Road network, CO2 emissions, linked to sustainable development: A European analysis

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Abstract. The issue of road transport and the environment is paradoxical. Road mobility provides substantial socioeconomic benefits, supporting the mobility demands of passengers and freight. On the other side, road transport activities are associated with negative environmental impacts. The transport sector is responsible for approximately one quarter of greenhouse gas emissions. Moreover, the transport sector accounted for 57% of global oil demand and 28% of total energy consumption. The main aim of this study is to investigate the relationship between investment in road infrastructure and CO2 emissions, in the European countries, depending on the level of economic development of a country. The analysis was conducted in three separate groups: low-income, middle-income and high-income countries, according to their Gross Domestic Product (GDP). The latest IRF World Road Statistics (WRS) edition of 2022, covering data for the years 2015 to 2020, is the database which provide data for the analysis of the connection between the road networks and environmental consequences, expressed in specific indicators, in different countries.

1 Introduction

The issue of road transport and the environment is paradoxical. Road mobility provides substantial socioeconomic benefits, supporting the mobility demands of passengers and freight. On the other side, road transport activities are associated with negative environmental impacts. Achieving the UN Sustainable Development Goals depends on efficient multi-modal transport systems and services where roads play a central role. Effective road transport, road networks, tunnels and bridges, and the associated services are thus essential to ensure the sustainable mobility of people and goods [1].

Over the last three decades, the EU climate and energy policy framework has resulted in greenhouse gas (GHG) emission reductions in all sectors except transport. The European Green Deal states that achieving climate neutrality by 2050 requires a 90% reduction by 2050 in all transport GHG emissions compared with 1990. Road transport plays a crucial role in achieving this target, as it accounts for more than 70% of the EU's transport GHG emissions [2]. There is a broad framework of legislation to support the EU's aims to achieve its climate goals, including a reduction in the GHG emissions of road transport. Targets and incentives are specified by the legislations for a potential impact on transport emissions.

There are different drivers behind the trends in CO2 emissions of the road transport. The main driving factor has been the growth in passenger transport volumes. Between 2000 and 2019, passenger road transport demand grew by 16.6%, except the period 2009-2012, following the economic crisis [2]. Other potential driving factors behind emission trends are the share of passenger-kilometers travelled by car in overall passenger transport activity, the energy efficiency (the energy consumed per passenger-kilometer), the effect of electrification (share of non-electric energy in the energy consumption), the share of biofuel effect, and the carbon intensity of fossil fuels [2].

The main aim of this study is to investigate the relationship between investment in road infrastructure and CO2 emissions, in the European countries, depending on the level of economic development of a country. The analysis was conducted in three separate groups: low-income, middle-income and high-income countries, according to their Gross Domestic Product (GDP). The latest IRF World Road Statistics (WRS) edition of 2022, covering data for the years 2015 to 2020, is the database which provide data for the analysis of the connection between the road networks and environmental consequences, expressed in specific indicators, in different countries [3].

2 Transport and carbon emissions

The significance of transportation in sustainable development was first highlighted during the United Nations Earth Summit in 1992, and it was emphasized in the summit's conclusion document, Agenda 21. During its nineteenth Special Session in 1997, the UN General Assembly noted that, over the next twenty years, transportation would be expected to be the major driving force behind a growing global demand for energy (in fact, it is now the largest end-use of energy in developed

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countries and the fastest growing in most developing countries) [4].

Both transportation and digitalization are on the verge of entering a new era of development as a result of the significant climatic change we are currently witnessing and the severe environmental harm brought on by ever-increasing anthropization. Additionally, the recent problems brought on by the COVID-19 epidemic and the Russian invasion of Ukraine have added pressure on the EU's economy, society, and ecosystems [5].

Mobility demands are met through transportation, which arise from daily activities like living and working as well as from the consumption, commerce, and production of products and services. Because these activities typically do not all happen in the same location, transportation is required [6].

