ISSN 1648-0627 / eISSN 1822-4202

VILNIUS TECH
Vilnius Gediminas Technical University

BUSINESS: THEORY & PRACTICE

2025
Volume 26
Issue 2
Pages 277–286
https://doi.org/10.3846/btp.2025.23005

INFLUENCE OF TRANSPORT AIR POLLUTANTS ON CLIMATE CHANGE IN EU: CASE OF LITHUANIA

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Article History:
- received 29 December 2024
- accepted 19 January 2025

Abstract. The purpose of the research paper is to observe and analyse how the motorization rate of EU countries influence climate change during the last decades in terms of inventory of emissions of air pollutants from transport, giving an example of Lithuania. Passenger cars are a major polluter, accounting for 61% of total CO_2 emissions from EU road transport. EU approved directions to transitioning to fossil-free transport and reducing car use in future to make the European Union carbon neutral by 2050. Research methodology is statistical analysis of motorization rate growth and air pollution in the EU countries during the period of 2014–2024. In the research paper the quantitative analysis and comparison method are applied. Findings: research paper shows that in the EU countries motorization rate is growing very fast. However the consequences of this vary from country to country. Significant disparities arise from the age of the vehicles, the type of fuel utilized, and the turnover rate of passenger cars, resulting in the current fleet not achieving an adequate decrease in CO_2 emissions. This research examines the correlation between motorization levels and CO_2 emissions across several EU countries over recent decades and offers potential solutions to this issue.

Keywords: transport air pollutants, climate change, influence of transport, CO_2 emissions, motorization rate, polluter.

JEL Classification: Q53, Q54, O18.

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1. Introduction

Development of technical progress and the acceleration of people's lifestyle constantly increase the number of vehicles used by population. However this growth of transport volume has a significant impact on the increase of the greenhouse effect. The United Nations (UN) and EU have put forward various initiatives to combat these consequences of the vehicles growth (European Automobile Manufacturers Association [ACEA], 2010):

- In October 2018, the United Nations stated that in order to avoid the catastrophic effects of climate change "the net anthropogenic global carbon emissions until 2030 must be reduced by 45% compared with 2010 level and around 2050 should become zero";
- Transitioning to fossil-free transport and reducing car use are necessary to meet European and national climate goals;
- By 2030, Electric Vehicles sales forecasts predict that 60% of all new vehicle registrations will be Electric Vehicles;
- The European Green Deal aims to make the European Union carbon neutral by 2050.

For a long time, the scientific literature was limited of studies analysing the impact of transport on climate change, i.e., mostly the dependence of the number of cars on a country's GDP, economic activity or road accident statistics. Only in recent decades have a growing number of studies focused on the aforementioned problem.

Chapman (2007) analysed the principal contributors to greenhouse gas emissions within the transport sector and noted that new technological innovations will be the sole solution to the climate change problem. He summarized that, in the future, in order to provide sustainable transport, policy makers must combine short-term behavioural changes with long-term technological solutions. Simultaneously, other researchers, including Gonzales et al. (Topics. European Parlament, 2019), have investigated the dynamic correlation between passenger car CO_2 emissions in 13 EU nations from 1990 to 2015 and the dieselization of these vehicles, alongside technological advancements, fuel efficiency, mobility, economic activity, and motorization rates. They assessed that CO_2 emissions have diminished due to technological advancements and enhanced fuel economy; nevertheless, rising motorization rates, economic activity, and diesel usage have counteracted this good effect.

Helmers et al. (European Economic and Social Committee, 2016) investigated CO_2 emissions from passenger cars in Europe in many EU countries during the 1995–2015 period, i.e., the so-called "diesel boom". In this period, millions of consumers switched from petrol to diesel cars because of the lower price of diesel in many EU countries. Those authors analysed whether this policy was efficient with respect to mitigating climate change; their results showed that switching from one fossil fuel to another does not yield any tangible benefit. They concluded that, in the future, a policy of introducing low-emissions vehicles, such as battery electric cars, must be applied.

Hooftman et al. (2018) explained that the EU and the industry "created a European 'diesel island' with no equal worldwide". It is now clear that the European dieselization strategy failed to make any significant progress in reducing total CO_2 emissions from passenger cars.

The objective of the research paper is to observe and analyse how the motorization rate of EU countries influence climate change during the last decades in terms of inventory of emissions of air pollutants from transport, giving an example of Lithuania. Main hypothesis of the research paper is formulated as follows: "Among the EU countries exist countries with high, middle and low car CO_2 emissions in g CO_2/km. This depend on motorization rate, renewal of cars and sources of fuel".

2. Analysis of factors influencing climate change

2.1. Influence of motorization growth

A high motorization rate correlates with air pollution in urban settings, leading to significant energy consumption, noise, the urban heat island effect, traffic congestion, and the loss of open space due to road infrastructure construction. The expansion of suburbanization correlates with a heightened reliance on private automobiles due to the inadequacy of public transportation for suburban inhabitants. The efficacy of a sustainable strategy will primarily be assessed by its capacity to shift a portion of kilometers traveled in private automobiles to public transportation, so alleviating environmental strain.

Road transport accounts for the largest percentage of transport emissions and in 2021 was responsible for 72% of all EU domestic and international transport greenhouse gas emissions. Passenger cars are a major polluter, accounting for 61% of total CO_2 emissions from EU road transport (Senge et al., 2008). As road transport is the focus of the majority of applied and planned measures in the member states, this proportion will decrease, as the de-carbonization process in road transport is more rapid than in other modes of transportation.

