20% of total emissions (Rigogiannis et al., 2023). Carbon dioxide (CO_2) emissions in particular stand out as a result of the use of vehicles based on fossil fuels. In this context, strategies such as electric vehicles and the integration of renewable energy sources have been developed to reduce emissions (Mavrin et al., 2020).

Graph 1: Net Greenhouse Gas Emissions (Tonnes Per Capita)



Source: https://ec.europa.eu/eurostat/web/main/data/database

From Graph 1, it is clear that net greenhouse gas emissions per capita in European countries between 2020, 2021 and 2022 show different trends. While the graph reveals important differences between countries, it also shows that trends in certain countries stand out in a striking way. First, data for 2020 are generally lower than in other years. This can be attributed to the impact of the economic slowdown caused by the COVID-19 pandemic. Especially in Sweden, greenhouse gas emissions have increased significantly compared to other countries. In 2022, Sweden's emission level reached a very high level of around 100 tons per capita, while in other countries this value was generally below 20 tons. This suggests that energy-intensive sectors in Sweden's economic structure or transportation policies may have had a boosting effect on emissions during this period.

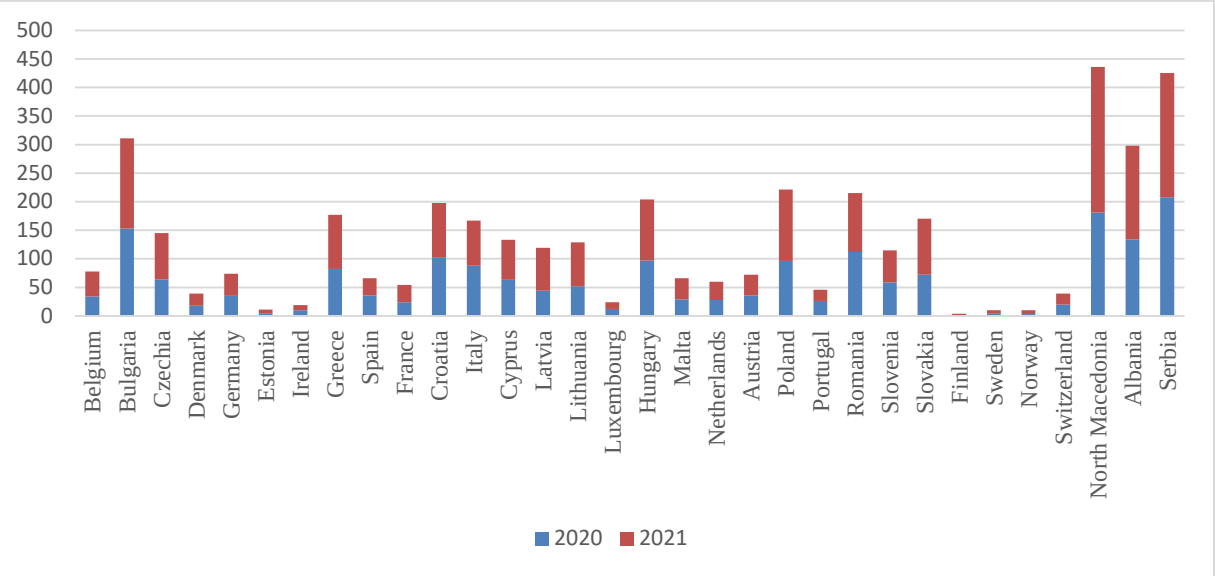
Another remarkable country is Luxembourg. While Luxembourg had a high initial level in 2020 compared to other countries, the rate of increase in emissions in the following years remained relatively limited. This may indicate that the energy efficiency policies implemented in the country were partially effective. However, it should be noted that Luxembourg's per capita emissions are still above the European average. In Eastern European countries such as Bulgaria, Romania and Hungary, emissions have remained at consistently low levels over the years. It can be concluded that the industrial structure and energy consumption patterns in these countries may be less carbon intensive than in other Western European countries.

Finally, it is observed that in 2021, emissions in some countries show a slight increase, while in others they remain stable. These differences can be explained by the diversity in energy policies implemented by countries in their post-pandemic economic recovery processes. For example, countries such as Germany and Denmark may have continued their carbon-reducing policies, while in other countries, growth in sectors that may cause an increase in emissions was observed in parallel with increased energy demand.

4.2. Mortality due to Fine Particulate Matter

Air pollution is one of the most serious impacts of road transportation on human health. In particular, fine particulate matter (PM2.5) causes serious health problems such as lung and heart disease, leading to premature deaths. In EU countries, the health impacts caused by PM2.5 levels account for tens of thousands of premature deaths annually (Osorio-Tejada et al., 2018). These particles are mainly produced by the combustion of fossil fuels and levels are higher in high traffic areas.

Graph 2: Premature Deaths Due to Exposure to Fine Particulate Matter (%)



Source: https://ec.europa.eu/eurostat/web/main/data/database

It is noteworthy that Graph 2 shows that the impact of exposure to fine particulate matter (PM2.5) on premature mortality varies over the years in different countries. The data for 2020 and 2021 reveal large differences between countries, while at the same time strikingly reflecting the direct impact of environmental risks on health. At first glance, it is striking that Balkan countries such as North Macedonia and Serbia are at high risk of premature mortality due to PM2.5 exposure. In 2021, the premature mortality rate in North Macedonia reached around 450 persons/million, while in Serbia it was closer to 400 persons/million. These levels are quite high compared to Western European countries, indicating that air quality in these countries needs to be addressed as a serious public health issue. On the other hand, these data point to the devastating health impacts of the widespread use of fossil fuels in energy production and limited environmental regulation.

Countries showing lower values include Ireland, Norway and Switzerland. For example, in 2021, Ireland's premature mortality rate was below 50 people/million. This shows that environmentally friendly energy policies and strict regulations to protect air quality are effective in these countries. Moreover, the generally lower values in Northern European countries can be interpreted as a finding supporting the positive impact of investments in green energy on public health.