The society benefits significantly from meeting mobility needs. Accidents, traffic jams, and environmental damage are some of its unfavorable outcomes. The related costs are frequently not internalized, which results in an inaccurate picture of the sector's true effects on society and the environment.

Because of its reliance on fossil fuels, the transport industry contributes significantly to greenhouse gas (GHG) emissions in the EU-27. In 2019, transport exhaust emissions (including aviation bunkers) accounted for 25.9% of total GHG emissions in the EU-27. While overall GHG emissions have decreased by 24% over time, transportation emissions have increased by 33%. As a result, transportation's contribution to GHG emissions has increased.

The EU's GHG emissions were significantly lower in 2020 than in 2019 because to the extraordinary circumstances produced by the COVID-19 epidemic. This was also true for GHG emissions from transportation. They were 18.6% lower in 2020 than in 2019, although GHG emissions were 7% higher in 2020 compared to 1990.

CO2 emissions accounted for 98.8% of all GHG emissions from transportation in 2019. In addition to these, there are those relating to the production and distribution of transportation fuels and power. These are included in the 'other sectors' emissions as long as they occur within the EU-27. GHG reporting also does not yet account for aviation's non-CO2 consequences [8].

With the current policy framework, it is projected that CO2 emissions from road transport in the EU will decrease by 35% by 2050 (compared with 1990). The decrease will be largely driven by the increased efficiency of vehicles, including a shift to electric vehicles.

Transport demand is projected to increase, and modal shift to have a limited effect on emissions. In 2020, passenger and freight transport volumes dropped as a result of the pandemic. In the period after 2020 the EU Reference Scenario 2020 projects a rebound in passenger and freight transport volumes by 2025 and a further increase afterwards. Compared with 2015, the number of passenger-kilometers travelled by road/rail is forecast to be about 13% higher in 2030, and 27.4% higher in 2050. For inland freight transport, the scenario forecasts a rise of 31% by 2030 compared with 2015, and an increase of 55% by 2050, in terms of tonne-kilometeres. Energy efficiency will be a key factor in reducing emissions.

Vehicle energy efficiency is projected to increase, driven by vehicle efficiency standards. The higher energy efficiency is realized by improvements in vehicles with an internal combustion engine (ICEVs) and also by the electrification of vehicles, which is expected to grow faster in the coming decade. Electrification will have an increasing effect. With existing policies, the share of electricity in road transport is projected to reach 2.7% in 2030 and 11.5 % in 2050.

A good strategy to aid in the reduction of carbon emissions is to make the fleet of vehicles more efficient and electric, which also has some positive effects on other areas of road environment. However, the amount of their contribution to other facets of sustainable road travel is constrained due to issues with rebound effects and other environmental repercussions. Changes in transportation demand and modal shifts, which would also lessen the other environmental effects of road travel, might make significant contributions to GHG emission reductions [9].

In addition to accelerating the reduction of GHG emissions and external costs of road transportation, the combined shift to clean vehicles and fuels will also strengthen local economies while improving the quality of life in cities and neighborhoods with less congested streets that promote social cohesion.

3 Road network and CO2 emissions

The connection between road infrastructure network and CO_2 emissions is significant and complex. Road infrastructure plays a crucial role in transportation, and the type, design, and maintenance of these networks can have a substantial impact on the amount of CO2 emissions produced. Some key factors that illustrate this connection are:

- Vehicle Efficiency: The design and condition of road infrastructure can affect vehicle efficiency. Smooth and well-maintained roads can reduce rolling resistance and improve fuel efficiency, leading to lower CO2 emissions per mile travelled.
- Traffic Flow and Congestion: Efficient road networks with proper planning and management can reduce traffic congestion. Congested roads lead to more idling and stop-and-go traffic, which results in higher fuel consumption and increased CO2 emissions.
- Road Design and Urban Planning: Well-planned road infrastructure can promote public transportation, walking, and cycling, which are generally more sustainable modes of transport with lower emissions compared to individual car usage. Increased use of public transport and non-motorized transportation options can lower overall CO2 emissions from the transportation sector.
- Vehicle Miles Travelled (VMT): The extent and connectivity of road networks influence how much people travel by car. More extensive road networks can encourage greater vehicle usage and result in higher VMT, leading to more CO2 emissions.