The EU Member States reported an increase of 14.3% in the motorization rate of passenger cars (number per thousand inhabitants) in the period 2012–2022 (Figure 1):

Passenger cars are motor vehicles designed for road use, excluding mopeds and motorcycles, meant for transporting people and accommodating no more than nine individuals, including the driver. Romania (86.2%), Croatia (44.8%), and Hungary (40.9%) saw the most significant rises when comparing statistics from 2022 to 2012. In 2022, Latvia (414), Romania (417), and Hungary (424) recorded the lowest rates. Italy (684), Luxembourg (678), Finland (661), and Cyprus (658) exhibited the highest rates according to Eurostat (2024b). Conversely, Latvia exhibits a very low motorization rate, with 418 cars, despite a 10% increase in registered vehicles from 2018 to 2023.

In 2022, Lithuania attained a motorization rate of 589 passenger automobiles per one thousand residents. During the examined period, motorization increased nearly fourfold from 133 vehicles per one thousand residents in 1990. After a pause in the time series in 2014 (Figure 2), the data indicated consistent development from 2015 to 2020 (Statista, 2023).

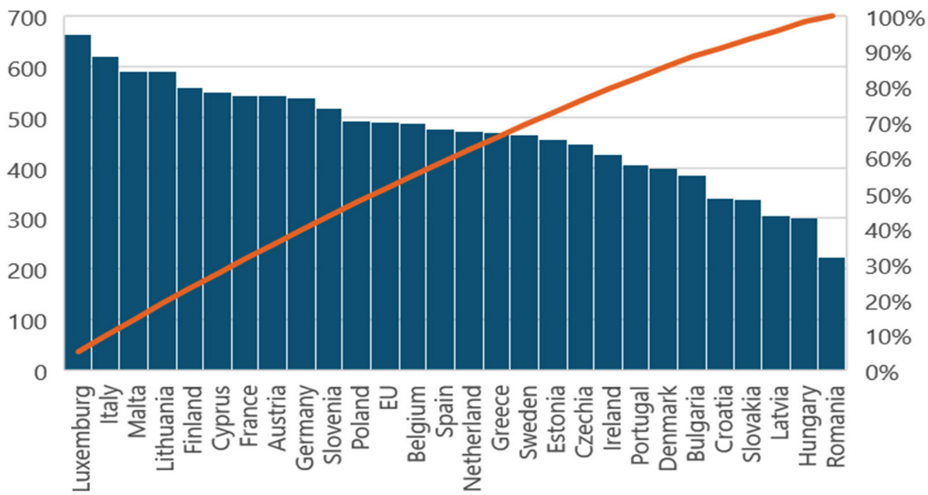

Figure 1. Motorisation rate of passenger cars in EU, 2012–2022 (number of passenger cars/thousand inhabitants) (source: Eurostat, 2024a)

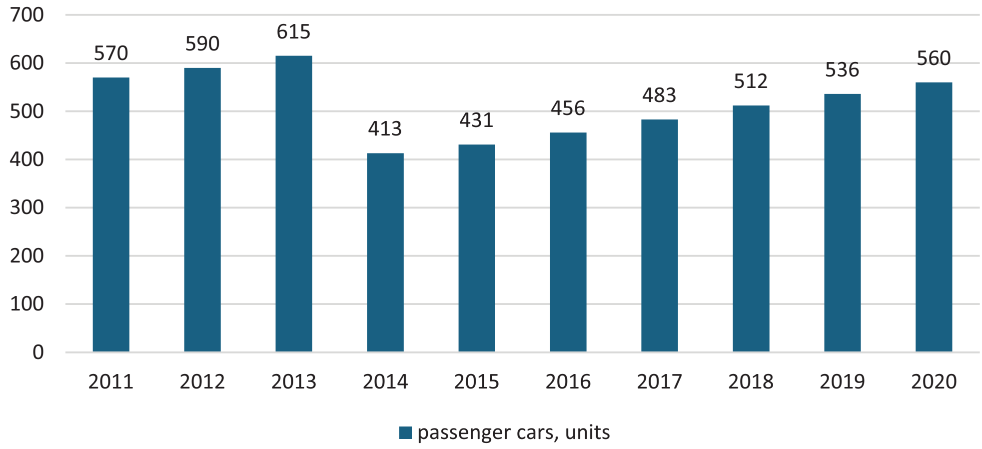

Figure 2. Number of passenger cars per 1,000 inhabitants in Lithuania from 2011 to 2020 (source: Statista, 2023)

Road transport accounts for the largest percentage of transport emissions and in 2021 was responsible for 72% of all EU domestic and international transport greenhouse gas emissions. Passenger cars are a major polluter, accounting for 61% of total CO_2 emissions from EU road transport (Senge et al., 2008). As road transport is the focus of the majority of applied and planned measures in the member states, this proportion will decrease, as the de-carbonization process in road transport is more rapid than in other modes of transportation.

Average CO_2 emissions from new cars was 122.3 g CO_2/km in 2019, better than the EU target of 130 g CO_2/km for the period 2015–2019, but well above the target of 95 g/km set for 2021 onwards. This amount can vary based on the vehicle's fuel efficiency, annual mileage, and fuel consumption. The 2020/21 CO_2 target for the passenger car fleet of the European Union is 96 grams per kilometre (European Environment Agency, 2020).