Comparing 2020 and 2021, a significant increase in premature deaths due to PM2.5 exposure was observed in most countries. This increase can be attributed to increased activity in the industrial and transportation sectors as the economy recovers. This trend is particularly clear in countries such as Italy and Poland. While premature mortality in Italy was around 150 persons/million in 2020, it exceeded 200 persons/million in 2021. A similar upward trend was recorded for Poland.

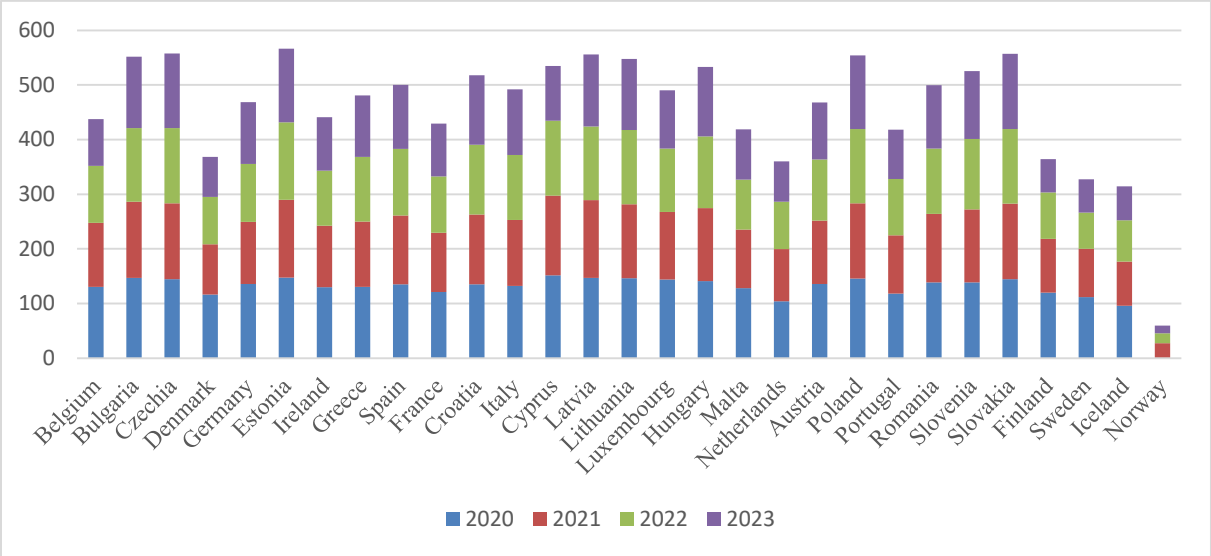
4.3. CO_2 Emissions from New Passenger Vehicles

In recent years, the carbon footprint of passenger vehicles has been at the center of sustainable transportation policies. The average CO2 emissions per kilometer produced by newly manufactured vehicles are considered as an important indicator in this context. Makarova et al. (2020) found that carbon reduction technologies in vehicle production have become increasingly widespread and have

significantly reduced emissions. However, despite these improvements, the overall increase in vehicle use complicates efforts to limit overall carbon emissions.

Graph 3 provides an important indicator for assessing the environmental impact of new passenger vehicles in European countries. It provides a detailed picture of the trends in the average carbon emissions per kilometer of new passenger vehicles over the four-year period from 2020 to 2023. In particular, analyzing each year separately allows us to compare countries' environmental performance and their success in achieving their sustainability goals.

Graph 3: Average CO2 Emissions Per Km from New Passenger Cars (Grams Per Kilometre)



Source: https://ec.europa.eu/eurostat/web/main/data/database

Overall, the graph reveals a certain downward trend in the carbon emissions of European countries. However, this reduction has occurred at different speeds from country to country, with slower progress in some countries. For example, although countries such as Germany and Poland have made a significant improvement in reducing carbon emissions by 2023, the emissions per kilometer of vehicles in these countries are still higher than in many Western European countries. Germany has an emission level of around 400 grams/km in 2020, falling to below 300 grams/km in 2023. This could be a result of Germany's investments in green engine technologies.

On the other hand, Norway, one of the Northern European countries, has consistently stood out as one of the countries with the lowest carbon emission values since 2020. In particular, it was observed that it reached almost zero level in 2023. This clearly reflects the success of Norway's policies encouraging the use of electric vehicles. Factors such as the high share of electric vehicles in total vehicle sales and the expansion of charging infrastructure have played a key role in Norway's radical reduction of carbon emissions.

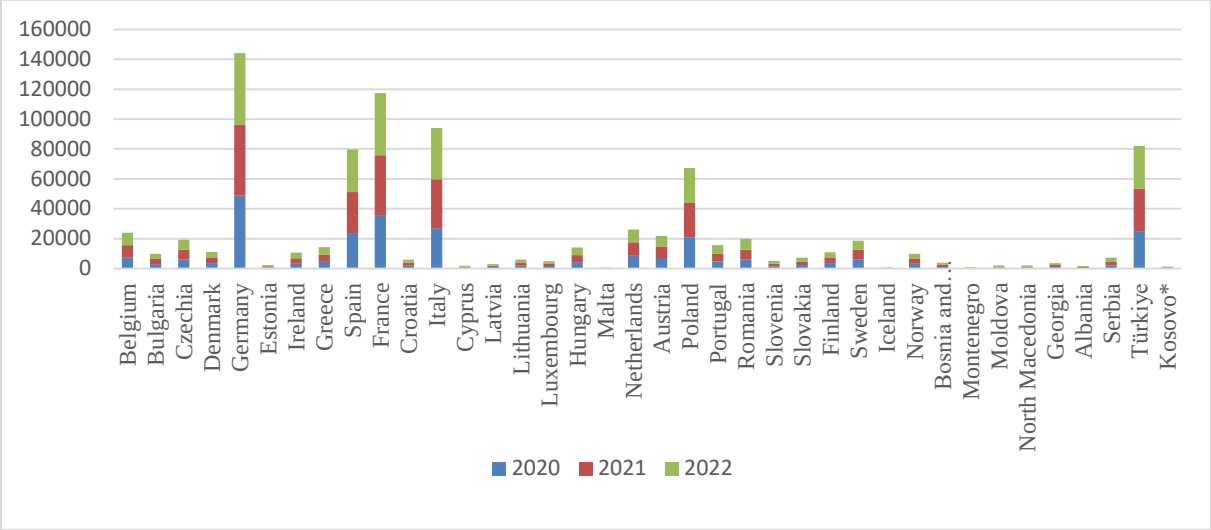
By 2023, countries such as Luxembourg, Denmark and Sweden have also achieved significant reductions in carbon emissions. While Luxembourg's emission level was around 450 grams/km in 2020, this value dropped below 350 grams/km in 2023. Sweden, on the other hand, has a level of just over 300 grams/km in 2020, and approaches the 200 grams/km limit in 2023. This trend reflects these countries' efforts to create a more sustainable transportation sector by increasing sales of electric and hybrid vehicles.