- Vehicle Load and Weight Limits: Roads that are not designed to handle heavy loads can result in increased emissions from freight vehicles, especially when they have to take detours or use less efficient routes.
- Road Construction Materials and Practices: The materials used in road construction, such as asphalt and concrete, have their own carbon footprint due to the energy-intensive manufacturing processes. Additionally, road construction practices can contribute to emissions, especially if heavy machinery and equipment are used without considering their environmental impact.
- Access to Alternative Fuels and Charging Infrastructure: A well-designed road network should consider access to alternative fuels (e.g., electric charging stations, hydrogen refuelling) to encourage the adoption of low-emission vehicles.
- Encouraging Fuel Efficiency and Clean Technologies: Properly designed road networks can also facilitate policies that promote fuel efficiency, such as speed limits, emissions standards, and incentives for adopting cleaner vehicle technologies.
- Land-Use Planning: The location and design of roads can impact land-use patterns. Well-planned road infrastructure can promote mixed-use development and reduce the need for long-distance travel, leading to lower CO2 emissions.
- Rural vs. Urban Roads: The type of road infrastructure (rural vs. urban) can impact the emissions profile. Urban roads might have more frequent stops and starts, while rural roads might have higher speeds, affecting fuel consumption differently.
- Maintenance and Repair: Neglected road infrastructure can lead to deteriorated conditions, resulting in increased fuel consumption and emissions as vehicles navigate through potholes and uneven surfaces.

Economic Development and Trade: Road infrastructure also plays a role in economic development and facilitating trade. Efficient transportation routes can positively impact industries, but they may also increase the movement of goods and contribute to higher emissions from freight transport.

Efforts to reduce CO2 emissions from road infrastructure networks typically involve a combination of improved planning, investment in public transportation, better maintenance, encouraging sustainable transportation modes, and promoting the adoption of low-emission vehicle technologies. As societies move towards more sustainable transportation systems, the role of road infrastructure will be crucial in achieving emission reduction goals. To mitigate CO2 emissions related to road infrastructure, governments and urban planners can focus on sustainable transportation planning, investing in public transit, promoting non-motorized transportation, improving road maintenance, and encouraging the adoption of low-carbon and electric vehicles. Additionally, adopting greener road construction practices and materials can also contribute to reducing the carbon footprint of road infrastructure.

4 European countries analysis

The relationship between GDP per capita of a country and the road network is not a one-way causation. While a well-developed road network can positively impact GDP per capita, a higher GDP per capita can also enable countries to invest more in road infrastructure, leading to further economic development.

A well-connected road network facilitates the transport of goods and services between different regions within a country and across borders. This enhanced connectivity promotes trade, which can boost economic activity and contribute to GDP growth. An extensive and well-maintained road network allows for the efficient transportation of goods from production centres to markets. This reduces logistics costs and improves supply chain efficiency, which can positively impact businesses and industries, leading to higher productivity and economic growth. Countries with robust road networks are often considered more attractive for investment and development. Businesses are more likely to invest in regions with good transportation infrastructure, as it reduces operational costs and expands market reach.

However, it's crucial to balance the positive economic impacts of road development with environmental and social considerations. Sustainable and efficient road planning is essential to minimize negative effects on the environment, such as increased carbon emissions and habitat destruction, and to ensure equitable access to opportunities for all citizens.