Average CO_2 emissions (Figure 3) from new passenger cars registered in Europe have fallen steadily in recent years: year-on-year by 12% in 2020, 12.5% in 2021 and 5.3% in 2022. The main driver of reductions is the surge in electric vehicle registrations, which reached 23% of the EU new car fleet in 2022.

European officials revised CO_2 emissions regulations for passenger vehicles. New vehicles typically demonstrate enhanced fuel efficiency relative to used vehicles, and recent EU regulations regarding automobiles and CO_2 emissions, with other automotive legislation, will influence future developments. Nevertheless, the automotive industry demonstrates a prolonged adoption curve for innovative technologies. Moreover, the anticipated increase in traffic volume will mitigate the effects of technology. To reduce short-term greenhouse gas emissions and enhance energy efficiency, further measures must be considered.

It is essential to acknowledge that fuel consumption directly affects CO_2 emissions, and that efforts aimed at reducing greenhouse gas emissions from vehicles would mitigate the significance of oil imports and dependence on them. Recent EU laws, such as the Low Carbon Economy Guidelines and the White Paper on Transport, enhance the execution of these initiatives by addressing the implementation process. The 2011 White Paper (Eurostat, 2021) outlined 10 objectives for a competitive and resource-efficient transportation system, serving as guidelines for attaining a 60% reduction in greenhouse gas emissions. The White Paper delineates a strategy comprising 40 initiatives aimed at achieving these objectives throughout the forthcoming decade.

The European Green Deal (ACEA, 2010) aims to make the European Union carbon neutral by 2050. To reach this objective, all sectors must be de-carbonized. In its proposal for the Climate Law (Peleckienė et al., 2022), the European Commission presented a 55% increase in the intermediate GHG reduction target by 2030, which was approved by the European Council at the end of 2020. Moreover, in December of 2020, the European Commission published the "Sustainable and Smart Mobility Strategy", which outlined a plan for ensuring the green transformation of EU transportation systems.

2.2. Renewal of the passenger car fleet

In 2022, the renewal rate of passenger cars (ratio of first-registered to total passenger cars, excluding imported second-hand vehicles) in the EU ranged from 1.0% in Bulgaria to 9.5% in Luxembourg (Table 2). Renewal rates have tended to slow down in the majority of EU Member States since 2012, but between 2017 and 2019 an increase in the rates had been registered in some countries (Germany, France, the Netherlands and Romania). From 2020 to 2022, the renewal rates dropped again in all EU Member States (European Comission, 2024). Highest share of "youngest" passenger cars in Luxembourg. The shares of the "youngest" passenger cars (less than 2 years old) were highest in Luxembourg (18.9%), Germany (14.8%), Sweden (14.2%), Belgium (13.7%), Ireland (13.1%, 2022 data), Austria (12.6%) and the Netherlands (12.3%). By contrast, several EU countries reported a large share of "old" passenger cars (20 years or older) in 2023. The EU countries with the highest shares of old vehicles were Romania (33.2%), Finland and Estonia (both 32.3%), Poland (29.3%, 2022 data), Portugal (27.8%), Malta (26.4%), and Lithuania (25.9%).

Table 1. Renewal rate of passenger cars in 2023 (source: European Comission, 2024)

	2 years and less	From 2 to 5 years	From 5 to 10 years	From 10 to 20 years	Over 20 years
Luxembourg	18.95	26.13	27.91	21.01	6.01
Germany	14.79	17.43	25.92	32.68	9.19
Sweden	14.17	14.87	27.56	32.63	10.77
Belgium	13.68	21.84	29.14	27.31	8.02
Ireland	13.12	24.75	32.83	29.29	0s
Austria	12.57	17.53	29.05	32.47	8.38
Netherlands	12.25	16.94	25.50	37.67	7.63
Denmark	10.05	18.87	32.93	32.52	5.64
Portugal	8.80	11.47	19.00	32.92	27.81
Czechia	8.71	10.31	17.26	63.72	0
France	8.53	16.50	24.58	39.84	10.55
Italy	7.76	17.05	16.17	59.02	0
Estonia	7.30	8.96	16.15	35.32	32.28
Spain	6.75	10.95	20.93	36.58	24.79
Croatia	6.64	9.26	20.40	46.36	17.35
Slovenia	6.51	11.60	27.79	43.03	11.07
Hungary	6.10	9.32	13.04	50.97	20.57
Malta	5.38	7.04	23.31	37.82	26.45
Poland	5.26	7.80	12.79	44.85	29.30
Finland	4.75	9.51	18.33	35.10	32.31
Lithuania	4.50	5.58	12.83	51.22	25.87
Latvia	4.43	5.80	13.26	52.19	24.31
Cyprus	3.67	8.36	21.13	47.63	19.21
Romania	3.28	5.29	10.68	47.53	33.23

2.3. Global climate change and emissions of air pollutants from transport

Currently, the cars used by the population still do not ensure a sufficient reduction of CO_2 emissions. Motorization rate of the European Union counts 560 passenger cars per 1,000 inhabitants on average in 2022, which grew by 11.4% from 2012 year (Table 1). Simultaneously the global climate was currently warming by 0.2 °C per decade due to human activity. The period 2011–2020 was recorded as the warmest decade. CO_2 produced by human activity is the biggest contributor to global warming. In 2020 its concentration in the atmosphere was 48% higher than in the pre-industrial period. Since every ton of CO_2 emitted contributes to global warming, so all emissions reductions can help to slow it down. However, transport also consumes one of the largest non-renewable natural resources and is responsible for around 25% of the EU's total carbon dioxide (CO_2), which is the main greenhouse gas (Celasun et al., 2023). Knowing the significant and irreversible negative impact of CO_2 on human health and global ecosystems, scientists and business practitioners are analysing this problem trying to create technological innovations and find new possibilities to solve it. Beside this, aiming to become the world's first climate-neutral continent, the EC announced the European Green Deal in December 2019, the most ambitious set of measures that should provide opportunities for European citizens and businesses (EUR-Lex, 2019), to take advantage of the sustainable transition to a green economy and to achieve its obligations under the international Paris Agreement, to ensure climate neutrality by 2050.