4.4. Final Energy Consumption in Road Transportation

Energy consumption in road transportation varies greatly in terms of environmental impacts depending on the type of fuel used. Systems that predominantly use fossil fuels cause high carbon emissions, while transportation systems based on renewable energy sources significantly reduce this impact. Othman et al. (2019) argue that energy efficiency and the diffusion of alternative fuels in the transportation sector is a fundamental solution to achieve sustainable energy consumption targets.

Graph 4 shows the energy consumption for road transport in different countries between 2020 and 2022, and how this consumption varies by fuel type. The graph provides important clues for understanding country differences in energy consumption and trends over time. In particular, countries such as Ireland and Turkey show very high levels of energy consumption in road transport compared to other countries. In Ireland, total energy consumption reaches around 140 thousand TOE in 2022, while in Turkey it is around 120 thousand TOE. This can be attributed to rapid economic growth and increasing transportation demand in both countries.

Graph 4: Final Energy Consumption in Road Transport by Type of Fuel (Total-Thousand Tonnes of Oil Equivalent)



Source: https://ec.europa.eu/eurostat/web/main/data/database

Western European countries, such as Germany and Belgium, have shown a more balanced energy consumption trend. Germany's energy consumption in 2022 is around 30 thousand TOE, which is close to the European average. This may reflect Germany's energy efficiency policies and efforts to switch to alternative fuel types. On the other hand, Eastern European countries and the Balkans are characterized by lower energy consumption values. For example, energy consumption in North Macedonia and Albania remains below 10 thousand TOE even in 2022. This can be explained by the limited economic activity in these countries and the low level of road transport.

5. ECONOMIC SUSTAINABILITY

Economic sustainability refers to the stability of economies in the process of achieving environmental and social goals. Indicators such as investments in environmental protection, environmental taxes and climate-related economic losses play a key role in achieving sustainable development goals. Othman et al. (2019) argue that investments in environmental protection serve as a bridge linking economic growth and environmental sustainability. Moreover, Chauhan et al. (2008) argue that environmental taxes are an important source of financing sustainable projects while helping to offset the costs of environmental damage.

In the European Union, economic sustainability indicators vary from country to country, which is directly related to the effectiveness of policies and the breadth of their implementation. Rigogiannis et al. (2023) emphasize that renewable energy and green investments are important components of economic sustainability. In this framework, assessing the long-term effects of environmental investments and tax policies is important for the EU's sustainable development strategies.

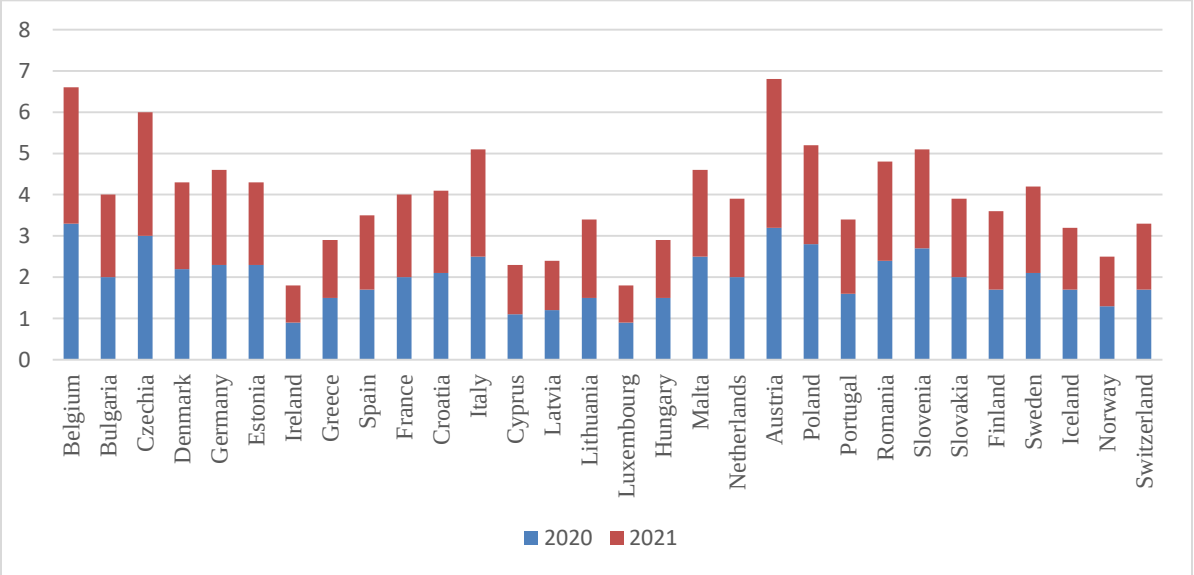
5.1. Expenditures for Environmental Protection

Environmental protection spending is an important financial indicator that reflects countries' commitment to achieving their environmental sustainability goals. These expenditures are usually directed towards areas such as waste management, air quality improvement, biodiversity conservation and renewable energy projects. Wang (2019) emphasizes that environmental protection spending has a

direct impact on targets such as emission reduction and resource efficiency. Moreover, Othman et al. (2019) argue that environmental expenditures are actually an element of economic sustainability by demonstrating the positive effects of such expenditures on economic growth.