The total road network refers to the length of roads within a specific geographical area, such as a country or a continent. It includes all types of roads, from major highways and expressways to local streets and rural roads. The length of the total road network can also vary widely between countries and regions. More developed and densely populated areas tend to have more extensive road networks, while less developed or sparsely populated regions may have smaller road networks.

In the present research, countries have been grouped according to their geographical location, while taking into account both the level of prosperity and the road infrastructure network development.

Therefore, three groups of European countries were created, as follows:

- Northwest countries: Denmark (DK), France (FR), Netherlands (NL), Finland (FI), Sweden (SE) and United Kingdom (UK)
- Southern countries: Greece (EL), Spain (ES), Italy (IT) and Portugal (PT)
- Central/Eastern countries: Bulgaria (BG), Czech Republic, (CZ), Poland (PL), Romania (RO) and Slovenia (SI).

Northwest countries are more prosperous with an average GDP per capita over 25.000$, followed by Southern countries whose average GDP per capita ranges between 12.000$ and 25.000$ and Central/Eastern countries with an average GDP per capita less than 12.000$.

The latest IRF World Road Statistics (WRS) edition of 2022, covering data for the years 2015 to 2020, is the database which provide data for the analysis of the connection between the road networks and CO2 emissions from road transport, in different countries [3].

Specifically, an attempt to correlate graphically, presented in a Figure, the diachronically evolution of two indicators, the total road network (in Km) and the inland transport CO2 emissions (in millions of tonnes per year) by road is achieved, in a European country.

It is generally accepted from literature that the highest road densities are associated with densely populated and wealthier countries [9].

In all Figures, a drop in values of the CO2 emissions is remarked, in 2020, due to the Covid-19 pandemic and the implementation of different restricted measures for transport in all countries.

In Figures 1-6, the evolution of the two mentioned indicators, for the period 2015-2020, of six of the Northwest countries (Denmark, France, Netherlands, Finland, Sweden and United Kingdom) are presented. It is remarked an increasing rate of the number of the length of the road network per year, except in Finland. In these countries, the corresponding rate of the CO2 emissions from road transport, per year, is declining. The reasons for these rates are different for each country. The road transport policy of each country, different measures for the sustainable mobility issues, challenges and incentives may be different from country to country.

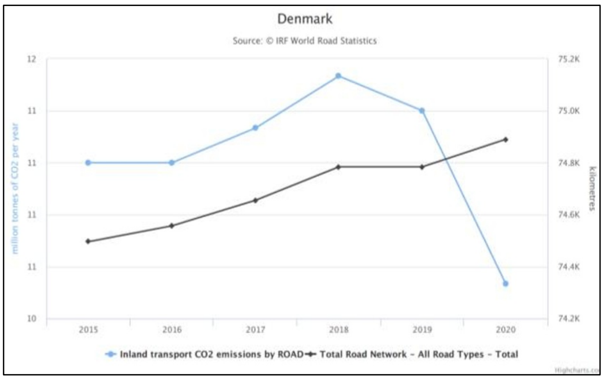

Fig. 1. Inland transport CO2 emissions by ROAD and Total Road Network for Denmark.

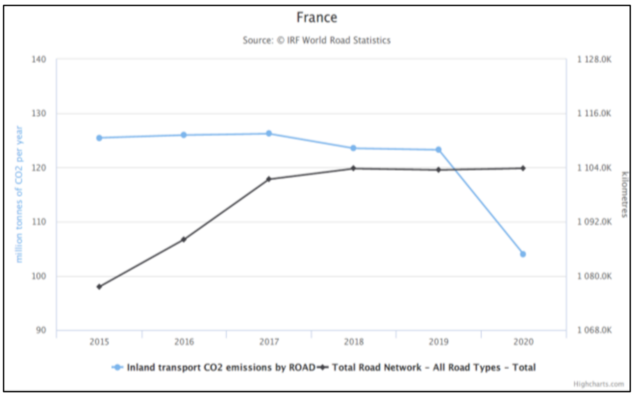

Fig. 2. Inland transport CO2 emissions by ROAD and Total Road Network for France.