Factors including the proliferation of electric vehicles, encompassing heavy-duty models, the utilization of sustainable fuels, the implementation of innovations in the transportation sector, the design of residential areas, and the regulatory legal framework governing standards and imposing restrictions on exhaust emissions can rapidly influence the attainment of the objective. The advancement of electric vehicles is a critical objective of the European Union (EU) to mitigate emissions.

The consequences of climate change now include, among others, intense droughts, water scarcity, severe fires, rising sea levels, flooding, melting polar ice, catastrophic storms and declining biodiversity (Eurostat, 2024a). Climate change has two unique aspects (EUR-Lex, 2018): the current and prospective costs are enormous for both rich and poor, and it provide that compares simple, numerical indicators of just how far out of balance we are – and how rapid and strong the adjustments must be if we are to avert disaster (Senge et al., 2008). Unlike so many other global social and environmental problems, in one sense climate change is simple – because its primary dimensions are measurable. Scientists now have extensive evidence of how rapidly CO_2 and other green house gases are accumulating in the atmosphere, and how that compares with historical levels (Portinson Hylander et al., 2024; Tarazona et al., 2023; Wang Wai Ng et al., 2024).

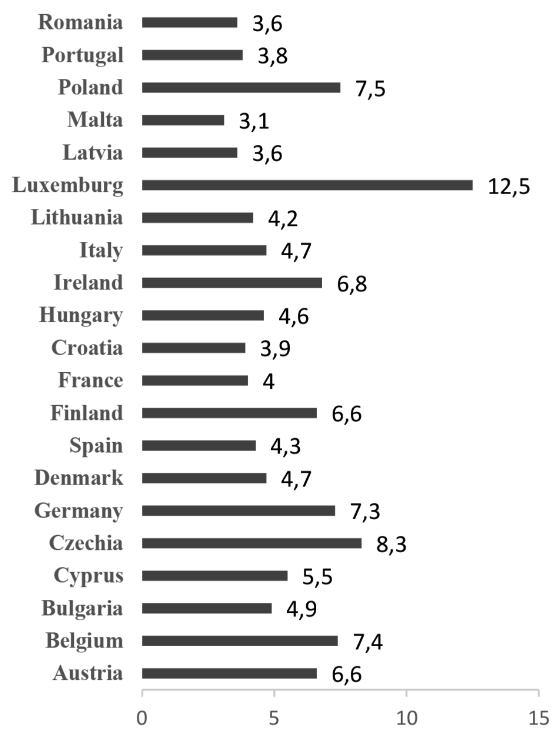

Figure 3. Emissions (metric tons per capita) in EU countries in 2020 (source: Eurostat, 2024b)

The transport sector causes substantial negative impacts on the environment and human health. Transport is responsible for about a quarter of the EU's total greenhouse gas (GHG) emissions, and causes air pollution, noise pollution and habitat fragmentation.

Emissions from the transport sector are further regulated by vehicle emissions standards and fuel quality requirements. Local and regional air quality management plans, including initiatives such as low-emission zones and congestion charges in cities, are active in many areas.

The Ambient Air Quality Directive establishes limitations or target values for pollutant concentrations in ambient air, whereas the NEC Directive imposes emission reduction targets for total national emissions of five air pollutants (NO_x, SO_2, NMVOC, NH_3, and PM2.5). The European Commission has recently suggested a modification of the Ambient Air Quality Directive to better match air quality standards with WHO guidelines, aiming to position the EU on a path toward achieving the zero pollution goal by 2050. Directive 2008/50/EC of the European Parliament and Council, dated 21 May 2008, concerning ambient air quality and the enhancement of air purity throughout Europe.

Together, such policies have delivered progress in reducing the emissions of many pollutants from the transport sector. Between 1990 and 2021 (thus including COVID-19 pandemic effects) across the EU-27, emissions of nitrogen oxides (NO_x) from transport decreased by 53%, sulphur oxides (SO_x) by 83%, carbon monoxide (CO) by 89%, methane (CH4) and non-methane volatile organic compounds (NMVOCs) by 64% and 89% respectively. At the same time, between 2000 and 2021, EU-27 transport emissions of particulate matter (including non-exhaust emissions) with particle diameter of 10 μm/2.5μm or less (PM10/2.5) decreased by 47%/56% respectively (European Environment Agency, 2024). At the same time, two air pollutants have demonstrated substantial growth in recent decades. Between 1990 and 2021, transport emissions of ammonia (NH_3) increased by 109% (136% in 1990–2019) while nitrous oxide (N_2O) increased by 28% (39% in 1990–2019). Although transport contributions of NH3 emissions are limited compared to agriculture and other sectors, their impact on air quality, especially within cities, is reported to be very high. N_2O, while a powerful greenhouse gas, is also currently considered a dominant ozone depleting substance.