Graph 5 shows the share of environmental protection expenditures in countries' GDP for 2020 and 2021. In 2021, Austria and Belgium are among the leading countries in spending on environmental protection. Austria's spending reaches around 7% of GDP, outpacing other European countries. This shows that Austria attaches importance to environmental policies and makes environmental sustainability a priority. Similarly, in Belgium, this ratio hovered around 6%, well above the European average.

Graph 5: National Expenditure on Environmental Protection(%GDP)



Source: https://ec.europa.eu/eurostat/web/main/data/database

In contrast, Baltic countries such as Latvia and Lithuania allocate a lower proportion of GDP to environmental protection spending. In these countries, the share was below 2% in 2021. This suggests that environmental spending may be limited in these countries and that environmental protection priorities are less relevant due to economic pressures. Another noteworthy aspect is that Western European countries show a stable trend in environmental spending. Countries such as Germany and France have kept their environmental protection spending at around 4% of GDP in 2020 and 2021. This shows that these countries are committed to environmental sustainability.

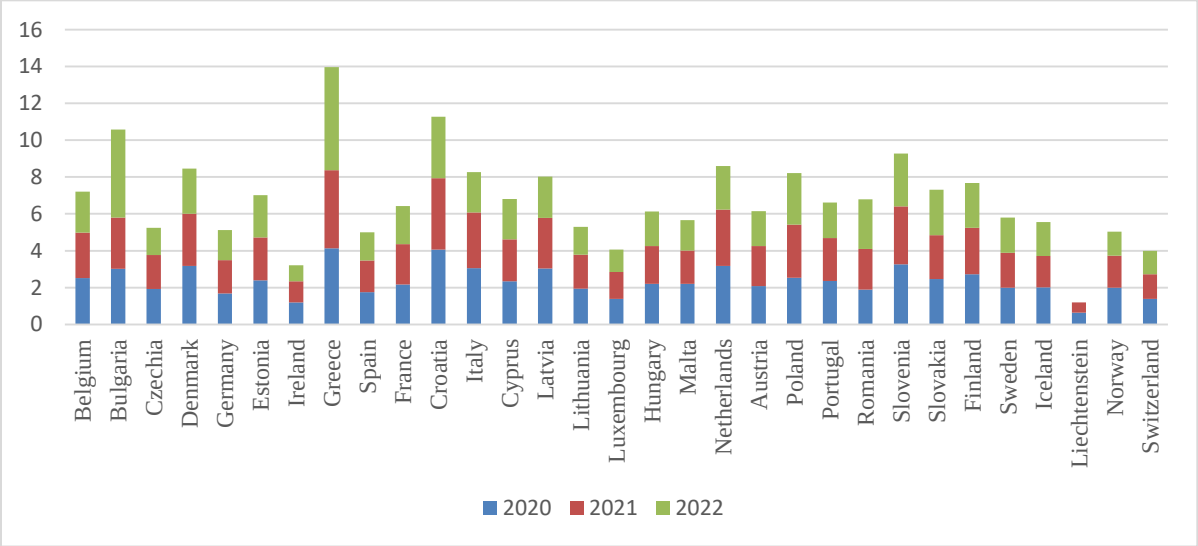
5.2. Environmental Tax Revenues

Environmental taxes stand out as an effective financing tool for reducing environmental damage within the framework of economic sustainability. These taxes aim to reduce environmental impacts such as carbon emissions, energy consumption and waste management, while at the same time providing governments with financial resources to support environmental projects. Rigogiannis et al. (2023) emphasized that environmental taxes are an important instrument that combines both economic and environmental sustainability. Moreover, Osorio-Tejada et al. (2018) argue that such taxes offer an effective mechanism to steer consumers towards more environmentally friendly options.

Graph 6 shows the ratio of environmental tax revenues to GDP in European countries in 2020, 2021 and 2022. This graph provides important data to compare the extent to which countries allocate financial resources to environmentally friendly policies and the impact of environmental taxes on economies. When the graph is analyzed, Greece is the leader in the ratio of revenues from environmental taxes to GDP in 2022. This ratio, which reaches approximately 14%, is quite high compared to other European countries. This shows that Greece imposes high environmental taxes to combat environmental pollution and that these taxes have an important place in the economic structure.

Among Western European countries, countries such as Italy and the Netherlands have shown a steady upward trend in revenues from environmental taxes. While Italy increased the ratio of environmental taxes to GDP to over 8% in 2022, in the Netherlands this ratio was around 7%. This trend demonstrates that these countries are effectively using economic instruments to support environmental sustainability. In Eastern European countries such as Bulgaria and Romania, the ratio of environmental tax revenues to GDP has generally hovered around 3-4%. This shows that environmental taxes are less integrated into the economic structure in these countries. The limited fiscal impact of environmental policies in these countries indicates that these countries need to support environmental protection policies with more financial resources.

Graph 6: Environmental Tax Revenues (%GDP)