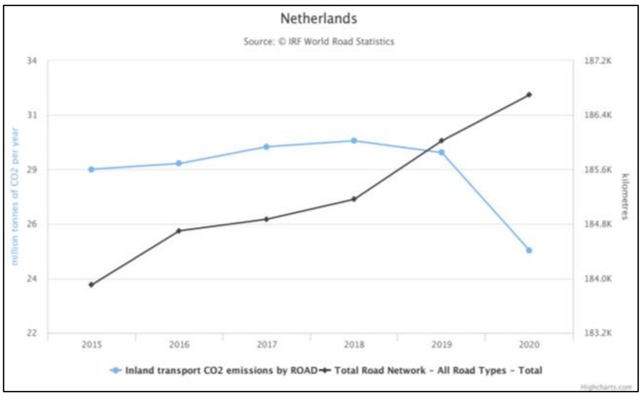

Fig. 3. Inland transport CO2 emissions by ROAD and Total Road Network for Netherlands.

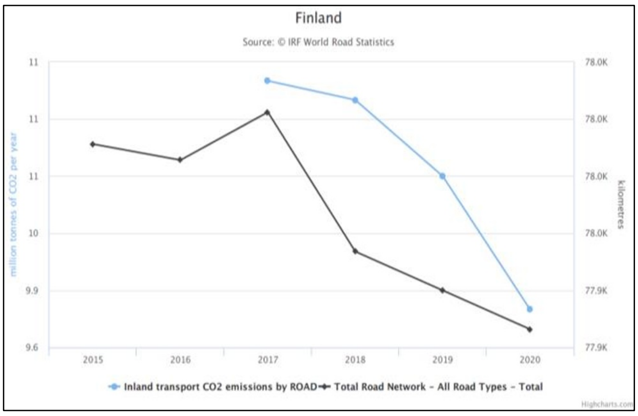

Fig. 4. Inland transport CO2 emissions by ROAD and Total Road Network for Finland.

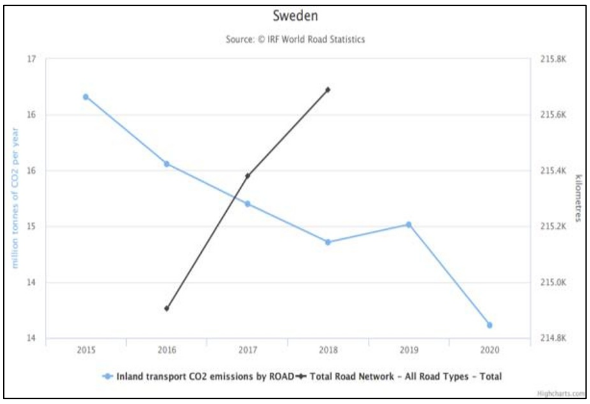

Fig. 5. Inland transport CO2 emissions by ROAD and Total Road Network for Sweden.

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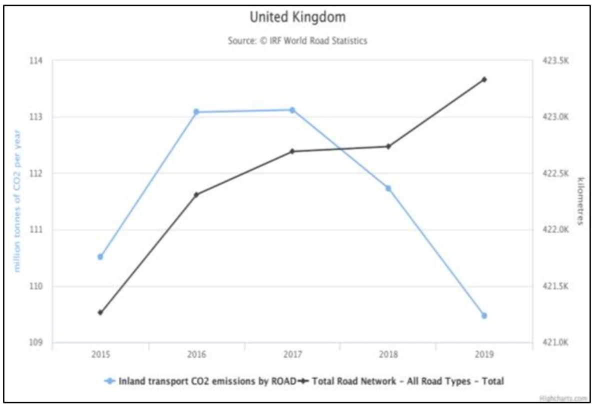

Fig. 6. Inland transport CO2 emissions by ROAD and Total Road Network for United Kingdom.