2.4. Influence of passenger cars by fuel type

In 2022, half of the passenger cars in a typical EU country had a petrol engine. In 11 out of 23 EU Member States for which 2022 data are available, more than 50% of the cars were petrol cars (Figure 2). The Netherlands reported the highest percentage of petrol cars (85.2%), followed by Cyprus (78.2%), Finland (72.6%) and Denmark (68.6%). Diesel-driven cars exceeded the 50% threshold in Lithuania (67.0%), Latvia (65.9%), Ireland (57.2%), Portugal (56.5%), Croatia (55.8%), Spain (54.3%), France (53.4%), Austria (52.3%), Romania (50.2%) and Slovenia (50.1%). Alternative fuels (excluding hybrid vehicles) made a significant contribution in Italy (10.0%), Sweden (8.3%) and Lithuania (7.1%). The large share of alternative energy cars in Turkey is explained by LPG cars, either initially registered so, or converted from conventional cars. On the other hand, the significant share of alternative fuel in Norway (20.1%) is mainly driven by battery-only electric cars (BEV).

In 2022, half of the passenger cars in a typical EU country had a petrol engine. In 11 out of 23 EU Member States for which 2022 data are available, more than 50% of the cars were petrol cars.

Over the years, the push for green and sustainable solutions for our various technological needs has been growing. As of 2023, battery-electric vehicles have comprised 15.7 percent of the share of vehicle sales in Europe. A further 26.4 percent for hybrid electric vehicles still shows more motivation for moving toward more electric alternatives to diesel and petrol-powered vehicles.

In 2022, the renewal rate of passenger cars (ratio of first-registered to total passenger cars, excluding imported second-hand vehicles) in the EU ranged from 1.0% in Bulgaria to 9.5% in Luxembourg (Table 5). Renewal rates have tended to slow down in the majority of EU Member States since 2012, but between 2017 and 2019 an increase in the rates had been registered in some countries (Germany, France, the Netherlands and Romania). From 2020 to 2022, the renewal rates dropped again in all EU Member States.

The highest number of electric cars in the world is in Norway, where for the first time in 2020 more electric cars than any other type were registered. In September 2021, more than 14% of all vehicles registered in Norway were electric vehicles (Ministry of Transport and Communications of Lithuania, 2021). Lithuania is still a long way off from such numbers, with approximately 43,000 electric cars out of a total of 1.5 million auto mobiles (Chapman, 2007), or less than 0.3% of the entire fleet. In total, 75% of cars in Lithuania are older than 11 years (Hooftman et al., 2018), and the average age of a car is 14 years, contributing significantly to air pollution. Unbelievable quantities of pollution are being released into the atmosphere. The amount of pollutants emitted into the atmosphere depends on the amount of fuel burned and the car's design: 3 g/km if manufactured in 1983; 2.3 g/km if manufactured in 1996. The rate of auto mobile ownership in Lithuania is increasing rapidly, from 190 per 1000 inhabitants in 1995 to 456 in 2019.

Battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are slowly penetrating the European Union market (PHEVs). Each year, a growing number of individuals purchase new electric vehicles. Their number increased from 700 in 2010 to approximately 550,000 in 2019, representing 3.5% of their new registrations. It should be emphasized that electric car registrations grew rapidly in the year 2020, accounting for approximately 11% of newly registered passenger vehicles.

There are 6440 electric cars in Lithuania, of which 3720 are pure electric and the remainder are plug-in hybrids.

This number of electric cars represents 0.4% of the nation's transportation vehicles. The goal of Lithuania is to increase the percentage of electric cars and other zero-emission cars powered by alternative fuels to 20% of the total proportion of cars by 2030.

Germany, France, and Italy had the highest pollution (809.7; 442.9; 418.4 kilotonnes CO2), but their motorization growth rate was low (7.7%, 19%, 15%), whereas in member states such as Poland and the Czech Republic, where pollution was high (390.7 and 122.6 kilotonnes CO_2), the motorization growth rate was correspondingly high (146%, 65%). This can be explained by the diversity of pollutant sources in the EU member states and the age of passenger cars in the EU member states. According to the 2019 report from the ACEA, the average age of passenger cars in the EU is 10.8 years (Ministry of Transport and Communications of Lithuania, 2021), while the average age of cars in Estonia, Lithuania, and Romania is over 16 years.

To summarize: In 2019, the rate of motorization growth per 1000 inhabitants in Lithuania was 60.5%, which significantly augmented the greenhouse effect and accelerated global warming. Importantly, fuel consumption directly affects CO_2 emissions, with road vehicles accounting for 72% of all greenhouse gas emissions from domestic and international transportation. Therefore, the development of technologies and investments by Lithuanian transport companies aimed at reducing the amount of gas emitted by vehicles that contribute to the greenhouse effect would aid in reducing the significance and reliance on oil imports. Electric vehicles emit half as much pollution as the average internal combustion engine, and this investment could reduce greenhouse gas emissions.

3. Methodology of research

In the article were used descriptive statistics, comparative analysis of data, synthesis and generalization analysis. Firstly the scientific literature analysing the impact of transport on climate change and still unexplored areas was reviewed. In chapter 1 analysis of factors influencing the air pollution was completed:

1) comparison of motorization growth rate on climate change in EU countries;
2) comparison of renewal of the passenger car fleet;
3) comparison of share of passenger cars by fuel type.