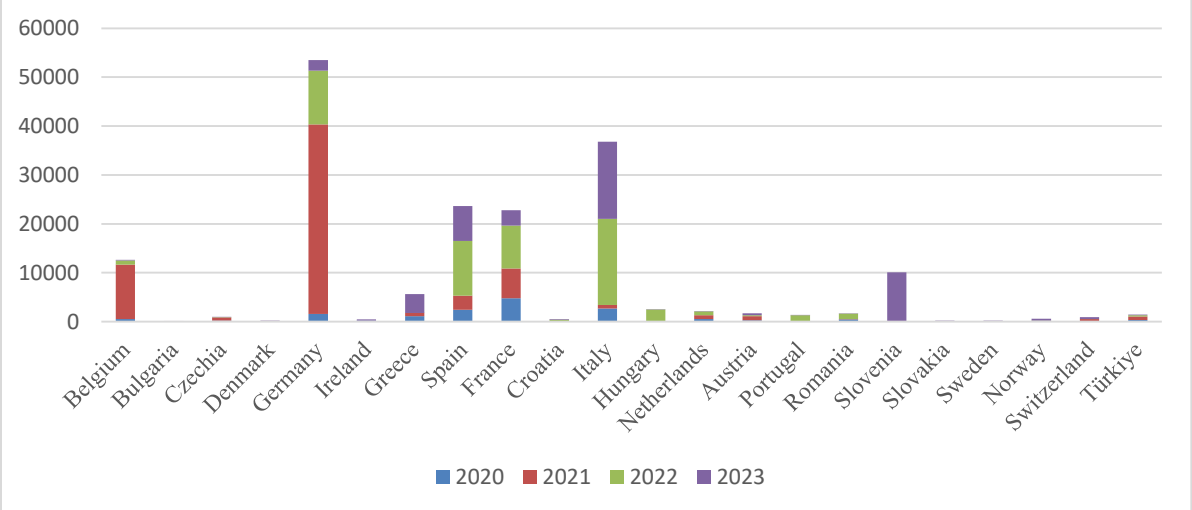


Source: https://ec.europa.eu/eurostat/web/main/data/database

5.3.Climate-related Economic Losses

In recent years, the economic impacts of climate change have been at the center of sustainable development efforts. Disasters such as extreme weather events, forest fires, droughts and floods create huge financial burdens on economies. Osuntogun and Koku (2007) emphasized that such events have profound impacts not only on the environment but also on social and economic sustainability. Managing these impacts is possible by building resilient infrastructures and developing policies to mitigate climate-related risks.

Graph 7: Climate-Related Economic Losses (Values at Constant 2022 Prices)



Source: https://ec.europa.eu/eurostat/web/main/data/database

Graph 7 shows climate-related economic losses in European countries between 2020 and 2023 at constant 2022 prices. The graph provides an important comparison to understand how the economic impacts of climate change differ across countries. Germany is particularly notable for its losses in 2021. In 2021, Germany's climate-related economic losses amounted to around €50,000 million. This reflects the impact on the economy of the extreme rainfall and floods that occurred in Germany that year. Since Germany's losses are higher than all other European countries combined, this year highlights the need for stronger policies to tackle climate change in the country. Italy is another country that stands out with increasing economic losses in 2023. Climate-related losses have increased from low levels in 2020 to close to €30,000 million in 2023. This increase could be the result of increased heat waves, droughts and declines in agricultural production.

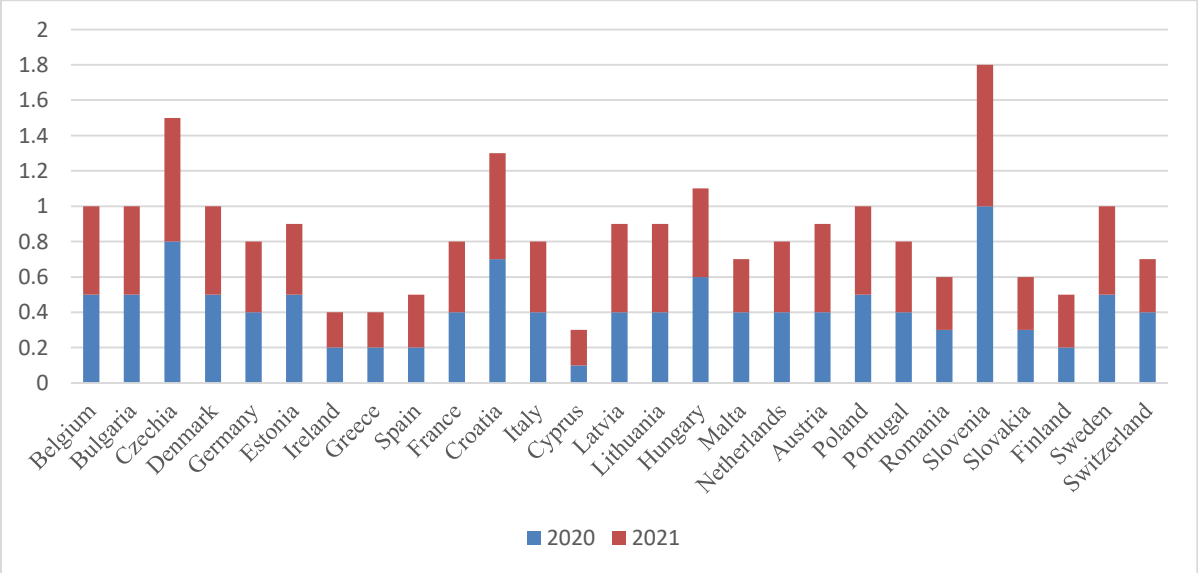
Other Western European countries, notably France and Spain, have shown a more stable trend in terms of climate-related economic losses. Spain stands out with losses reaching around €10,000 million in 2023. A similar level of losses has been observed in France, but the rate of increase of these losses is more limited than in other countries. In countries such as Eastern European countries and Turkey, climate-induced economic losses remained at very low levels. Turkey's losses in this period were below EUR 1,000 million, indicating that the process of climate change impacts turning into direct costs is more limited in these regions. However, it should be noted that these low values may be due to limitations in measuring impacts or the low sensitivity of economic activities to climate risks.

5.4. Environmental Protection Investments of the Total Economy

Environmental protection investments are critical for economic activities to undergo a sustainability-oriented transformation. These investments are directed towards areas such as waste management, clean energy projects, biodiversity conservation and carbon reduction, contributing to solving environmental problems. Wang (2019) argues that environmental protection investments not only support the achievement of environmental goals, but also contribute to economic growth in the long run.