In Figures 7-10, the evolution of the two mentioned indicators, for the period 2015-2020, of four of the Southern countries (Greece, Spain, Italy, and Portugal) are presented.

It is difficult to reach to concrete conclusions for the correlation between the two indicators for these countries. The investment for road infrastructure network is depended mainly into financial policy and government plan for new projects.

Concerning to the CO2 emissions, conversely to the previous group of countries, it is remarked an increasing rate of the amount of emissions.

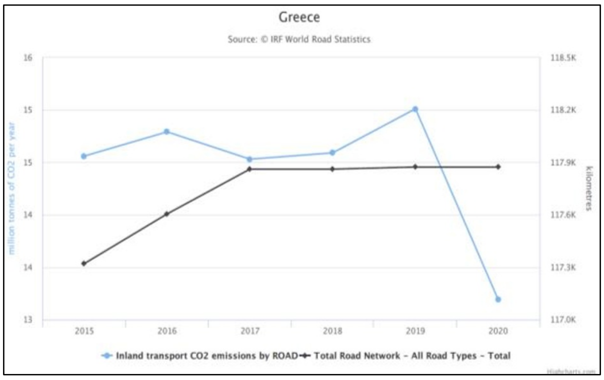

Fig. 7. Inland transport CO2 emissions by ROAD and Total Road Network for Greece.

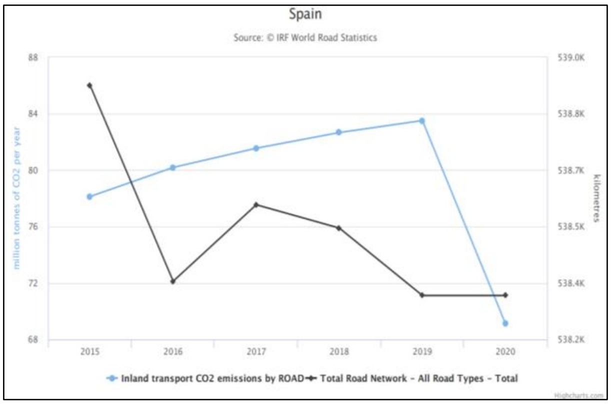

Fig. 8. Inland transport CO2 emissions by ROAD and Total Road Network for Spain.

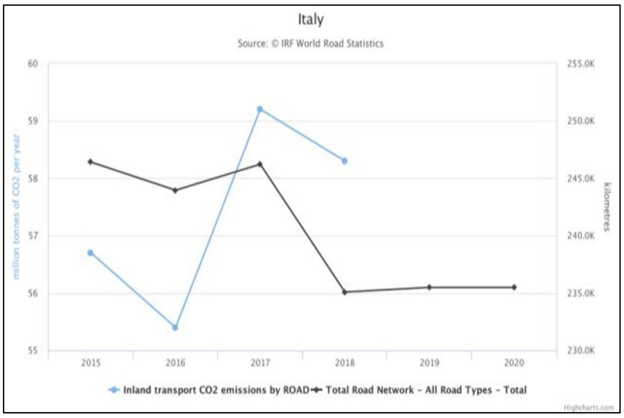

Fig. 9. Inland transport CO2 emissions by ROAD and Total Road Network for Italy.

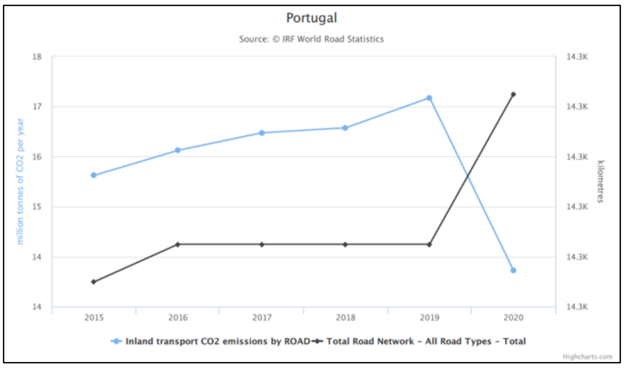

Fig. 10. Inland transport CO2 emissions by ROAD and Total Road Network for Portugal.