Data analysis will facilitate the determination of the relationship between CO_2 emissions per kilometer, the age of vehicles, and the type of fuel utilized. The primary hypothesis of the study paper posits that within the EU, there are nations exhibiting high, medium, and low levels of automotive CO_2 emissions measured in grams of CO_2 per kilometer. This depends on the rate of motorization, the renewal of vehicles, and the sources of fuel. Should the theory be validated through statistical analysis of EU countries categorized by their development levels, the authors will address the idea and offer recommendations for future research. If the hypothesis is not substantiated by the data or analysis, it will either be rejected or remain in the hypothesis stage for further examination.

In the following research, we will use WASPAS, or Weighted Aggregates Sum Product Assessment, is a contemporary decision-making technique. Introduced in 2012, this model is recognized as a robust method in Multiple Criteria Decision Making (MCDM). Waspas combines elements from the Weighted Sum Model (WSM) and the Weighted Product Model (WPM). This model will help us to properly rank our countries. The main criteria for research were taken amounts of vehicles according to their age as they are contributing significantly to air pollution and reflect the real picture of renewal of the passenger car fleet. The criterion specification and weights used in model are given in Table 2.

4. Research

WASPAS, or Weighted Aggregates Sum Product Assessment, is a modern decision-making methodology. This paradigm, introduced in 2012, is acknowledged as a robust approach in Multiple Criteria Decision Making (MCDM). Waspas integrates components from the Weighted Sum Model (WSM) and the Weighted Product Model (WPM).

Table 2. Criterion specifications

	Name	Type	Weight
1	2 years and less	+	0.3
2	From 2 to 5 years	+	0.15
3	From 5 to 10 years	–	0.1
4	From 10 to 20 years	–	0.15
5	Over 20 years	–	0.3

The following Table 3 shows the decision matrix.

Table 3. Decision matrix

	2 years and less	From 2 to 5 years	From 5 to 10 years	From 10 to 20 years	Over 20 years
Luxembourg	18.95	26.13	27.91	21.01	6.01
Germany	14.79	17.43	25.92	32.68	9.19
Sweden	14.17	14.87	27.56	32.63	10.77
Belgium	13.68	21.84	29.14	27.31	8.02
Ireland	13.12	24.75	32.83	29.29	0
Austria	12.57	17.53	29.05	32.47	8.38
Netherlands	12.25	16.94	25.5	37.67	7.63
Denmark	10.05	18.87	32.93	32.52	5.64
Portugal	8.8	11.47	19	32.92	27.81
Czechia	8.71	10.31	17.26	63.72	0
France	8.53	16.5	24.58	39.84	10.55
Italy	7.76	17.05	16.17	59.02	0
Estonia	7.3	8.96	16.15	35.32	32.28
Spain	6.75	10.95	20.93	36.58	24.79
Croatia	6.64	9.26	20.4	46.36	17.35

End of Table 3

	2 years and less	From 2 to 5 years	From 5 to 10 years	From 10 to 20 years	Over 20 years
Slovenia	6.51	11.6	27.79	43.03	11.07
Hungary	6.1	9.32	13.04	50.97	20.57
Malta	5.38	7.04	23.31	37.82	26.45
Poland	5.26	7.8	12.79	44.85	29.3
Finland	4.75	9.51	18.33	35.1	32.31
Lithuania	4.5	5.58	12.83	51.22	25.87
Latvia	4.43	5.8	13.26	52.19	24.31
Cyprus	3.67	8.36	21.13	47.63	19.21
Romania	3.28	5.29	10.68	47.53	33.23

4.1. Data normalization

Data normalization is the process of organizing data in a database to minimize redundancy and improve integrity. It includes creating tables and establishing relationships between those tables according to rules designed both to protect the data and to make the database more flexible by eliminating redundancy and inconsistent dependency. Preparing data for analysis, normalization typically refers to scaling numeric data to ensure that different features contribute equally to the distance calculations or other evaluations according algorithm. There are common steps involved in data normalization. First step before normalization we must analyze data distribution, to understand the range of features, mean, standard deviation or distribution. Next step is choosing one of normalization techniques, depending on data specifics, which rescales data to have a mean of O and standard deviation of 1.

For positive indices, normalize each criterion value by dividing it by the maximum value in its respective criterion.

$$\bar{x}_{ij} = \frac{x_{ij}}{\max x_i x_{ij}}, \tag{1}$$

$i = 1, 2, 3, \ldots\ m$ and $j = 1, 2, 3, \ldots\ n$.

For negative indices, normalize by dividing the minimum criterion value by each individual criterion value.

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}}, \tag{2}$$

$i = 1, 2, 3, \ldots\ m$ and $j = 1, 2, 3, \ldots\ n$.

The Table 4 below represents the normalized matrix.

Table 4. Normalized matrix

	2 years and less	From 2 to 5 years	From 5 to 10 years	From 10 to 20 years	Over 20 years
Luxembourg	1	1	0.383	1	0
Germany	0.78	0.667	0.412	0.643	0
Sweden	0.748	0.569	0.388	0.644	0
Belgium	0.722	0.836	0.367	0.769	0
Ireland	0.692	0.947	0.325	0.717	NaN