Graph 8 shows the ratio of environmental protection investments to GDP in European countries in 2020 and 2021. This graph provides an important dataset for understanding the place of investments in environmental sustainability in the economic structure and the differences between countries. Slovakia performed remarkably well in terms of investments in environmental protection in 2021, increasing its investments to around 1.8% of GDP. This shows that Slovakia has made a serious financial commitment to support environmental sustainability goals and is one of the leading countries in Europe in this area. The high investment rate may be due to spending on renewable energy, waste management and water resources protection projects.

Graph 8: Environmental Protection İnvestments of Total Economy (% GDP)



Source: https://ec.europa.eu/eurostat/web/main/data/database

Bulgaria was also among the countries with a significant increase in environmental investments. In 2020, the share of environmental protection investments in GDP was below 1%, while in 2021 it increased to 1.4%. This increase can be attributed in particular to the impact of infrastructure development projects and anti-pollution programs. Among Western European countries, Germany has maintained a stable level of investment in environmental protection as a percentage of GDP. In 2021, this ratio was around 0.8%. Although in advanced economies such as Germany, this ratio seems to be relatively lower, the total amount of investments is quite high compared to other countries. This may indicate that Germany is spending more efficiently and on a large scale on environmental projects.

6. TRANSPORTATION AND SAFETY

Transport and safety are two important dimensions that affect the environmental and economic sustainability of road transport systems. Indicators such as traffic accidents by road type, the share of buses and trains in public transport, and goods transport by road provide information on the efficiency, environmental impacts and safety of transport systems. Basbas et al. (2009) argue that traffic accidents are directly related to road infrastructure and driver behavior and that traffic management policies should be strengthened to reduce accidents. Moreover, Osorio-Tejada et al. (2018) argue that environmentally friendly planning of public transportation systems can improve both traffic safety and energy efficiency.

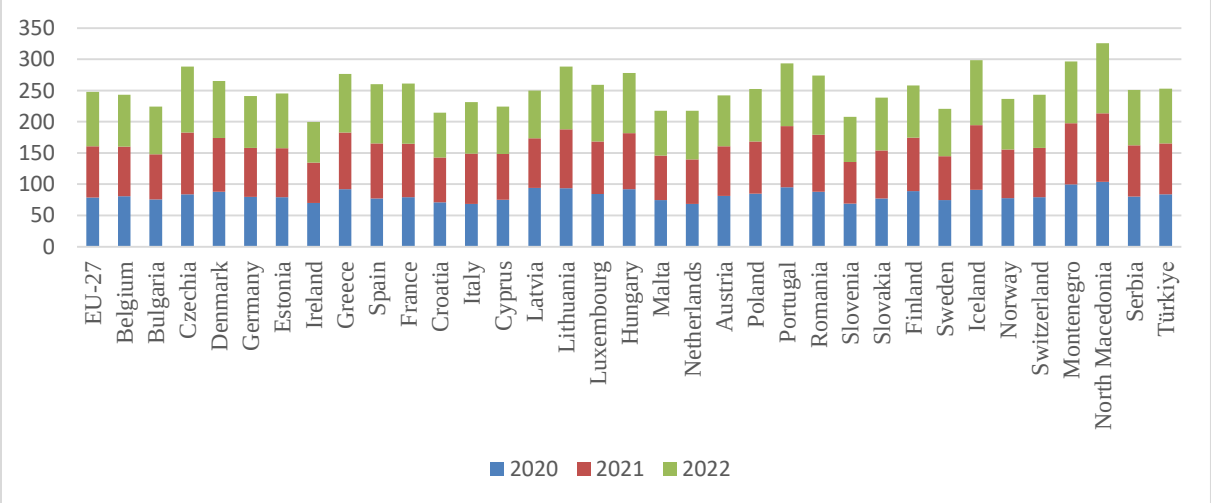
Transportation and safety indicators in European countries vary depending on the geographical characteristics, infrastructure levels and transportation policies of the countries. Ongel (2016) emphasizes that the expansion of public transport systems is an effective solution to reduce urban traffic congestion and environmental impacts. In this context, it is crucial for European Union countries to increase investments in sustainable infrastructure and implement environmentally friendly policies to improve transportation and safety indicators.

6.1. Passenger Transportation Volume as a percentage of GDP

Passenger transportation is an important indicator of economic growth and social mobility. The volume of passenger transport as a percentage of GDP provides information on the intensity of a country's economic activity and the efficiency of its transport infrastructure. Merkisz-Guranowska et al. (2013) argue that passenger transport volume is a reflection of the economic growth potential of countries and is directly linked to transport investments. Moreover, Osorio-Tejada et al. (2018) draw attention to the positive effects of the preference for public transport and environmentally friendly systems in the transport sector on economic sustainability.

Passenger transport data as a percentage of GDP provides an important indicator to measure the level of development of countries' transport sectors and the success of sustainable transportation policies. In particular, increasing investments in public transport and promoting innovative transport solutions can contribute to aligning this indicator with environmental and economic sustainability.