Finally, in Figures 11-15, the evolution of the two mentioned indicators, for the period 2015-2020, of five of Central/Eastern countries: (Bulgaria, Czech Republic, Poland, Romania and Slovenia) are presented.

The rate of the total road network and the CO2 emissions from road transport are both increasing. The road infrastructure of these countries is under development and there is no any robust evidence the correlation between road network and CO2 emissions.

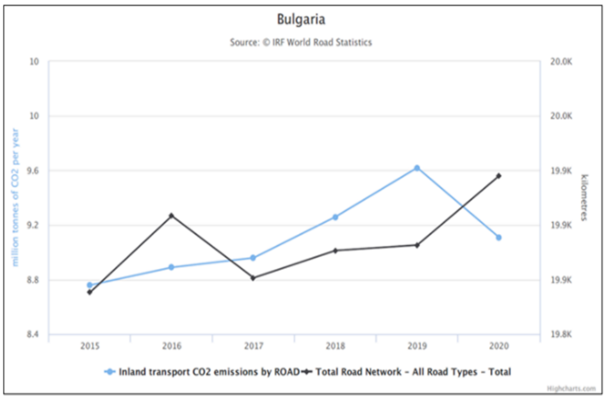

Fig. 11. Inland transport CO2 emissions by ROAD and Total Road Network for Bulgaria.

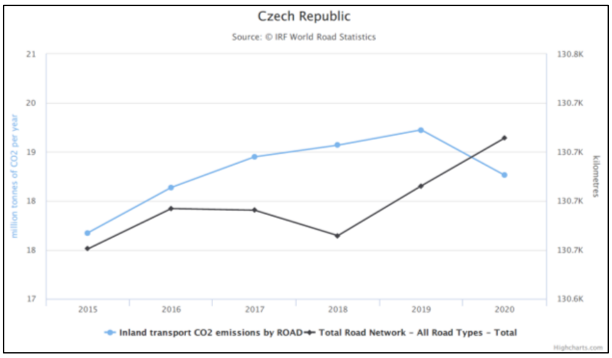

Fig. 12. Inland transport CO2 emissions by ROAD and Total Road Network for Czech Republic.

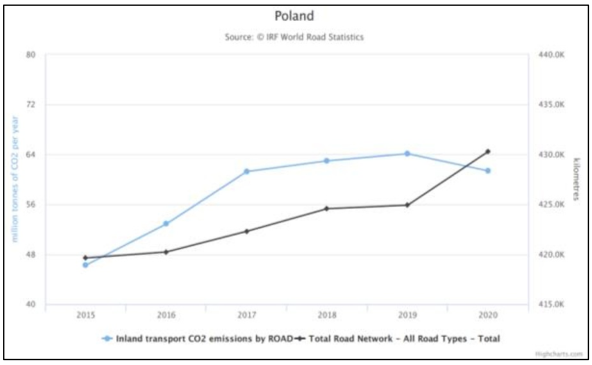

Fig. 13. Inland transport CO2 emissions by ROAD and Total Road Network for Poland.

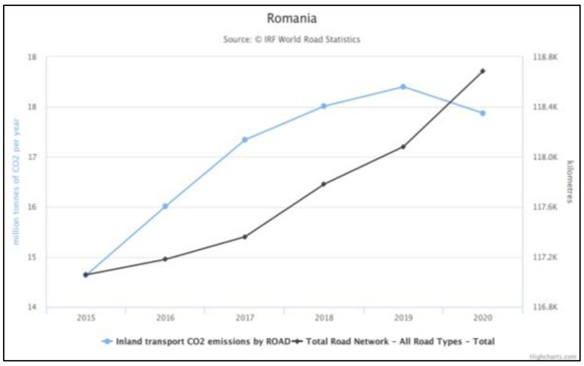

Fig. 14. Inland transport CO2 emissions by ROAD and Total Road Network for Romania.