End of Table 4

	2 years and less	From 2 to 5 years	From 5 to 10 years	From 10 to 20 years	Over 20 years
Austria	0.663	0.671	0.368	0.647	0
Netherlands	0.646	0.648	0.419	0.558	0
Denmark	0.53	0.722	0.324	0.646	0
Portugal	0.464	0.439	0.562	0.638	0
Czechia	0.46	0.395	0.619	0.33	NaN
France	0.45	0.631	0.434	0.527	0
Italy	0.409	0.653	0.66	0.356	NaN
Estonia	0.385	0.343	0.661	0.595	0
Spain	0.356	0.419	0.51	0.574	0
Croatia	0.35	0.354	0.524	0.453	0
Slovenia	0.344	0.444	0.384	0.488	0
Hungary	0.322	0.357	0.819	0.412	0
Malta	0.284	0.269	0.458	0.556	0
Poland	0.278	0.299	0.835	0.468	0
Finland	0.251	0.364	0.583	0.599	0
Lithuania	0.237	0.214	0.832	0.41	0
Latvia	0.234	0.222	0.805	0.403	0
Cyprus	0.194	0.32	0.505	0.441	0
Romania	0.173	0.202	1	0.442	0

4.2. Obtaining Weighted Normal Matrix

Calculate the Weighted Sum Model (WSM) by summing the normalized values of criteria, each multiplied by its corresponding weight.

$$Q^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} w_j, \tag{3}$$

$Q^{(1)}$ reflects the weighted aggregated sum of normalized criteria values for each alternative.

Compute the Weighted Product Model (WPM) by taking the product of normalized values raised to the power of their weights.

$$Q^{(2)} = \prod_{j=1}^{n} \bar{x}_{ij} w_j, \tag{4}$$

$Q^{(2)}$ represents the weighted aggregated product of normalized criteria values for each alternative.

The Table 5 below show the values of WSM and WPM, respectively.

Table 5. WSM and WPM Values

	WSM	WPM
Luxembourg	0.638	0
Germany	0.472	0
Sweden	0.445	0
Belgium	0.494	0
Ireland	NaN	NaN
Austria	0.433	0
Netherlands	0.417	0

End of Table 5

	WSM	WPM
Denmark	0.397	0
Portugal	0.357	0
Czechia	NaN	NaN
France	0.352	0
Italy	NaN	NaN
Estonia	0.322	0
Spain	0.307	0
Croatia	0.279	0
Slovenia	0.281	0
Hungary	0.294	0
Malta	0.255	0
Poland	0.282	0
Finland	0.278	0
Lithuania	0.248	0
Latvia	0.244	0
Cyprus	0.223	0
Romania	0.249	0

4.3. Final calculations and ranking

Combine the Weighted Sum Model (WSM) and Weighted Product Model (WPM) using a weighted average approach (λ = 0.5).

$$Q_i = \lambda Q^{(1)} + (1-\lambda)Q^{(2)}. \quad (5)$$

The resulting Q values determine the final rankings, where higher Q corresponds to a better-ranked alternative.

The Table 6 below depict the values of Q and the rankings of the alternatives, respectively, for the given parameter λ = 0.5.

Table 6. Alternatives ranking

	Q	rank
Luxembourg	0.319	1
Germany	0.236	3
Sweden	0.223	4
Belgium	0.247	2
Ireland	NaN	19
Austria	0.217	5
Netherlands	0.208	6
Denmark	0.198	7
Portugal	0.179	8
Czechia	NaN	19
France	0.176	9
Italy	NaN	19
Estonia	0.161	10
Spain	0.153	11
Croatia	0.139	14
Slovenia	0.141	13
Hungary	0.147	12

End of Table 6

	Q	rank
Malta	0.127	15
Poland	0.141	13
Finland	0.139	14
Lithuania	0.124	16
Latvia	0.122	17
Cyprus	0.111	18
Romania	0.124	16

The resultant *Q* values establish the ultimate rankings, with elevated *Q* indicating a superior-ranked option. Luxembourg, Germany, Sweden, and Belgium attained the highest ratings according to the WASPAS technique, securing 1st, 3rd, 4th, and 2nd ranks, respectively. Lithuania, Latvia, Cyprus, Romania, Italy, the Czech Republic, and Ireland scored the lowest ratings. The Weighted Sum Model (WSM) and Weighted Product Model (WPM) were employed to compute the Weighted Normal Matrix.

5. Discussion and interpretation of results obtained

Scientific literature review show that scientists (Chapmen, Gonzales, Helmers, Hoofman), who analysed dynamic relationship between passenger cars and CO_2 emissions, that in last decades many consumers switched from petrol to diesel, but the European dieselization strategy failed to make any significant progress in reducing total CO_2 emissions from passenger cars. In the future a policy of introducing low-emissions vehicles, such as battery electric cars, must be applied, new technologies must be used. Research results show that a half of the passenger cars in a typical EU country had a petrol engine, that passenger cars are a major polluters, accounting for 61% of total CO_2 emissions from EU road transport. The average amount of new car emissions of EU in 2022 year was 66.6 g CO_2/km. The statistical data comparing CO_2 emmisions show that EU countries can be grouped into five groups according to their level of CO_2 emissions:

1) 130–150 g CO_2/km (Lithuania, Latvia, Estonia, Slovakia, Hungary, Bulgaria, Czechia, Cyprus);
2) 110–130 g CO_2/km (Romania, Greece, Austria, Slovenia, Croatia, Italy, Spain);
3) 100–110 g CO_2/km (Portugal, France, German, Belgium, Ireland);
4) 80–100 g CO_2/km (Netherland, Denmark, Finland);
5) 0–80 g CO_2/km (Sweden).