Graph 9: Volume of Passenger Transport Relative to GDP



Source: https://ec.europa.eu/eurostat/web/main/data/database

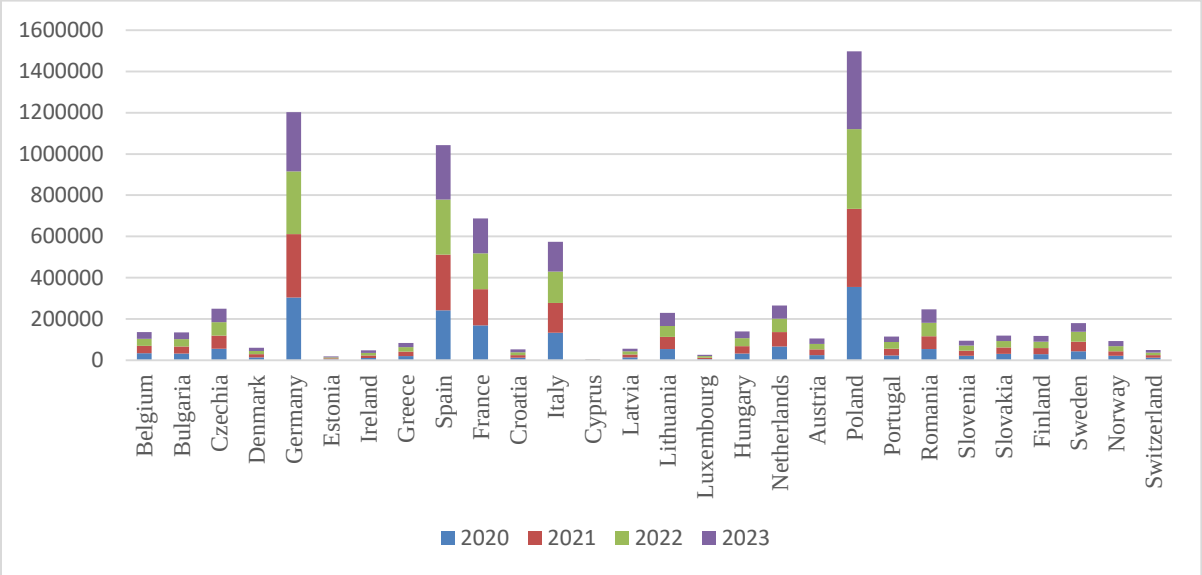
Graph 9 shows the volume of passenger transport compared to GDP in European countries in 2020, 2021 and 2022. The graph provides important data to examine the importance of the transport sector relative to the economic size of the countries and the evolution of passenger transport over time. In 2022, Turkey and North Macedonia differ markedly from other European countries in the ratio of passenger transport volume to GDP. Turkey's ratio over this period reaches around 250, indicating the high share of the transport sector in the country's economic activity. North Macedonia was at a similarly high level, demonstrating that economic growth in these countries can be directly linked to the transportation sector.

Among Western European countries, countries such as Germany, France and Italy have maintained a more balanced level of passenger transport volume compared to GDP. In 2022, the ratios in these countries ranged between approximately 150-200, indicating that in developed countries the efficiency of transport infrastructure and the demand for transport are distributed more in line with economic size. Among Eastern European countries, countries such as Bulgaria, Romania and Lithuania have relatively low levels of passenger transport volume to GDP ratios. This may be due to limited transport infrastructure in these countries or to the fact that the transport sector contributes less to economic activity than other sectors. The EU-27 data, which is the overall average for the European Union, reflects a gradual increase in transport volumes from 2020 to 2022. This increase can be attributed to the post-pandemic economic recovery and increased mobility. However, the fact that this increase is relatively controlled also indicates that sustainable transport policies are partially effective.

6.2. Transportation of Goods by Road

As one of the largest stakeholders in the goods transportation sector, road transport is a key element of economic sustainability. This mode of transport plays a major role in international trade and logistics processes, especially thanks to its flexibility and wide access network. Merkisz-Guranowska et al. (2013) emphasize that road transport has a direct impact on economic growth and trade volume. However, the environmental impacts of this mode of transport and its burden on infrastructure are also important factors to consider.

Graph 10: Goods Transport by Road (Million Tonne-Kilometre)



Source: https://ec.europa.eu/eurostat/web/main/data/database

Graph 10 shows the amount of freight transported by road transport in European countries between 2020 and 2023. The graph provides important data to assess the road transport performance of countries and the changes in this process. In 2023, Germany and Poland stand out as the countries with the highest volumes of road transport. The amount of freight transported in Germany tops the list with around 1.2 million ton-kilometers, while Poland is close to the same level. This shows that both

countries have strong logistics and transportation infrastructure and play important roles as logistics hubs of Europe.

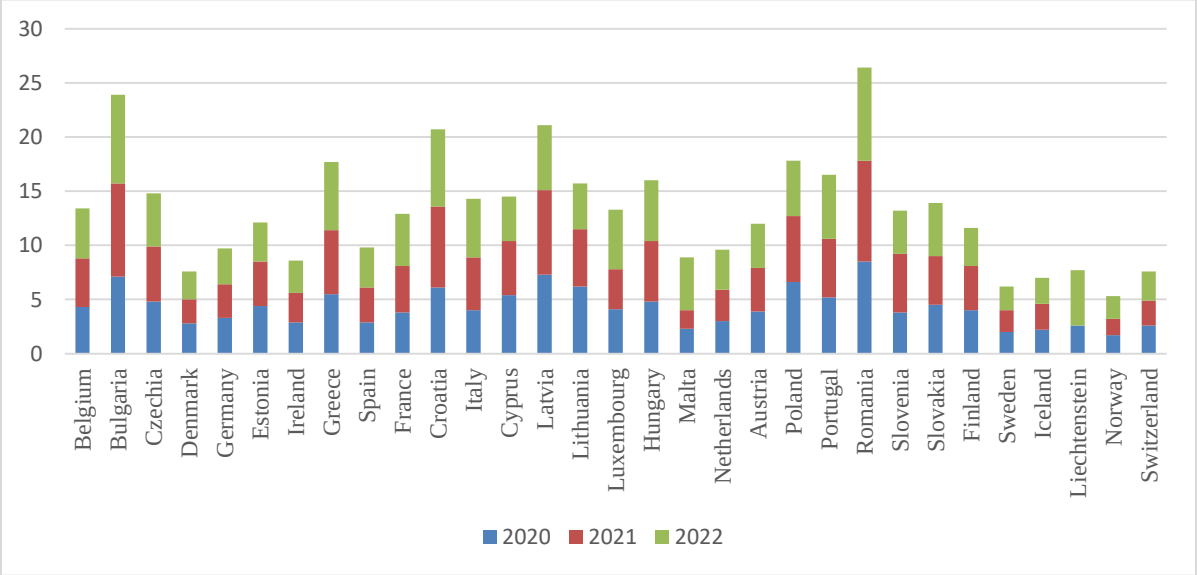
Among Western European countries, France and Italy have shown a remarkable stability in their transportation volumes. In 2023, France reached around 800 thousand tons-kilometers, while Italy's volume was around 500 thousand tons-kilometers. This shows that both domestic and foreign trade in these countries is supported by a strong transport infrastructure. Among Eastern European countries, Bulgaria and Romania have lower transport volumes. In Bulgaria, the volume of freight transported in 2023 was below 100 thousand tons-kilometers. This may suggest that logistics infrastructure in these countries may be limited and their economies are less dependent on the transport sector.