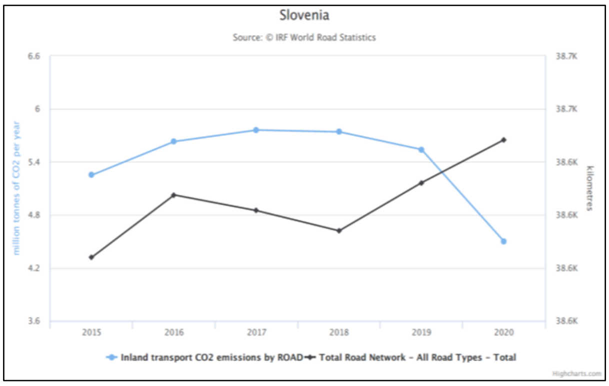

Fig. 15. Inland transport CO2 emissions by ROAD and Total Road Network for Slovenia.

5 Discussion and Conclusions

One of the 17 United Nations Goal is the Sustainable Goal, "Make cities and human settlements inclusive, safe, resilient and sustainable". The achievement of this goal is dependent on effective multi-modal transportation networks and services, with roads playing a critical role. Effective road transportation, road networks, tunnels and bridges, and associated services are consequently required to secure the long-term movement of people and products and to ensure that no one is left behind.

The road sector has already made tremendous steps to lower its environmental footprint while maintaining commercial continuity. In accordance with the Paris Agreement, the sector's main organizations, have joined together to reaffirm their commitment to effectively reducing CO2 emissions to zero by 2050.

In this paper, we investigate the potential effects of the total road network on CO2 emissions using data of 15 countries in EU, from 2015-2020, by examining data from the wealthiest countries to developing countries. To accomplish the above purpose, the examined countries have been grouped in three categories.

In both developed and developing countries, road networks play a vital role in shaping economic development, trade, and social interactions. Farhadi (2015) [10] shows, for a sample of OECD countries, that transport infrastructure positively affects economic growth. The developed countries have extensive road networks with well-maintained highways, modern transportation systems, and efficient connectivity between cities and regions. In developing countries, road networks can vary widely in terms of quality and coverage. Efforts to improve road networks in developing countries often involve investments in infrastructure development, road maintenance, and the implementation of transportation policies that prioritize accessibility and safety.

We expect the relationship between road transport infrastructure and emissions over a time span to be complex. It is estimated that economic growth and population are channels through which transport infrastructure transmits to CO2 emissions. Findings from literature suggest that the construction of road infrastructure projects are characterized by a significant amount of emissions due to the use of large quantities of emission-intensive materials as asphalt and concretes and fuel-intensive equipments [11, 12].

From the analysis of the data of the examined countries, there is a lack of robust evidence on the correlation between road infrastructure network and CO2 emissions. A European Commission expectation is that transport infrastructure will provide more efficient and effective options for transportation, hence, reducing emissions. Additionally, the European Automobile Manufacturers' Association (ACEA) supports that "intelligently designed, well-built and well maintained roads are key to further reducing road transport CO2 emissions in Europe" [13]. Thus, in order to reduce the levels of emissions from transport infrastructure projects, it is important that policymakers invest in research and improvements in efficient production processes.

Shifting infrastructure investment for low-emissions may put more pressure on public and private investment, the infrastructure required for the low-emission transition is integral to meeting many of the Sustainable Development Goals. Investment in infrastructure for electric cars, intelligent transport systems, smart grids and public transport, may produce a reduction in CO2 emissions over the long term since such investments result in a reduction in the use of more polluting trucks, cars, and small vehicles [14].

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