Analysis of research results shows that countries with high carbon footprint: for example Luxemburg having 115.8 g CO_2/km in 2023 had 18.9% of passenger cars being less than 2 years old. But in Lithuania the average age of passenger cars is 14.7 year, in Estonia – 16.6, Latvia – 15.2, and they are contributing significantly to air pollution. However, there are very large inequalities among EU countries in CO_2 per capita emissions and average age, for example in Sweden: 66.6 g CO_2/km with 10.7 year; Denmark: 86.3 g CO_2/km with 8.9 year average age of passenger cars. But Germany, France, and Italy had the highest pollution (809.7; 442.9; 418.4 kilotonnes CO_2), but average age of passenger cars is 10, 10.8 and 12.5 year.

Statistical analysis of passenger cars power sources in EU countries found that petrol constitutes 50.6%; dysel – 40.8%, hybrid – 3.1%, LPG – 2.6%; Battery – 1.2% and other. In 2022, half of the passenger cars in a typical EU country had a petrol engine. In 11 out of 23 EU Member States for which 2022 data are available, more than 50% of the cars were petrol cars. Battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are slowly penetrating the European Union market (PHEVs).

The hyphothesis was not approved as statistical data of research showed mixed results of very large inequalities among EU countries in CO_2 per capita emissions and average age of cars. There are countries with very high footprint and the highest level of cars less than 2 years old and with low growth of motorization rate. From other side in some countries is the lowest level of footprint with comparably big amount of old cars and growing number of electric or hybrid-electric cars. Also there are big differences in motorization rate among new and old EU member states with highest pollution but motorization rate is low. This can be explaned by unequal conditions of economic development. In future researches should be used a method of selecting a probability sample to increase the study generalizability by analysing the effects of passenger cars influence on climate change by various approaches, about influence of governments on tax policies implementing electromobility, changing private passenger cars into public transport. Consequently, future studies may incorporate additional moderators, such as electric car prices, infrastructure, people's expectations.

6. Conclusions

1. Motorization rate of EU countries is steadily growing. Passenger cars are a major polluter, accounting for 61% of total CO_2 emissions from EU road transport. EU approved directions to transitioning to fossil-free transport and reducing car use in future to make the European Union carbon neutral by 2050.

2. Analysis of statistics of EU countries helped to determine that motorization rate of the European Union counts 560 passenger cars per 1,000 inhabitants on average in 2022, which grew by 11.4% from 2012 year. The transport sector causes substantial negative impacts on the environment and human health. Transport is responsible for about a quarter of the EU's total greenhouse gas (GHG) emissions, and causes air pollution, noise pollution and habitat fragmentation. Currently, the cars used by the population still do not ensure a sufficient reduction of CO_2 emissions.

3. Pollution of air is very dependant on fuel type, which is used by passenger cars. In 2022, half of the passenger cars in a typical EU country had a petrol engine (European Environment Agency, 2024). In 11 out of 23 EU Member States for which 2022 data are available, more than 50% of the cars were petrol cars. The highest percentage of petrol cars was reported in Netherlands – 85%, Cyprus – 78%, Finland – 73%. Diesel cars exceeded the 50% threshold in: Lithuania – 67%, Latvia – 66%, Ireland – 57%. The contribution of alternative fuels was significant only in Italy – 10%, Sweden – 8%, Lithuania – 7%. The highest percentage of battery-only electric (BEV) was reported by Denmark – 4%, Sweden – 4%, Netherlands –3.7%.

4. The renewal of passenger cars also has significant influence on air pollution. According statistics of Eurostat renewal rates have tended to slow down in the majority of EU Member States since 2012, but between 2017 and 2019 an increase in the rates had been registered in some countries (Germany, France, the Netherlands and Romania). From 2020 to 2022, the renewal rates dropped again in all EU Member States. In 2022, the renewal rate of passenger cars (ratio of first-registered to total passenger cars, excluding imported second-hand vehicles) in the EU ranged from 1.0% in Bulgaria to 9.5% in Luxembourg. In total, 75% of cars in Lithuania are older than 11 years, and the average age of a car is 14 years, contributing significantly to air pollution. The amount of pollutants emitted into the atmosphere depends on the amount of fuel burned and the car's design: 3 g/km if manufactured in 1983; 2.3 g/km if manufactured in 1996.

5. Factors including the proliferation of electric vehicles, encompassing heavy-duty models, the utilization of green fuels, the implementation of innovations within the transportation sector, the design of residential areas, and the regulatory legal framework governing standards and imposing restrictions on exhaust gas emissions, can most rapidly influence the attainment of the objective. The advancement of electric vehicles is a critical objective for the European Union (EU) to mitigate emissions.

6. The hypothesis was not validated, since the statistical data from the investigation indicated inconclusive results due to the varied economic development conditions among countries. Future research should employ a probability sampling method to enhance the generalizability of the study by analyzing the impact of passenger vehicles on climate change through various approaches, including the influence of government tax policies on the implementation of electromobility and the transition from private passenger cars to public transportation. Thus, next research may integrate supplementary moderators, like electric vehicle pricing, infrastructure, public expectations, and others.

7. The resulting Q values determine the final rankings, where higher Q corresponds to a better-ranked alternative. Luxembourg, Germany, Sweden, Belgium, received the highest ratings using the WASPAS method (1st, 3rd, 4th, 2nd ranking places respectively). The lowest ratings were received by Lithuania, Latvia, Cyprus, Romania, Italy, Czech Republic, Ireland. The Weighted Sum Model (WSM) and Weighted Product Model (WPM) were used to calculate the Weighted Normal Matrix.

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