In regions such as the Nordic countries and Switzerland, the volume of road transport is considerably lower than in other regions. Switzerland has a value of approximately 50 thousand tons-kilometers in 2023. This reflects that alternative logistics solutions such as rail and maritime transport are more widely used in these regions. Between 2020 and 2023, road transport volumes have generally increased. This increase can be attributed to the post-pandemic economic recovery and mobility in supply chains. It is noteworthy that this increase is faster in countries such as Germany and Poland compared to other countries.

6.3. Traffic Accident Fatalities by Road Types

Road traffic fatalities are one of the most critical social and safety issues in road transport. Depending on road types, these fatalities are a reflection of the reliability of infrastructure, traffic management practices and driver behavior. Osuntogun and Koku (2007) emphasize that infrastructure investments and traffic safety policies play a critical role in reducing traffic fatalities. However, Chauhan et al. (2008) also note that road safety strategies vary according to countries' level of economic development and investments in transportation systems.

Graph 11: Road Traffic Deaths, by Type of Roads (%)



Source: https://ec.europa.eu/eurostat/web/main/data/database

Graph 11 shows road traffic fatalities in European countries in 2020-2022 as a percentage by road type. The graph provides important data to understand differences in road safety and to assess countries' road safety policies. In 2022, Belgium and Romania are among the countries that stand out in terms of road traffic fatalities. In Belgium, this rate is one of the highest, reaching around 25%. This may reflect the inadequacy of traffic safety measures on non-urban roads and motorways or the impact of heavy traffic. In Romania, the rate was above 20%, indicating that this country needs to introduce more safety measures, especially on rural and non-urban roads.

Among Western European countries, Germany and France had more balanced rates of road fatalities. In Germany, the rate is around 10% in 2022. The high quality and safety standards of Germany's traffic infrastructure is a key factor supporting these low rates. In Eastern European countries, especially in Bulgaria and Poland, the number of deaths from road accidents is quite remarkable. In Poland, the rate rose to over 15% in 2022. This may be due to inadequate road infrastructure in rural areas or low awareness of driving safety.

In countries with high living standards and strong infrastructure, such as the Nordic countries and Switzerland, road fatalities remain very low. In Switzerland, this rate was only around 5% in 2022. This reflects the advanced traffic regulations and technologically-assisted driving safety measures in these countries. Between 2020 and 2022, mortality rates due to traffic accidents increased in many countries. This increase can be attributed to increased mobility and return to traffic after the pandemic. However, in some countries, traffic safety policies have failed to offset these trends.

7. CONCLUSION

Road transport is a critical sector that needs to be aligned with sustainable development goals in terms of both its economic and environmental impacts. Our study provides a comparative perspective with the findings in the literature by analyzing the environmental and economic impacts of road transport in European Union countries. The results obtained are largely in line with the literature, but differences are also observed in some areas.

In the literature, the environmental impacts of road transportation such as greenhouse gas emissions and energy consumption are prominent (Rigogiannis et al., 2023; Othman et al., 2019). Our study also revealed that fossil fuel consumption is still dominant in European countries, which directly contributes to GHG emissions. However, in some countries, the transition to renewable energy and the spread of electric vehicles have had positive effects. For example, low emission values in countries such as Sweden and Norway stand out as a finding supported in the literature (Mavrin et al., 2020). However, the fact that the health dimension, such as premature mortality due to PM2.5 exposure, is less emphasized strengthens the contribution of our study in this area.

In terms of economic sustainability, environmental protection investments and environmental taxes have been considered as an important tool in combating environmental problems. While the positive effects of these investments on economic growth are emphasized in the literature (Osorio-Tejada et al., 2018), our study reveals that especially environmental taxes show large differences across countries. In terms of climate-related economic losses, countries such as Germany and Spain face high losses. While this is in line with the findings in the literature, it suggests that the fact that such losses are more limited in developing countries may be associated with economic resilience and infrastructure deficiencies.

In the transport and safety dimension, the use of public transport such as buses and trains has been found to be an important factor in environmental sustainability (Merkisz-Guranowska et al., 2013). Our study found that increasing the share of these modes of transport is key to improving both traffic safety and reducing carbon emissions. However, social impacts, such as road accident fatalities, clearly show that safety issues, especially on rural roads, need to be addressed.

Several policy measures are needed to align the environmental and economic impacts of road transport with sustainable development goals. First, the transition from fossil fuels to renewable energy sources should be accelerated and electric vehicle infrastructure should be strengthened. This transition will play a critical role in reducing GHG emissions and optimizing energy consumption. In addition, both incentives and infrastructure investments should be increased to increase the use of low-carbon public transport such as buses and trains. These investments will contribute to lower carbon emissions by reducing the use of individual vehicles.

In addition, infrastructure development projects should be prioritized to improve traffic safety on rural roads and strict regulations should be implemented to prevent accidents. Increasing the effectiveness of environmental taxes is another important policy recommendation. Directing the revenues from these taxes to green projects and sustainable infrastructure will create an important resource to tackle environmental problems. Finally, it would be possible to increase the effectiveness

of sustainable transportation policies by encouraging experience and knowledge sharing among countries.

One of the major limitations of this study is the lack of recent data for some countries. This has prevented a full assessment of recent developments, especially in environmental impacts and transportation systems. Moreover, the focus on European countries only has limited the global perspective. Future studies could analyze the global impacts of transport systems by covering a wider time span and more countries. In addition, more in-depth analyses can be conducted using different data sources and modeling methods. For example, focus on the environmental and economic impacts of electric vehicle use. In addition, studies evaluating the impacts of innovative technologies in the transportation sector will make important contributions to the literature in this field.

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